UP THERE

The trail towards a more sustainable alpine hut.

A renovation project for Rifugio Carducci, 2297 mt., Alta Val Giralba, Dolomiti.

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ExploreLab 2020/21

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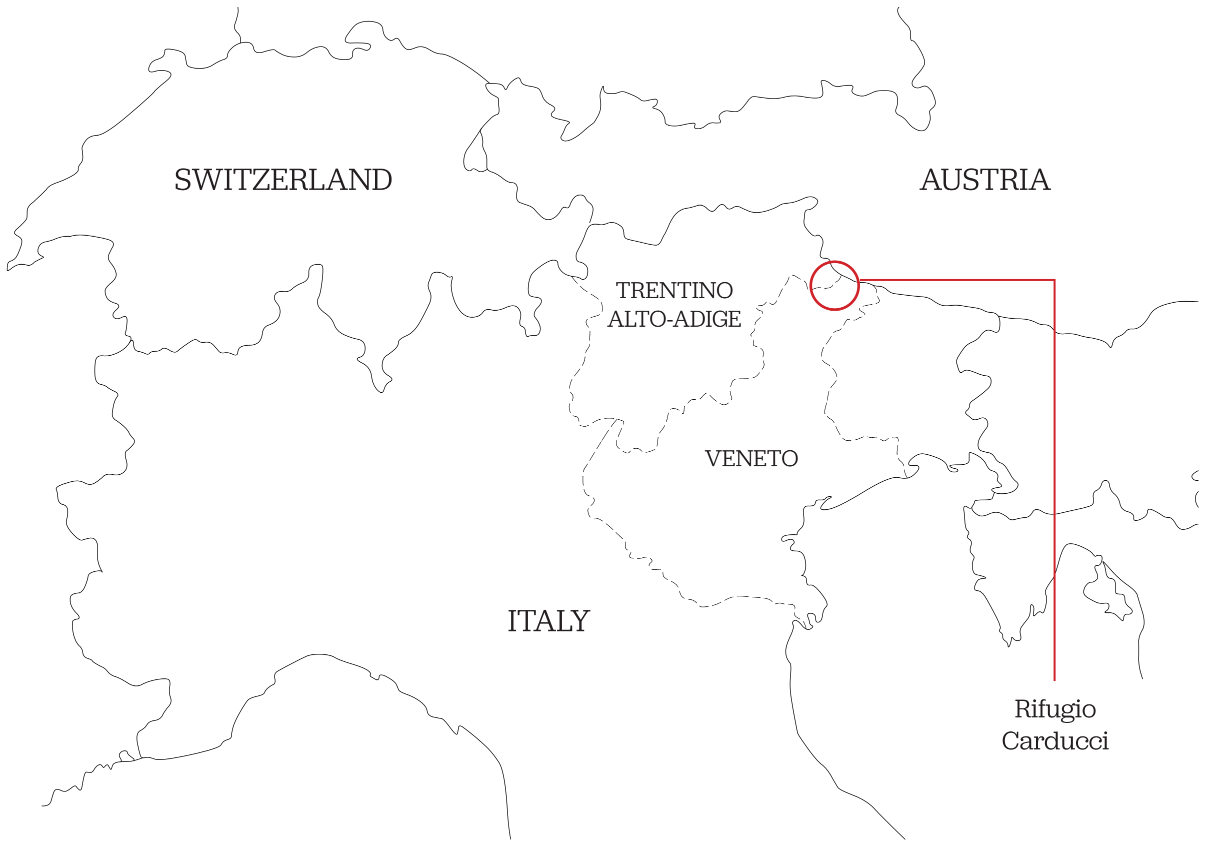
Introduction

Every year, during the season's final days around the beginning of October, a group of locals from both sides of Forcella Giralba, and mountain enthusiasts, meet at 2297 meters above sea level at the well-known Rifugio Carducci.
In close proximity with the italian and austrian border, at the intersection between the regions of Veneto and Trentino Alto-Adige, right underneath the Zwolferkofel (or Croda dei Toni in Italian) and Monte Giralba, the group meets to celebrate another year of mountaineering and friendship; another year of living the high-altitude, another year of inhabiting the Dolomites.
Musical instruments are airlifted, and those who would not be capable of reaching the refuge by foot can also take advantage of a short helicopter flight. The event briefly introduced here illustrates what mountains and alpine huts mean today: a meeting point where to share a common passion.
This meaning given to the alpine huts and the mountains has not always been the same as today. As beautifully explained by Walther Kirchner in his text Mind, Mountain, and History, "in the course of history, man's attitude toward mountains has not been static; it has changed" . Firstly, with indifference, then with fascination,



to scientific interest, and finally with sportive attitude, international, nationalistic, or commercial. This evolution towards the mountainous landscape has accompanied the western civilisation along with its development and widely changed from epoch to epoch.The drive towards the Alps' high altitudes has pushed for constructing an infrastructure of buildings known as refuges, or huts from the Italian Rifugio, the French Refuge, the German Hütte.
This thesis will interchangeably use the words refuge and huts to indicate this particular typology of built element.
These buildings, located within a system of trails and roads, have served as shelters and fundamental support for the civilisations that crossed the Alps, from the Roman armies crossing the Theodul Pass to today's multitudes of people living, working, and spending their precious free time within the peaks of the Alps.
It is at these unique buildings that this research is looking.
As the main protagonist of this work, Rifugio Carducci is one of the many high-altitude huts built in the Alps. Like all of them, it is faced with the changes occurring to the use of natural environments and the challenges that our civilisation is facing with climate change.

In today's scenes, the high-altitudes can be considered a playground for tourists, sports enthusiasts and professionals, and outdoors lovers. With a range of activities from trail running to paragliding and from trekking to free climbing. An ever-increasing number of people inhabits the high-altitudes during the year, being this for winter sports or summer activities. It needs to be clear that it is thanks to these activities that many mountainous regions remain inhabited and economically active.
The just mentioned infrastructure, and within it the huts, is called to cater for a differentiated clientele in need of shelter, information, education, restoration, and at times rescue. Together with providing all the mentioned functions (and others), the refuge has become a destination in itself. In many circumstances, the hut evolved into an observation platform to enjoy the surrounding landscape while tasting local delicacies and drinking refreshing beverages. What lies underneath the surface of this vast and fundamental infrastructure that makes accessible the breathtakingly beauty of nature are the challenges connected with the supply, maintenance and staffing of the huts themselves.
In many cases, the huts are found in difficulty-accessible locations, without a road connection and almost always disconnected from a municipal grid for electricity, water supply and sewage system. These aspects are often given for granted, but they become defining challenges in the context of high-altitude refuges.
What follows is a short introduction and overview of the challenges mentioned above. These are based on personal knowledge, conversations with the caretakers of Rifugio Carducci, and backed by several publications of the local chapters of the Italian Alpine Club, as well as from "Guida alle buone pratiche nei rifugi in Quota", a good practice guide for refuge's caretakers and owners made available by the initiative for transnational cooperation Espace Mont Blanc.
High-altitude alpine huts, when possible, are supplied via off-road vehicles, cable cars, often with backpacks, usually with helicopters transporting all the necessaries for the operation of the buildings.
Water is almost always a valuable commodity, when possible collected from local springs or streams, at times collected from the melting ice of a nearby glacier or snow reservoir, and at times collected from rainwater. These available sources of water, in a regular urban environment, would not be considered potable.
Energy supply is once again a challenging topic, but almost always solved using diesel-power-generators and on some occasions with solar panels and batteries in combination with the diesel generators. A solution that is gaining traction but that remains challenging for the risks of several days of overcast skies and/or shadow cast on the refuge from the nearby peaks.
The use of on-site diesel generators is still the number one source of electrical power for these buildings, considering that with higher altitudes, engines are reduced on power output, therefore requiring over-dimensioned engines and higher consumptions. Simultaneously, the demands remain considerable, with needs for light, heat, and electricity for cooking and operating refrigerators.
Once all the supplies are inputted into the refuge, what emerges is the challenge of dealing with waste and sewage. Waste is transported down to the valley, or at times, especially in the French Alps, it is incinerated on site. Gray and black waters can be disposed of in septic tanks or other locally-specific systems, depending on the possibilities of the refuge itself.

This research is part of a project aimed at renovating and expanding Rifugio Carducci, making it a shelter connected to its environment that is part of a healthy and well-functioning ecosystem.
Within this project, it was essential to study the refuge within its environment, understanding it as an element part of a network of trails, as a contributor to the local economy, and as a built element that require inputs of energy, water and supplies. In essence, it was necessary to understand the refuge as a machine of systems, working at different levels and scales, concurring to the existence of the refuge itself.
In this research paper, the refuge will be presented as a thermodynamic machine, studying where efficiency can be improved, closing loops or connecting different

elements. To do so, the refuge will be presented starting from its characteristics of shelter, to then move on with the study of its local environment and current systems; finally proposing a roadmap for a Rifugio Carducci better connected to its ecosystem and ultimately holistically more sustainable.

Problem Statement And Research Questions

The challenges here introduced can give an idea of the complexity of inhabiting the high-altitudes; places that at the same time are fragile and harsh; source of pleasure for those visiting them, and source of living for those working thanks to them.
Given the need for climate action, it is ever more necessary to tackle the challenges that the built environment of high altitudes puts in front of us. As a society, we shall continue to evolve our relationship with our natural environments and develop solutions to live more in concert with it.
In the specific case of high-altitude alpine refuges, the call is to develop solutions capable of fostering the buildings' vocation of fundamental footholds, architectural contact points between built and natural environment. The call is to develop alpine refuges that are part of their natural environment without harming it. That is instead capable of improving the (eco)systems within which they are built-in.
The consequence of this call to action is the main research question for this research work: How can the positive impact of a high-altitude alpine refuge towards its (eco) system be maximised?
Starting from this perspective, the research led the renovation project towards investigating a broader question, introducing the relationship between user, building, and environment. From this the formulation of a series of research sub-questions:

- How does the user interact with the building and the environment?
- How does the environment interact with the building?
- How does the building interact with the environment?

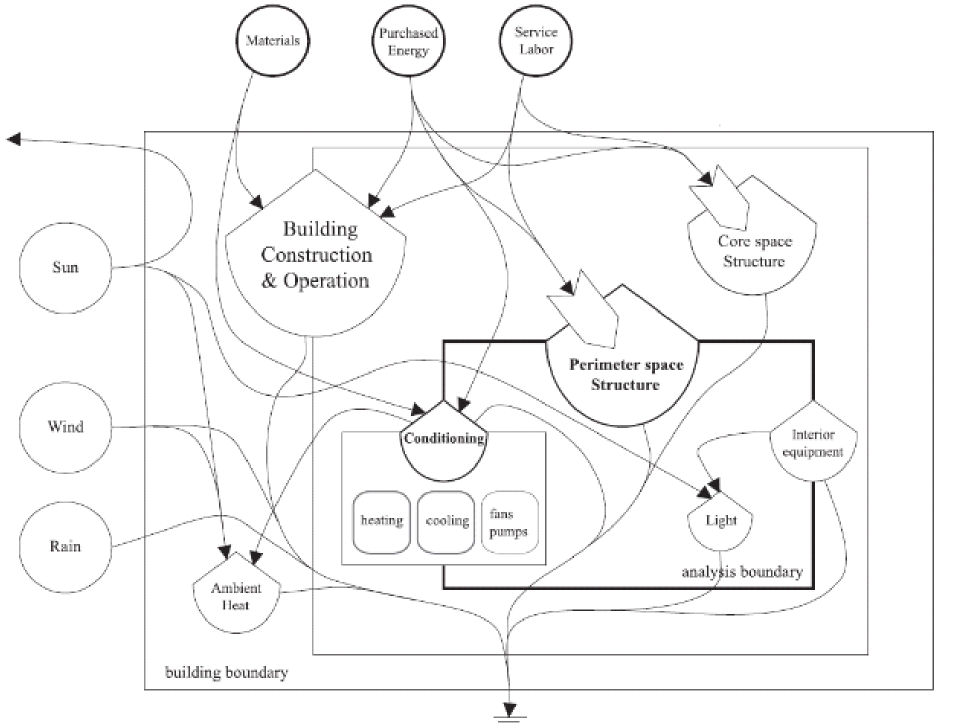
The study of interdependencies between the different ingredients of the alpine refuge is used to form a holistic approach towards the redevelopment of the refuge. Within the scope of this research-focused part, the goal was to study the environment and the refuge systems to provide an underlay of data to inform the project. From this point onwards, the study developed on the individuation and development of systems that are, according to the research results, capable of improving the connection of the refuge with its ecosystem.

Theoretical Framework (Considerations Of Systems Ecology In Architecture)

In an interconnected society, we are accustomed to relying on interdependencies of our daily lives; not differently, the built environment depends on an endless cycle of inputs and outputs, from the conceptual design phase to the final demolition of a building. All aspect before, in between, and after are themselves composed of several streams and cycles. Separately, these can be evaluated, accounted for, and optimised. But it remains necessary to consider the built environment from a more holistic overview, as an infinite work of transformation, of cycles of inputs and outputs. To quote William Braham and his book Architecture and Systems Ecology: "[...] meaningful narratives about buildings are ultimately thermodynamic".
With these considerations, starting from the laws of thermodynamics, the research aims at understanding Rifugio Carducci as a node within an (eco)system, a system of interconnected systems. This definition identifies the refuge as an element within an infrastructure of refuges, trails, routes. It sees it as a combination of systems for the supply and functioning of the refuge. In this research, the alpine refuge can be considered a building that "is an open thermodynamic and ecological system" .
As part of the physical environment, the built elements are governed by the two laws of thermodynamics. Therefore, the consequent concepts of exergy and entropy are strictly interconnected and fundamental for designing a sustainable built environment . These key concepts can be found in the two fundamental laws of thermodynamics:

1. Energy is always conserved;
2. During any process, the quality of energy is decreased (exergy) and disorder (entropy) is increased.

What these two fundamental concepts entail for architecture is a call for the designers to consider buildings at a broader scale, considering the effects and the necessary steps and ingredients essential for the life cycle of a built element.
In Odum's words, one of the early researchers to study the thermodynamics of system ecology, this process of understanding the interconnections is intended to achieve three ends: "maximise the intake of available matter-energy, maximise the transformation of the matter-energy, and reinforce the system through feedback" .
What results evident is that "the ability to do work is dependent not only on the form of energy, but also the system being considered" .



Yi, Srinivasan, Braham (2015) System Boundary Diagram | This image Exemplifies the concept of different systems connected to the building

The consequences of these considerations are twofold: the substantial refusal of a building as an autarchic system, and the research's positioning on maximising the positive impact of the built-with(in) the environment, a thermodynamic equilibrium of the building's (eco)system.

Autarky, a theory described as "an economic system of self-sufficiency and limited trade" , suggests that a system can work autonomously, without external influence. If this concept is considered with the laws of thermodynamics in mind, it appears evident that autarky simply can not exist.

A similar conclusion has been noted by Ákos Moravánszky while discussing the Monte Rosa hut in the Swiss Alps. In his article "My blue heaven: the architecture of atmospheres", he notes that the high altitude refuge "while almost entirely cut off from the physical energy networks, it is very much part of the socio-economic networks of attention-making" .

In conclusion, if even a high-altitude alpine hut is not autarchic, but instead part of systems, and even more part of its ecosystem, the natural consequence is that a built element can not be anything else than a thermodynamic process of intake, transformation, and feedback. It is, therefore, the role of the designer to tune the thermodynamic processes of building to work in balance with the (eco)systems feeding the building, maximising the positive feedback, reducing as much as possible the increase of entropy.

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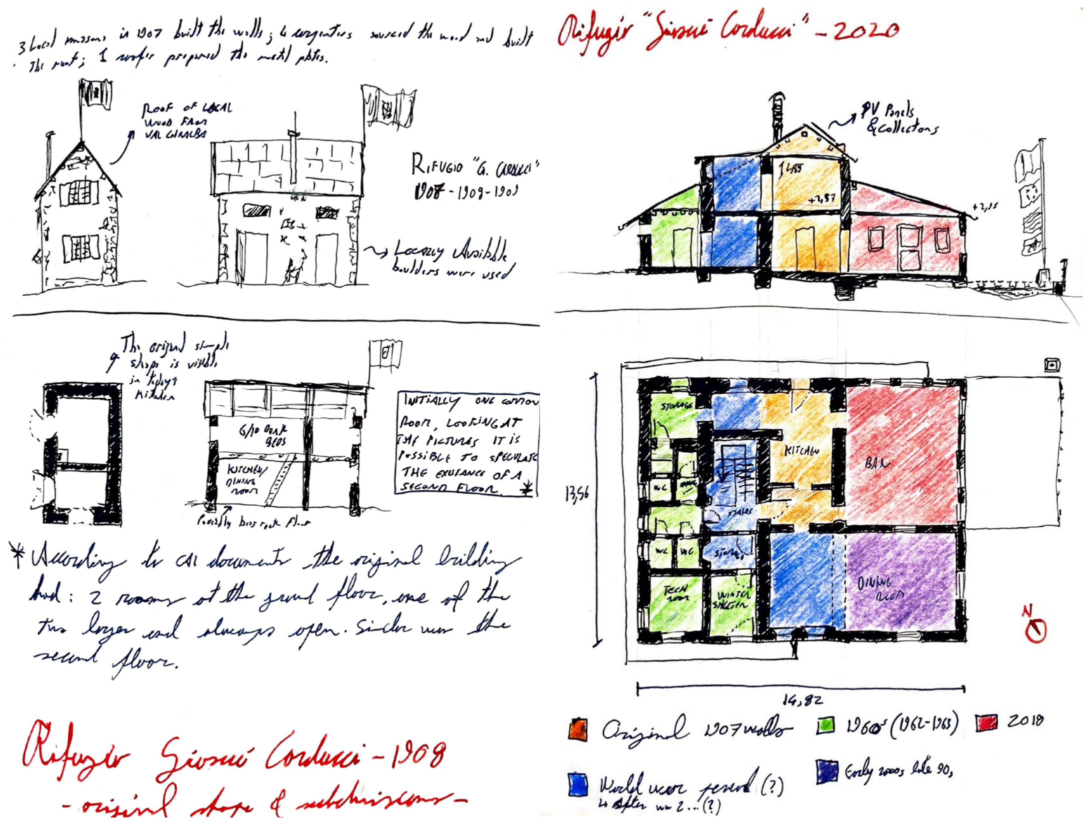
A Node Within An (Eco)System - Rifugio Carducci

As earlier mentioned, the theoretical framework on which this research is based aims at studying the high-altitude alpine refuge, in the specific Rifugio Carducci, as a node within an (eco)system. What this concept translates into is a look at the various systems that compose the environment of the refuge.



First Hut as built in 1908 (left), the Refuge today with evolution sequence (own illustration). Below two historic pictures of the Refuge. in 1908 and in 1963 (cartolinedairifugi.it)

Left: Italian soldiers reaching the Alta Val Giralba, winter 1915-1916 (racc. Giovanni de Donà. Vigo di Cadore). Right: forcella Giralba military logistic village, winter 1915-1916 (cap. Giovanni Sala, Biblioteca Storica Cadorina. Vigo di Cadore)

Starting from the overview of the mountain range within which the refuge is located, looking at its natural and economic environment, this section of the research will then move towards mapping (studying) the infrastructure of the refuge and the systems that are currently making it work. Finally, this section will explore the potential for improving the impact of the refuge on its environment, exploring and studying each system throughout the project's development and forming a strategy that will maximise the positive impact of the refuge on its (eco)system.
This section aims to use as much as possible hard data to understand if and how certain systems can be improved or implemented. Data is sourced from scientific literature; meteorological simulations are employed to study the local climate; detailed power generation and consumption are extracted from the refuge's control panel, and information of the refuge's systems and supplies is made available by the caretakers of Rifugio Carducci. Where precise data is not available, estimates are made based on the best available sources.

Rifugio Carducci Within Its (Eco)System

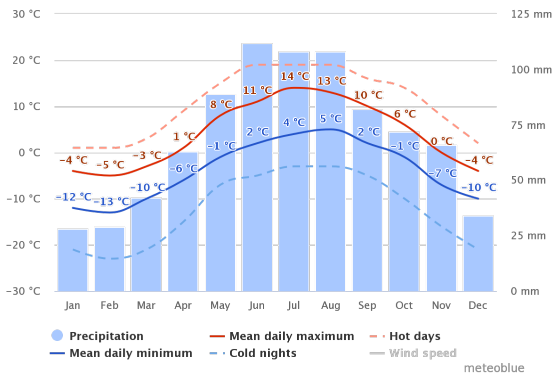
Located at 2297 meters above sea level, Rifugio Giosuè Carducci, named after the famous Italian poet that visited the Cadore area in1892, is defined as an alpinistic refuge capable of hosting 25 to 50 people overnight between fixed and temporary beds. The refuge hosts around 2300 people each season.
Sitting in the Alta Val Giralba, the refuge is surrounded by the peaks of Cima d'Auronzo, Croda dei Toni, and Monte Giralba, close to the border between Veneto and Trentino Alto Adige passing by Forcella Giralba (2431 meters above sea level). Open for less than five months per year, it is only accessible by four trails, two of which are fixed ropes routes. The only other possible way of access is by helicopter. The hut was first built in 1908 as a direct response of the Italian Alpine Club (CAI) to the Austrian/German Zsigmondy Hütte, still open today on the Sud Tyrol side of Forcella Giralba, around at one hour walk form Rifugio Carducci.
Sons of their time, Rifugio Carducci and Zsigmondy Hütte result from a nationalistic use, representation, and imagination of the high altitudes. The concept of Heimatschutz (defence of the homeland), aimed at forcing the recognition of identity was demanded the construction of the new refuges in a disputed area between the Austrian Empire and the young kingdom of Italy (Dini, Gibello, & Girodo, Andare per rifugi, 2020). Where the border was never clearly marked, alpinism and the construction of alpine huts became an important political activity. The Austrian/German alpine clubs, relying on more substantial funds, started to build bigger and more characteristic refuges than those, mainly wooden, built by the Italian SAT/CAI. The refuges built by the Austrian and German clubs were to recall the ideals of solemnity and solidarity while at the same time being intimate, sober and had to provide a feeling of protection. This translated into simple and sober geometric volumes, covered with a simple two-pitch roof. This typology rose from the romantic idea of the sheds built at lower altitudes for farming purposes, and it is because of this that the concept of refuge became connected with the idea of baita, while in reality, the huts came to inhabit an area previously free from any built element. As visible in the western part of the Alps, colonised in the earlier phases of alpinism, the aim was different and more focused on exploration and experimentation. This therefore translated into the development and construction of "high-tech" buildings, opening the way for prefabrication and often taking inspiration from nautical/aeronautical technologies. It is in the western part of the Alps that the first examples of prefabricated structures are employed. These were first built in the valley and then transported piece by piece to their location in the high altitudes.
Nevertheless, the first huts and Rifugio Carducci is always composed of the same elements: a common room with planks and straw and some simple cooking equipment. Often three walls are built-in wood/local rocks while the fourth is the wall of the mountain itself. A one pitch roof is normally used. The Grands Mulets refuge in 1878 became the first "managed refuge" with a caretaker and a cook providing a warm meal for the alpinists. As it will remain the same for Rifugio Carducci, the common single room during the day was used as a kitchen and dining room, while during the night, the same planks and straw became the bedroom. The concept of a single shared room evolved in today's "lager"; common

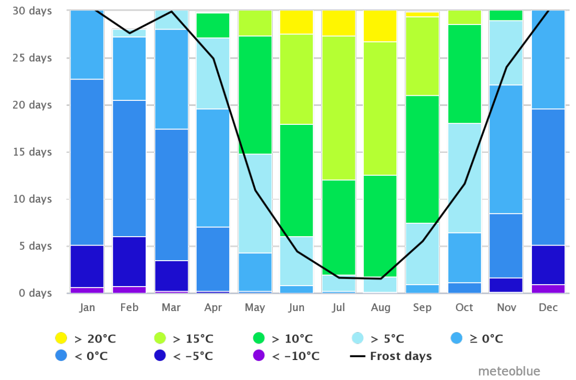
rooms with bunk beds where guests sleep all together. While the introduction of small more hotel-like rooms is recent and remains a prerogative to non-alpinistic refuges.
Finally, as is often the case, the hut underwent several modifications and expansions leading to today's form. In the image above, it is possible to see how, with time, the refuge grew from the original shape to today's volumes. This growth remains visible today.
The following sections will study Rifugio Carducci in its environment, looking in more details at its natural surroundings, as well as the infrastructure within which it is located. The refuge's systems of supply are then presented, completing the study of the current node within its ecosystem,

Natural Environment

Climate Analysis

Based on the data available on meteoblue.com, the simulated climate analysis of Rifugio Carducci is the result of 30 years hourly weather model and has a spatial resolution of approximately 30 Km. After contacts with ARPAV, Veneto's agency for environmental prevention and protection, the climate analysis available online can be considered as realistic. Data from the nearest weather station indicates slightly higher temperatures than those recorded by Meteoblue. Still, according to the ARPAV's experts, this can be reconducted to the effects of climate change on the specific area of the weather station and the location of the station itself. The closest ARPAV's station is located on Monte Piana, about 10 KM away from Rifugio Carducci.





The graphs above show the average temperatures and precipitations for 2020 (graph on the left) and the maximum temperatures in days per month (graph on the right).

Above are visible the graphs for the overcast (left) and precipitations amounts (right). As per data made available by ARPAV, the areas within the city limits of Auronzo are characterized by an average between 1000 and 2000 mm of precipitation per year (ARPAV - unità di Progetto Foreste e Parchi, 2013).

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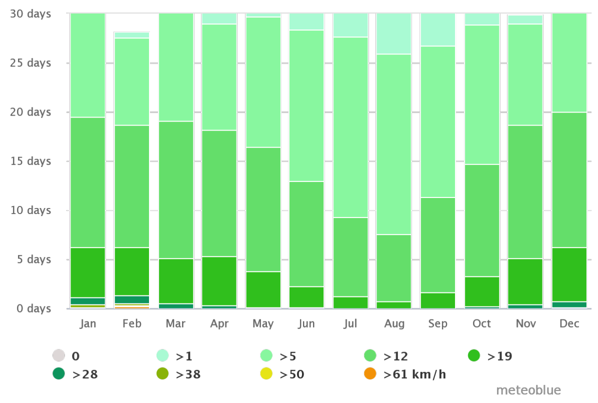
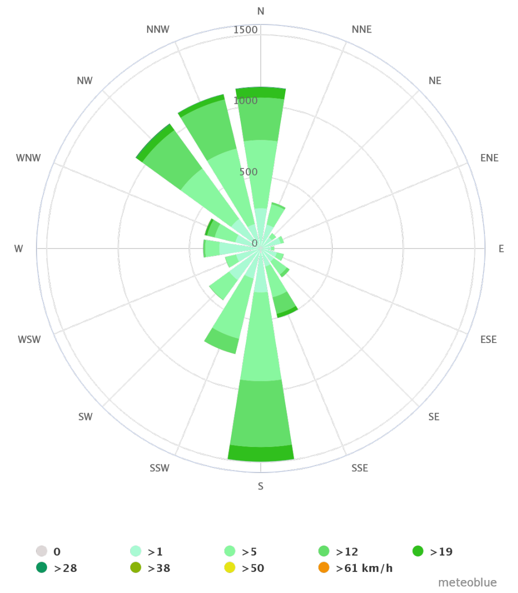
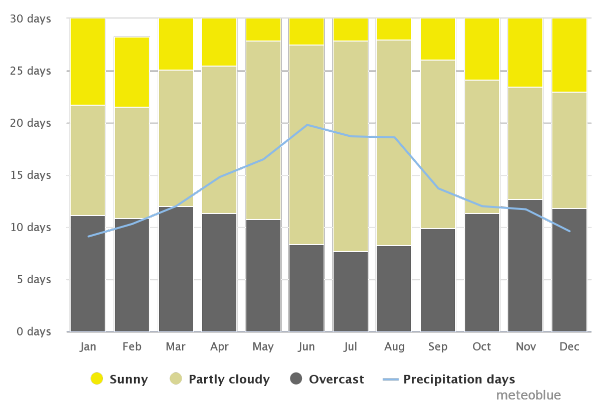
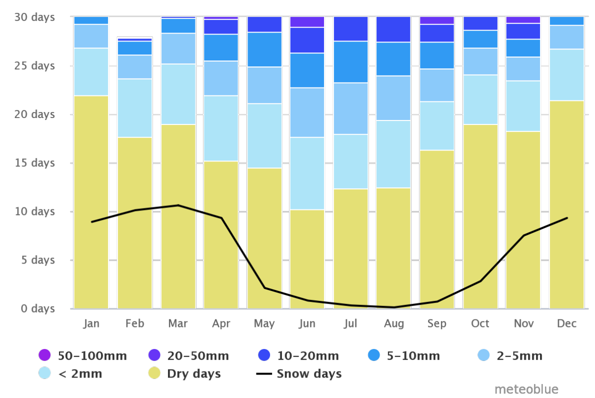


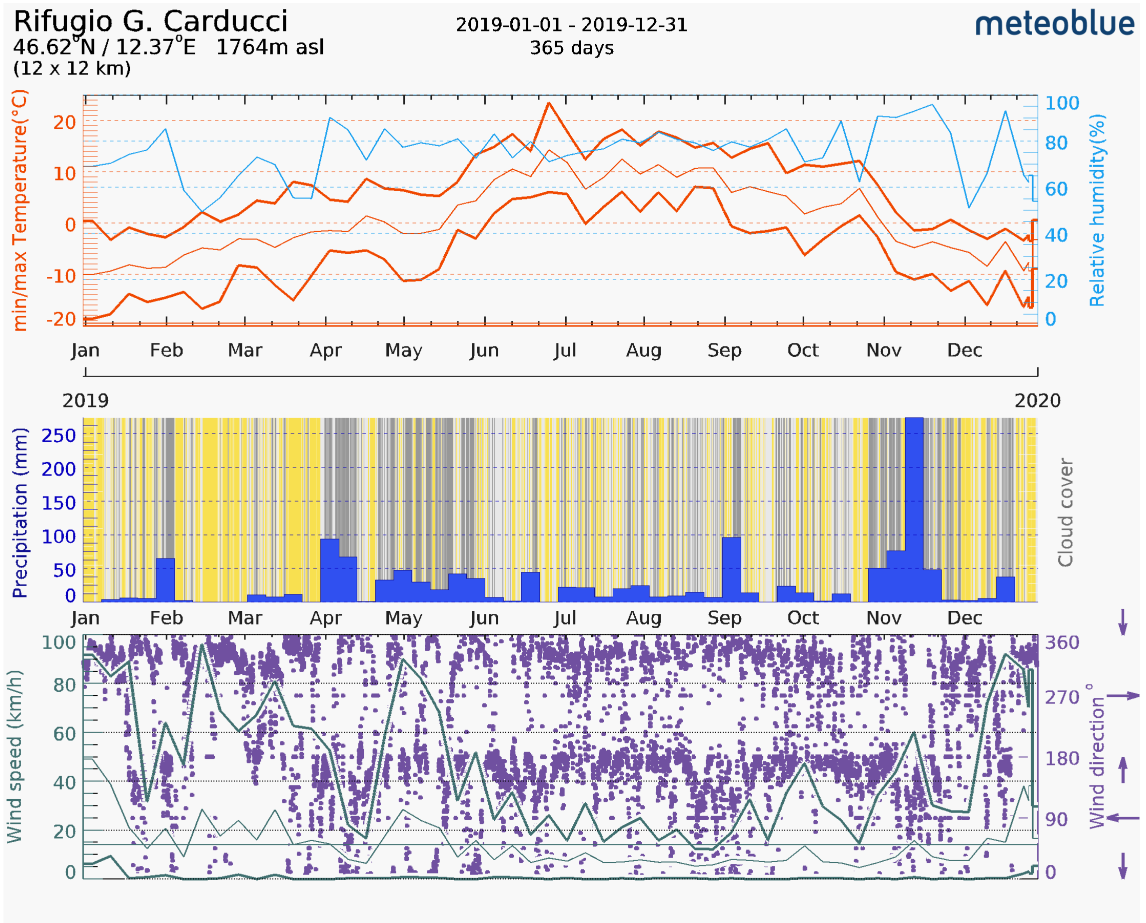


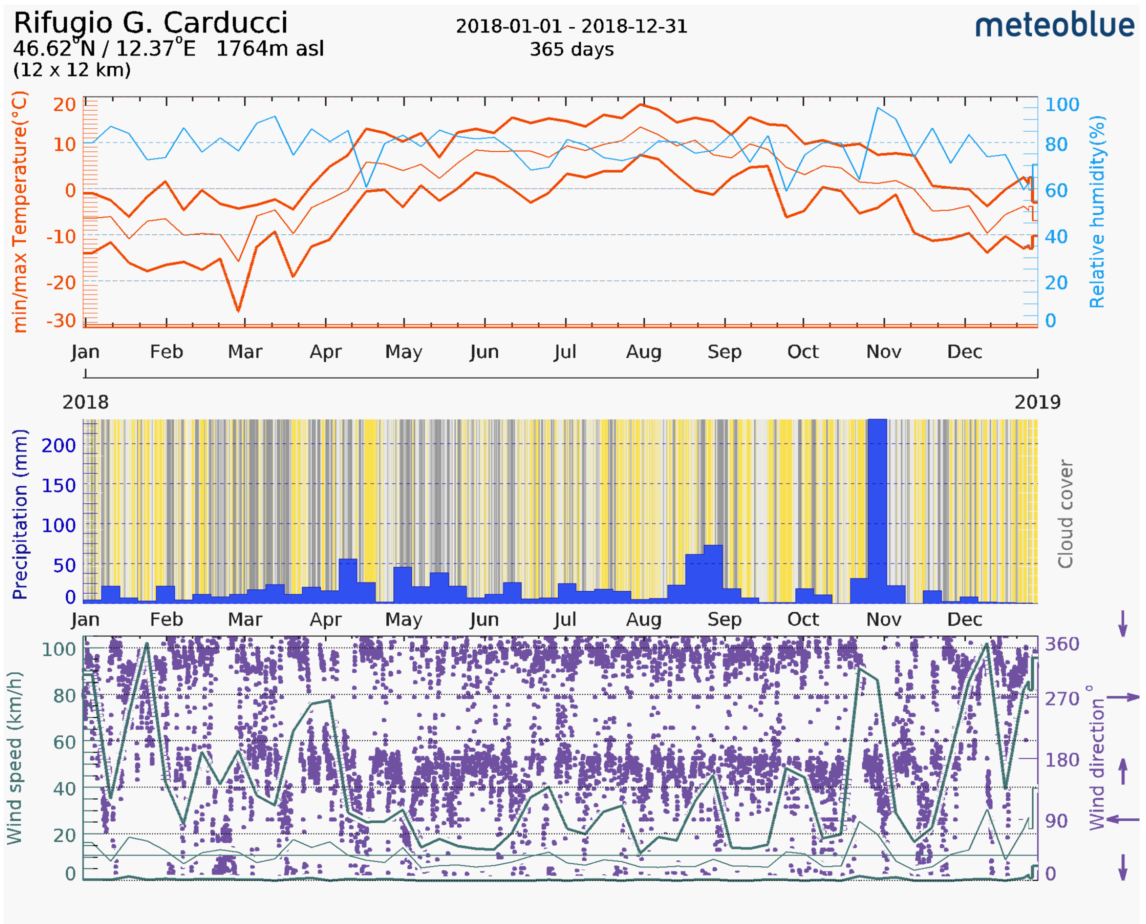


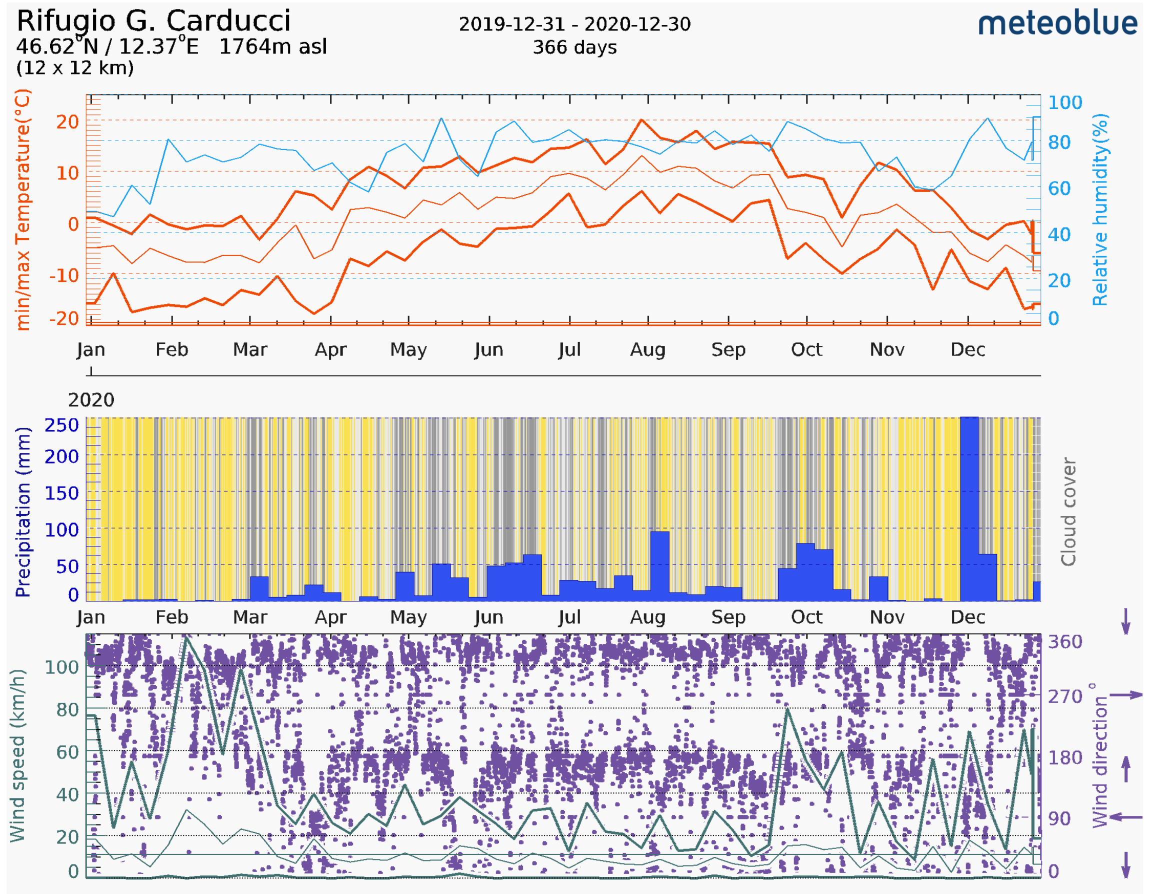


It is recorded that the months from May to October, the opening season for the hut, are characterised by an average of more than 100 mm of precipitation each month. This data is relative to the town of Auronzo, at 849 meters of altitude, that, given its location in the valley, sees the effects of the endoalpine climate. It is interesting to note that in the same report, it is specified that thanks to this climate, the forests within the city limits can produce 5.5 tons of wood per hectare per year. The refuge is located above the trees line that stops at around 1900/2000 meters above sea level. On the left are two more graphs from Meteoblue: a wind speeds graphs on top and a wind rose on the bottom. The available simulations show prevailing winds between 360° and 180° for the 2020 year. Below the two mentioned graphs are three climate history data for 2020, 2019, and 2018 on a 12x12 kilometres area at 1764 meters.

Weather data summaries graphs per year. 2018 (top), 2019 (middle), 2020 (bottom). Source: Meteoblue.



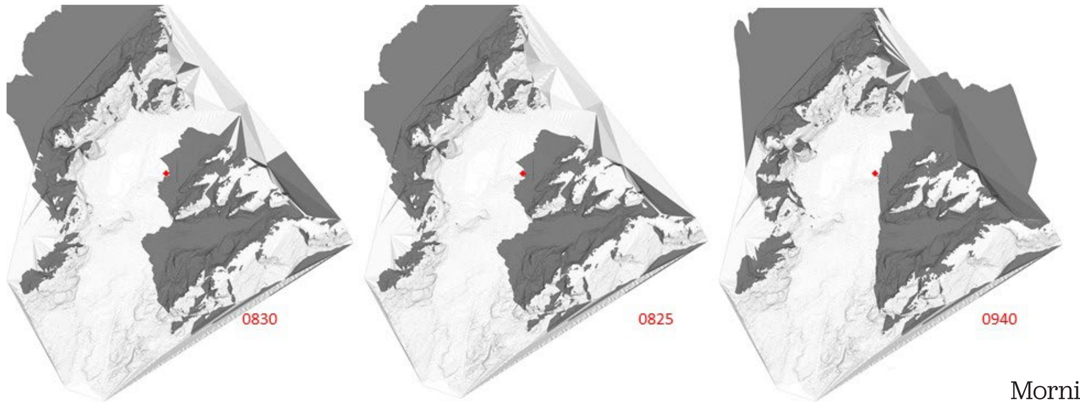




To conclude the climate analysis, the solar radiation for the town of Auronzo for the year 2020 is presented in a table provided by ARPAV (available as Appendix A attached to this report). Once again, this data is relative to the weather station of Auronzo, at 849 meters above sea level, and therefore needs to be adjusted for the 2297 meters of Rifugio Carducci. Nevertheless, they represent a starting point for this research, and further study will be necessary to adjust the available data. (Data is expressed in MJ/m2).

Cast Shadow Study

If in major cities fundamental aspects to consider during the design process are access to view and the relationship with the nearby urban texture, in high altitude the fundamental becomes the study of the surrounding landscape. On some occasions, alpine huts are located at the highest point available; see, for example, one of the first huts in the Dolomiti area Rifugio Nuvolau, or on a ridge, as is the case for Cabane de Tracuit. In the case of Rifugio Carducci, with it being first built as a base point for further exploration of the nearby peaks, the location is given by the proximity to the climbing routes. For this reason, the hut is located on a ledge in Alta Val Giralba, surrounded but peaks several hundred meters higher. This situation, naturally, casts shadows on the refuge that consequently has a somewhat limited window of time in which it is irradiated by the sun; fundamental aspect to consider, for example, when engineering the energy harvest capability of the hut or when considering solar gains and views. To inform the design for the renovation project, it is therefore necessary to understand the effects of the cast shadows on the refuge. To do so, a 3d model of the surrounding landscape was prepared, based on georeferenced survey maps provided by Veneto Region. Being the location at the border between two regions, different data sources were merged to develop the model. The result of this process is an accurate model used to study the hut in its physical environment, where a solar study revealed the boundaries and time range between which the refuge could harvest the maximum amount of solar energy. Below is presented an extract of the study: an overview of Alta Val Giralba, locating the refuge (in red) The drawings are showing the cast shadows for key times of the year: The average opening date, the summer solstice, and the average closing time in autumn. The study is therefore run between late May and late October. This time frame is dictated by the opening season of the refuge since optimising the hut's exposition for the winter sun would not be necessary being it closed. Thanks to this study it was possible to discover that the refuge was hit by direct solar radiation between 8.30 in the morning and 17.00 in the afternoon, with an Azimuth between 133° and 155°.



Morning

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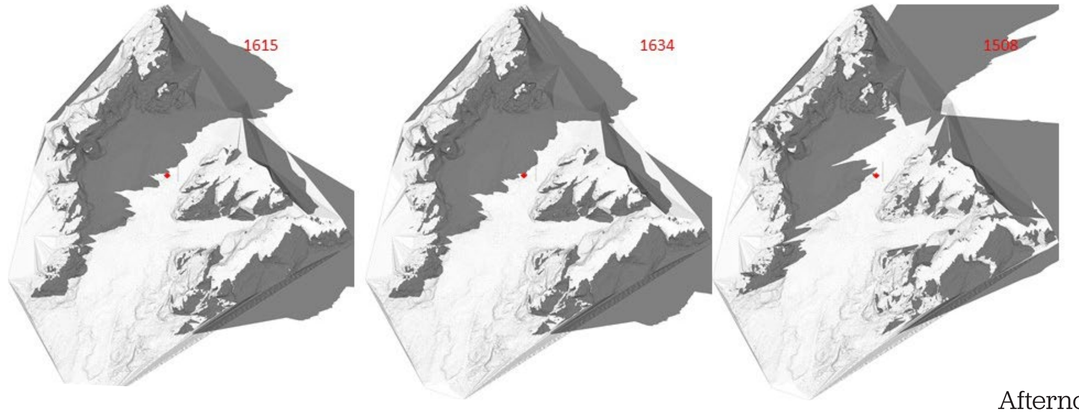
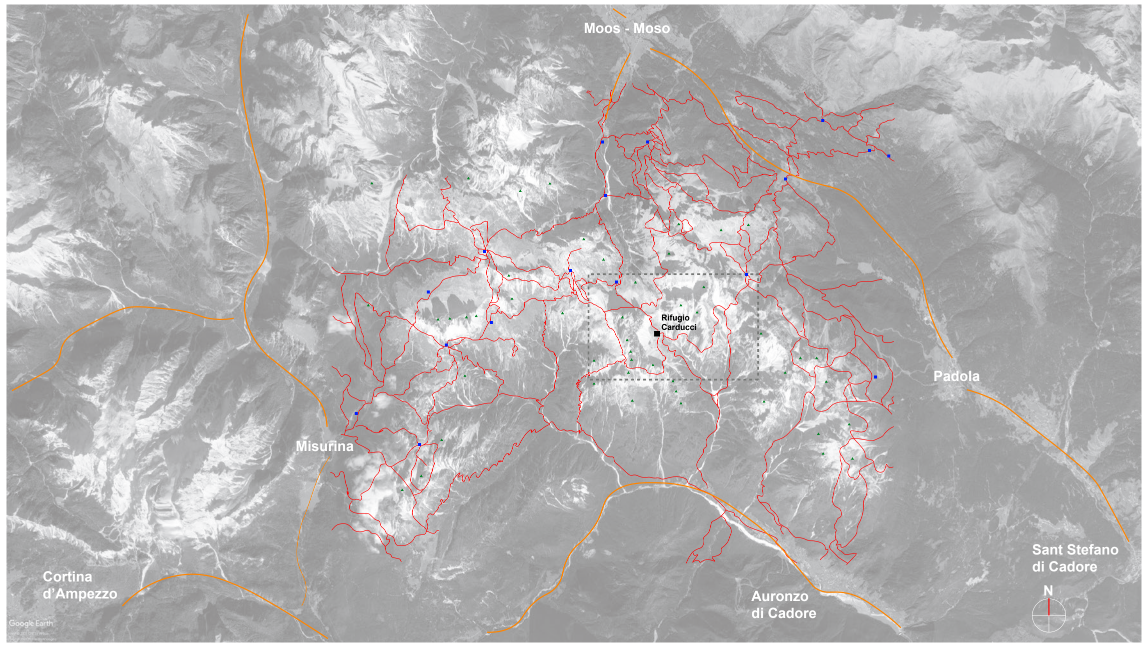


Afternoon

Infrastructure Of Connections

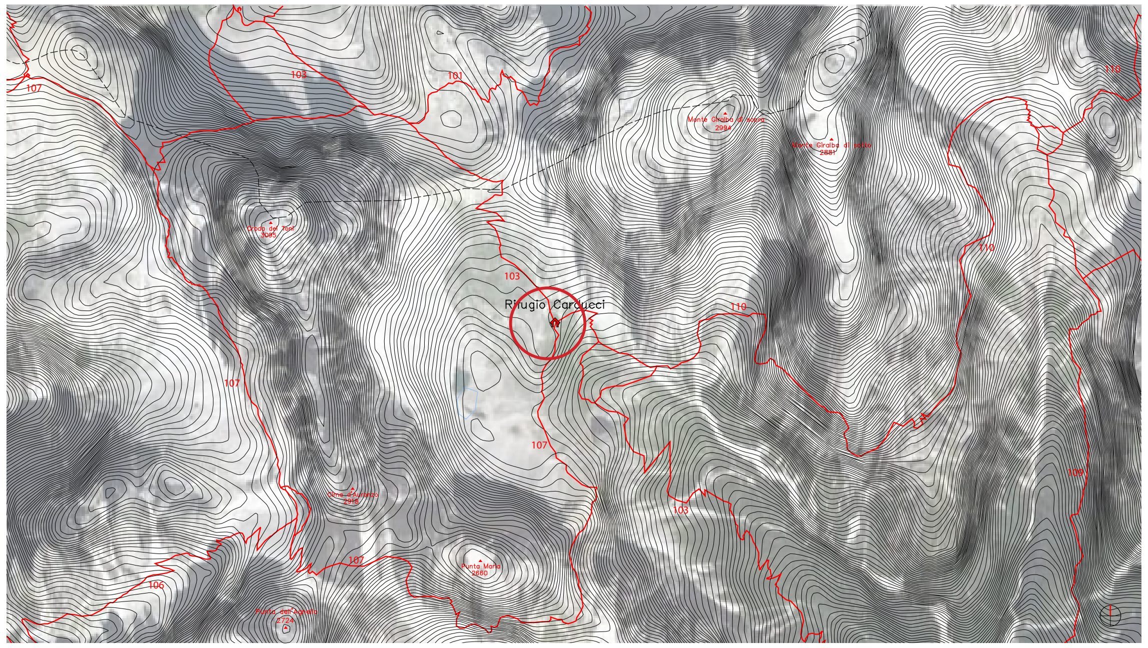
Finally, to locate the refuge within its ecosystem it is also important to understand the network of trails that Rifugio Carducci is part of. Without this network, the refuge would not be what it is, and would not function as it does today. Understanding the access ways to the refuge will serve to understand the hut's current systems in the following chapters.



Nearby towns, main roads (orange), trails interesting the area (red). Own illustration (base image Google Earth)

As already mentioned in this report, Rifugio Carducci is only reachable by foot trails, other than a helicopter flight for supplies and rescue needs. With excursionistic trails, it is possible to reach the refuge from the towns of Auronzo or Sesto, while with fixed-rope trails, it is possible to reach Rifugio Carducci from Rifugio Berti or from Bivouac A. De Toni.

From Auronzo, following trail number 103, it is possible to reach the hut by hiking up Val Giralba in about five hours and 1370 meters of elevation gain. Although this is the most direct access way, the more commonly used is from Sesto, on the Trentino Alto Adige side of the dolomitic group in which the refuge is located. Following the same trail number 103, it is possible to reach the hut in less than four hours, with an elevation gain of around 1000 meters. This access way starts at the beginning of Val Fiscalina for passing by the already mentioned Rifugio Comici. The two other main access ways, where sections of fixed ropes are present (and therefore climbing gear is required) starts from Rifugio Berti or Rifugio Auronzo. The first one with a nine to ten hours trail with an elevation gain of around 1400 meters, the second with a 5 to 6 hours trail that maintains a general altitude of 2300 meters, reducing the overall elevation gain (trail number 107).



Trails connecting to Rifugio Carducci. Own illustration (base image Google Earth).

Of course, these are just a few examples of possible access routes. As seen in the topographic map above, the area is interested by a large number of trails and fixed rope ways, allowing access from several locations.

Within the local infrastructure of trails, it is important to note that, passing by Rifugio Carducci, there are two multi-day routes known as Alta Via. Alta Via number 5, known as Alta Via di Tiziano (the famous 16th-century Italian painter), is a 6-7 days trail starting from Sesto, in Trentino Alto Adige, with arrival in Pieve di Cadore, in Veneto. A trail that crosses the dolomitic groups of Popera, Croda dei Toni, Marmarole, and Antelao. The second Alta Via passing by the hut is the recently inaugurated trail Dolomiti Without Borders, a project/trail connecting Italy and Austria along the former border and front lines of the Great War, through 12 fixed-rope trails; a 9 days route that connects 17 different huts.

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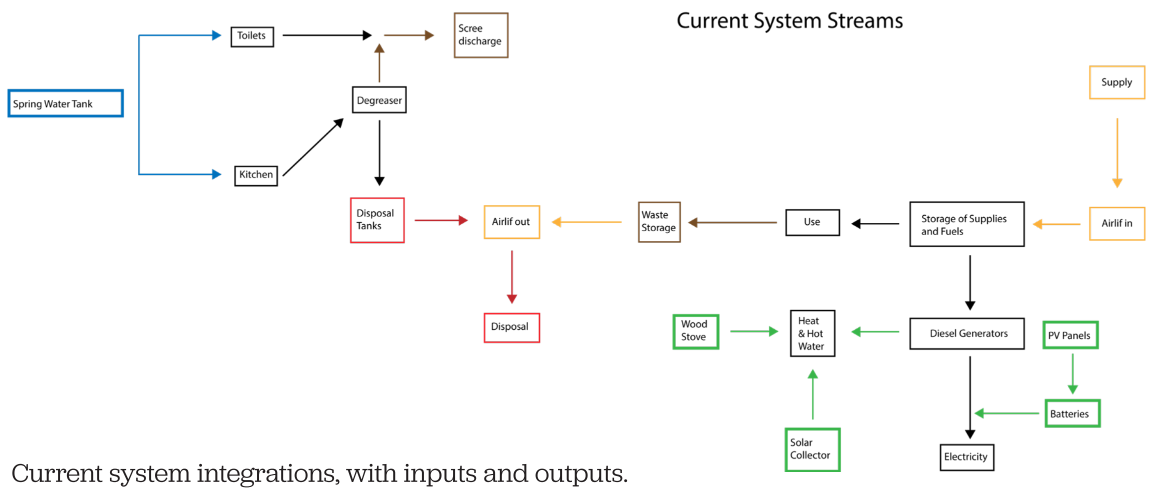
In conclusion, if we consider the refuge as a node within a network of connections, it is possible to see that, although occupying a relatively remote location, the hut is strictly interconnected with its territory. As seen below, it is possible to understand the network of trails as an urban transit map that connects the different parts of a city.

The Node's Systems

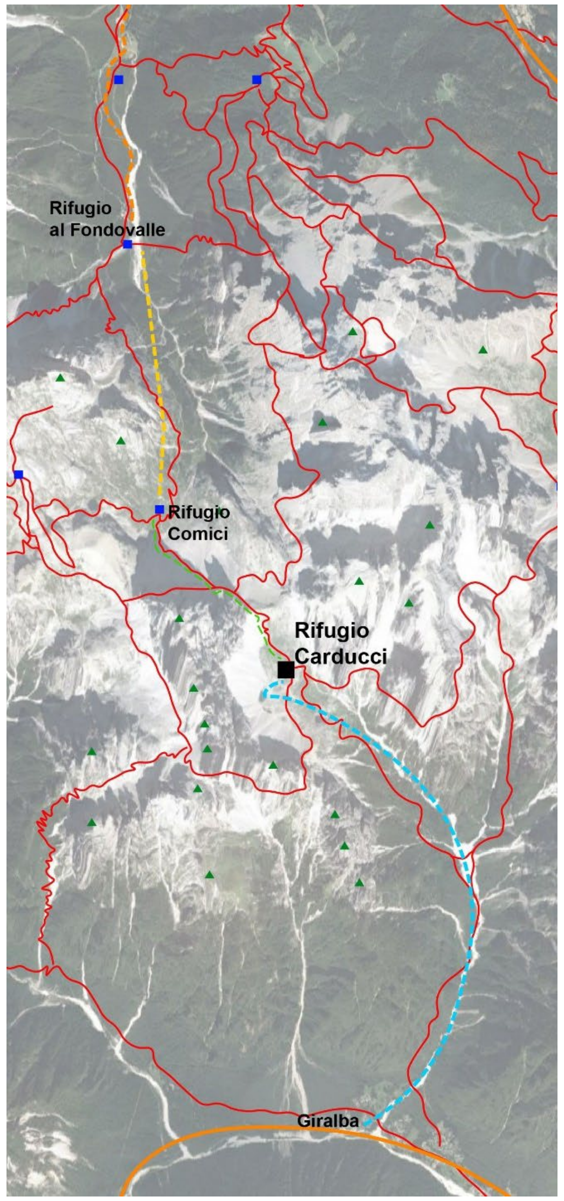
Given the specifics of the location, the refuge is not connected to any grid, being this electrical, hydric, or a sewage system; and as see in the previous section Rifugio Carducci is only accessible by several hours of hiking. During the years, the caretakers made several and valuable improvements to the various systems of the refuge and are always on the lookout for further modifications, this section of the report aims at painting the picture of these systems as they are at the time of the writing of this thesis. Studying the current node's systems will provide the foundations upon which the systems can be further improved.



Current system integrations, with inputs and outputs.

Supply

Starting from the general supply of food and materials to the refuge, it is to be noted that there are three options available to the caretakers: Backpack, cable car, and helicopter. Starting from the latter, the helicopter is the main vector that supplies the refuge from materials, fuel, food, and waste disposal. The helicopter is a fundamental and indispensable tool for all the huts infrastructure of the Alps and beyond. Currently, the only machine capable of delivering notable quantities of supplies to the huts, as well as being the main construction machinery of high-altitude and invaluable rescue vehicle. In the case of Rifugio Carducci, the helicopter that supplies the hut (Airbus H125) at that altitude can transport up to 800 kilograms of supplies. A cargo net is connected through a cable to the bottom



Supply lines to Rifugio Carducci. Orange: road connections. Yellow: cable car. Green: trail. Light blue: helicopter flight.

of the helicopter. The materials are then transported from the closest available road connection (usually the SS. 48, at the bottom of Val Giralba) to the refuge. A flight from the bottom of the valley to the refuge is known as rotation. Each rotation can transport 800 kilograms to and from the refuge with a cost of approximately 150 Euros per rotation and an initial call cost of 350 Euros. The time necessary from one rotation is a matter of minutes, with the flight to the refuge lasting around three minutes from take-off to landing. With the hut's opening in late May, the helicopter transports to the refuge around ten 800 kilos nets of supplies to the refuge, including most of the not-perishable items and part of the fuel necessary to run the generators. Throughout the season, the helicopter comes to the refuge up to a few times per month de-pending on the needs of the hut, transporting waste from the refuge to the valley, and transporting the 2500 litres of diesel necessary to run the generators for the season.

Perishable and smaller items are carried to the refuge by backpack from the caretakers or volunteers, either from Auronzo or from Sesto, on the Tyrolean side of the mountains. From Sesto, there is the availability of a small cable car that starts close to Rifugio Fondovalle and that arrives at Rifugio Comici. From Rifugio Comici supplies are transported by backpack, or at times with a tracked mini dumper.

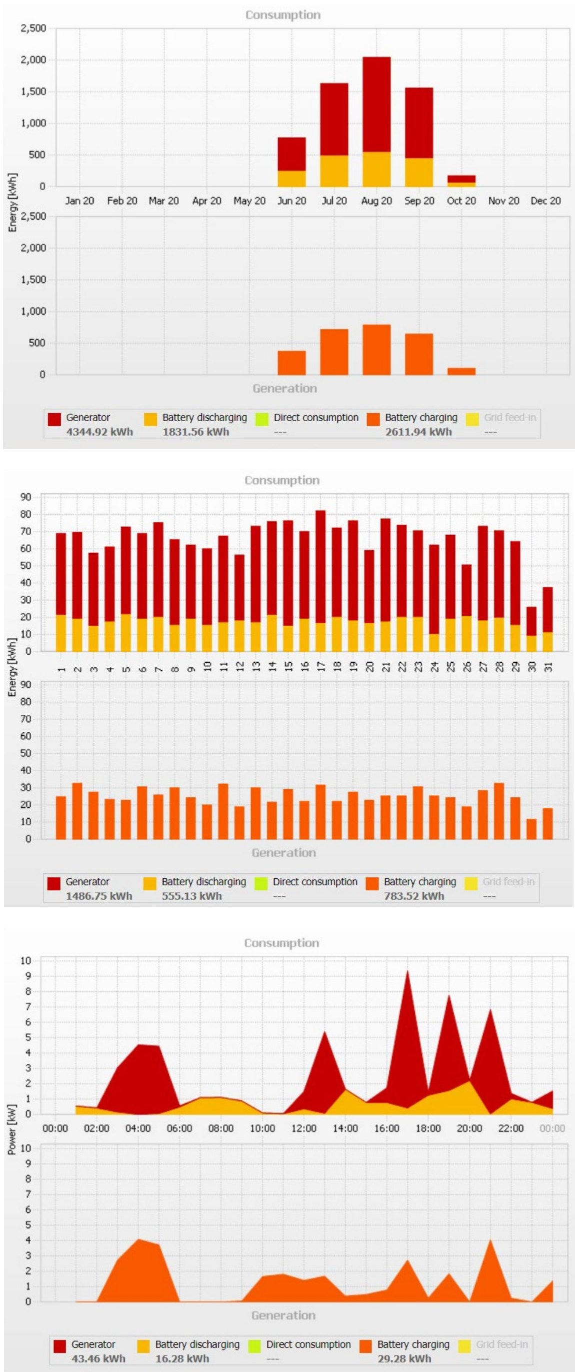
Today, the only food produced at the refuge are eggs, with this year's experiment of raising chickens directly at the refuge. Everything else is transported or carried to the refuge, and when possible, stored in one of the three freezers. A varied menu is offered to the guests depending on the supplies available. Regarding waste management, during the last years, the caretakers have greatly reduced the use of disposable items. However, on many occasions, given the health and safety regulations, they are still required to use some single-use items. Although common in the French huts, Rifugio Carducci waste is not incinerated on site but cleaned, sorted, and divided as much as possible. It is then stored outside a nearby woodshed, and once reached, an adequate volume is airlifted down the valley. Waste management is a delicate topic for huts' caretakers given the presence of animals and especially at higher altitudes of rodents.

Although seemingly out of place or overly detailed, these aspects are of fundamental importance for the understanding of the hut's functioning. Without these "lines of supply", the refuge could not exist, and the possibility to live the high altitudes would be significantly reduced. It is also interesting to see how these aspects do not play as much of a role in other typologies of buildings, while in this case, they are condition without which they could not exist.

Electricity

As already mentioned earlier in the report, it is com-mon for alpine huts to produce electricity using diesel generators and, to a certain degree, solar panels. It is often a combination of the two systems that powers a refuge. Before describing and studying the system used by Rifugio Carducci, it is important to note a few aspects relative to the specifics of generating electricity at high altitudes. The first consideration to make is the altitude. With the increase in elevation, and therefore the reduction in oxygen levels, fossil fuel burning generators lose efficiency and power output. The increase in fuel con-sumption and the reduced power output require more fuel to be transported to the refuge and bigger generators to be used. Altitude, on the other hand, improves the performance of solar panels with an increase of 42% between PV panels placed at 612 and 1764 meters above sea level (Chitturi, Sharma, & Elmenreich, 2018). Despite the increase in performance, the location of the huts often makes difficult the use of solar panels given the meteorological characteristics of the sites and the possible overcast shadow of the nearby peaks on the hut itself. The necessity of using batteries also provides a challenge to the huts' caretakers given the considera-ble weight to be transported to the location.

Regarding the specific systems used at Rifugio Carducci, as mentioned, a hybrid between diesel generation and PV panels is used. According to the notes taken during the last site visit, a 60 kW generator is installed at the refuge. At 2297 meters of altitude produces 45 Kw, consuming around 2500 litres of fuel per season. Along with it, a backup generator is also available in case of emergency. As it will be noted in the later sections, the heat from the generator is used to produce hot water along with 2 solar collectors. In addition to the generators, the refuge is equipped with a PV system of 5600 Wp, with a nominal battery capacity of 23,808 Wh. Below, a series of graphs are presented: The energy balance for the 2020 season, showing the combined use of generator and batteries; The energy balance for the month of August; the energy balance, as an example, for the 30th of July 2020. The daily balance is available for the 2019 and 2020 season of the refuge.



Graph showing seasonal, weekly and daily electricity consumption. From the Control Panel of the Refuge.

As seen from the graphs above, the primary source of energy remains the more reliable generator. In the previous section relative to the climate analysis, it was possible to see that the summer months are characterised by fewer sunny days than the rest of the year. It is also interesting to note that the generator, on the 30th of July, was used during the night to charge the batteries; this is visible also on other days of the season.

Water

Water supply is always a complex topic for a refuge. Usually built on the higher parts of a mountain range, it remains distant from the abundant springs of the valley.

As is often the case, huts rely on rainwater collection (not drinkable if untreated) or the water resulting from melting snow and ice. In the case of Rifugio Carducci, a small spring provides the water necessary to operate the hut.

Coming from the ice trapped between the rocks and the melting snow from higher altitudes, the spring is located within a few hundred meters from the refuge at a slightly lower altitude, just above Lago Nero.

The spring water is then pumped uphill to a 17.000 litres cistern, stored for the hut's use. This recently installed cistern is located underground and uphill from the refuge. The demands for hot water are co-generated by the diesel generator's heat and two solar thermal collectors located on the hut's roof.

Counter clockwise: springwater collection; pipes connecting the spring to the system; entrance to the underground 17.000 Litres water tank. (Own pictures)

Sewage

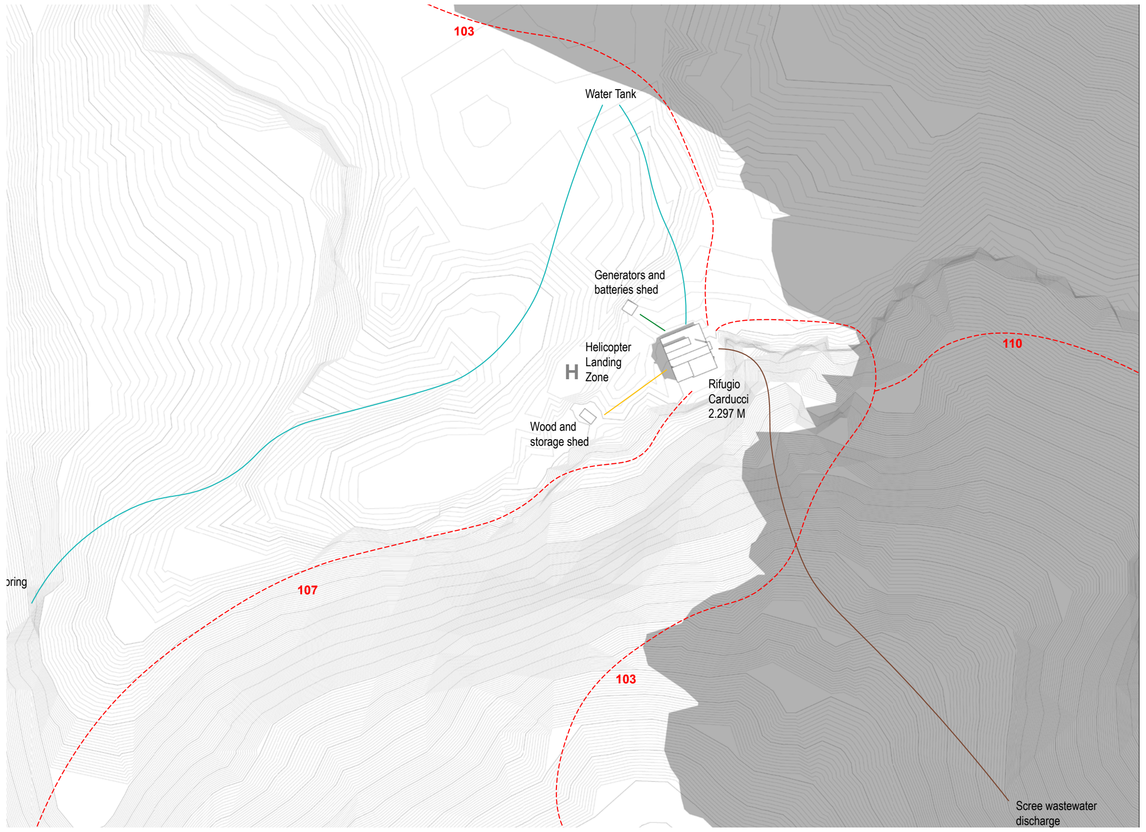
No one system works for all the alpine huts (CAI Lombardina, 2019). The refuge object of this study is equipped with a degreaser and a holding tank. The wastewater is then dispersed through a simple sub-irrigation system buried in the nearby scree downstream from the refuge. From a site visit in summer 2020, it was estimated that sewage was dispersed underneath the scree southeast of the refuge, at several hundred meters and 50 to 100 meters lower altitude. It remains unclear when and how the system was built; it is, therefore, difficult to assess the impact on the environment. Nonetheless, all the possible measures are taken uphill by the hut's caretakers.

Materials

With the first refuge built in 1908 and the several expansions throughout the more than one hundred years of its lifetime, the refuge is built with several different materials. The latest expansion is a combination of steel structure and wooden elements, while the rest of the refuge is probably a combination of concrete and locally sourced rocks. The use of concrete and locally available stones can be seen in the picture capturing the extension works that occurred at the refuge between 1962 and 1963. It is possible to speculate that part of the boulders used to build and expand the refuge was taken from the nearby ruins of World War 1 bar-racks and trenches. During the Great War, the Alta Val Giralba area was part of the front line between the Austrian Hungarian and Italian armies. The refuge was probably damaged during the war and rebuilt with the available materials leftover from the war efforts.

Renovation works in 1962. Source Zandonella Callegher

Floors and roof have a wooden structure with the roof being covered with metal sheets of the seam roofing system so common in the area. Given its light weight and resistance, this roofing system is often used for huts and generally for building in mountainous areas where the accumulation of snow and wind strength are to be considered.



Site / System Plan

The Study That Informs The Design

What was presented in the previous sections of this study served to gain an in-depth understanding of the ecosystem of an alpine hut. The concepts of ecosystem, or system ecology, served to paint a comprehensive picture of the studied building. Understanding that alpine huts, and buildings in general, are in no way closed systems, fully in-dependent for their surroundings, but instead exist only because in one way or another are systemically integrated within a broader system. In the case of Rifugio Carducci, for example, it would not be possible for it to exist without the complex network of trails crossing the Dolomites or again without being positioned where it is without the historical reasons that led to its construction. Finally, it would be possible to have the same building without the current systems supplying it with water and energy.

It can be argued that building within an ecosystem means, firstly, reading through the different layer of a building, from smallest to broader, from technical to historical, understanding its unique specificities. Only then, informed by this broader understanding, it is possible to consciously take design decisions aimed at improving the building within its ecosystem. The argument to be made is that, to reach the broader goal of a more sustainable built environment, it is imperative to understand the specifics of each building in each location. Only then it is possible to design buildings capable of using and improving their ecosystems of reference. In conclusion, the previous section of this research focused on gaining knowledge and a deep understanding of Rifugio Carducci, uncovering its uniqueness and peculiarities, understating what makes it work and how.

With this baggage of information, it was then possible to inform the design of the expanded and renovated hut, better integrating it within its ecosystem and therefore making the “refuge machine” more sustainable. The gained knowledge informed both the architectural design, as well as the technical design; aspects that in the scope of this project cannot be red separately. The following sections present the argumentations and design decisions taken to better integrate Rifugio Carducci within its ecosystem, focusing on the technical aspects of energy use, electricity production, water supply and water treatment. Furthermore, the following sections exemplify how the understating of a building’s system ecology inform the different design decisions.

A More Integrated Refuge

Based on the study of the system ecology of Rifugio Carducci, this section will focus on introducing and arguing the technical design decisions taken with regards to energy production and use, water supply and treatment, an argumentation on materials selection. Finally, a short speculation regarding an improved supply strategy based on the solutions proposed for the renovation project will be made.
ENERGY PRODUCTION & USE In the previous sections of this report, it was introduced that the current hut is powered by a diesel generator coupled with a solar panels/battery system. As seen in the electricity usage graphs, the current solar panels are insufficient to provide the necessary energy to power the refuge. This information, coupled with the solar study made thanks to the 3D model, shows that the hut is covered by cast shadows from the nearby peaks, leaving a shortened energy harvesting time between 8.30 and 16.30. At the same time, the solar study showed that with a 4° angle to the Azimuth, the south-facing roof of the current refuge is conveniently located to capture the sun’s energy. The refuge is therefore limited in sun exposition time but well-positioned for the use of PV panels.
Furthermore, given the hut’s altitude of almost 2300 meters above sea level, the efficiency of solar panels is sensibly increased. As presented in the article Efficiency of Photovoltaic Systems in Mountains Areas (Chitturi, Sharma, & Elemenreich, 2018) tests have shown that a PV panel at 1764 meters above sea level reached a 42% increase in efficiency than one at 612 meters. Based on this evidence, it is to be expected for this project to benefit from highly efficient solar panels thanks to the hut’s altitude. A consequence of the considerations mentioned above is the design decision to maximise the PV surface integrated into the refuge. In essence, the design goal implemented in the architectural proposal was to maximise the solar energy harvesting potential, dedicating the south-facing surfaces to the placement of Photovoltaic panels integrated into the architectural expression of the building. Thanks to the study of the local climate another important aspect were to be considered: the hut’s location is interested by north to south winds channelled by the Giralba valley and generated by the temperature difference between the high altitude area and the valleys below. Given the weather’s variability in the area, the refuge could also benefit from wind-generated energy, provided that further study is carried out ensuring the presence of turbulence-free airflow. Nevertheless, for the scope of this project, the use of a wind generator is considered as a possible option if the electricity produced by the solar panels would not reach sufficient levels.

The next step in the energy system design was to reconsider the energy carrier. As of the time of this project, Rifugio Carducci consumes about 2500 litres of Diesel per season and holds a battery storage capacity of 23.8 kWh. To reach the goal of eliminating the dependency from the combustion of fossil fuels it was necessary to provide a different and reliable energy carrier. While expanding the battery banks is possible it is necessary to consider the sourcing of natural resources necessary to produce the batteries, and at the same time consider the transportation to the hut itself and the lifespan that the batteries. Furthermore, a consideration must be made about the batteries’ storage during the winter months when the refuge is not in operation. What resulted was the need to carefully consider alternative options that would better answer to the needs of the hut as well as help answer to the primary design principle of this project: integrating and connecting the refuge to its environment. Once again, according to the sourced data, the area is interested by an average rainfall of 800 to 1100 millimetres per year, with an average of 100 millimetres during the summer months. As already mentioned earlier in this text, the refuge sources its water from a nearby spring, but given the nature of high-altitude areas water is always to be considered a valuable and scarce resource. The relative abundance of rainwater is not retained by the rocky landscape that allows the water to quickly reach the valleys. The two aspects of highly efficient PV capabilities and the possibility of capturing rainwater through the hut’s roof led to the consideration of on-site production of green hydrogen. This can be achieved through the electrolysis of rainwater during the high-intensity sun hours of the dolomitic early afternoons, when the refuge is al-most perfectly positioned to harvest solar energy and the electricity demands are low.

The Case For Hydrogen

In light of the recent moves of the European Commission towards the use of green hydrogen (produced through renewable resources) as a possible major contributor towards the reach of the set emissions cuts (European Commission, 2021) it is becoming apparent that hydrogen and fuel cell technologies are on the verge of gaining central relevance in our society. Very well including their use in the built environment. Research has shown the appearance on stage of high energy conversion efficiency capabilities projecting the hydrogen technology toward a wider use. To quote a recent study, "Fuel cells are a technology of the future here today, providing a change in the way heat and power are supplied to end-users. Fuel cells operating in CHP and trigeneration systems could finally provide the means by which energy generation can transfer from centralised to decentralised locales sustainably and effectively" (Elmer, Worall, Wu, & Riffat, 2015). As it appears clear, the technology can be employed in the built environment where energy reliability can be an issue, in the specific case of an alpine refuge this technology would completely eliminate the need for fossil fuel-based energy storage, providing a sustainable and reliable system. Hydrogen as an energy carrier has already been used in an alpine refuge: Refuge du Col du Palet in the Vanoise National Park, in the French Alps. The refuge since 2018 is using an electrolysis based system that stores the energy produced by the PV panels of the refuge. The system was designed and produced by MAHYTEC and POWIDIANA (Mahytec, 2018) and proves that hydrogen, fuel cells, and solar panels are indeed a viable solution for so-called off-grid buildings such as high-altitude alpine huts.

The Proposed Energy System For Rifugio Carducci

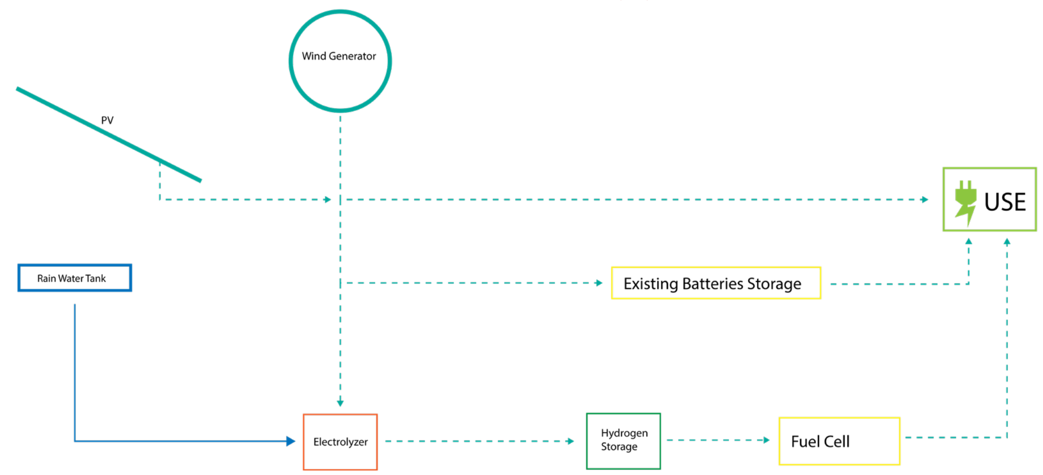
In conclusion, the proposed energy system for Rifugio Carducci would work as follows: The southern-facing roof surfaces of the renovated hut would harvest solar energy through an integrated photovoltaic surface; if necessary an integration of wind-generated power would be included in the system. At the same time, the north-facing roof surface of the project would be dedicated to collecting rainwater, considering 1 litre of possible recuperated water for every millimetre of rain falling on 1 square meter of surface. The collected water is stored in a water tank located inside the refuge to avoid its freezing and will be used later on in the system to extract hydrogen.

Once harvested, the energy will follow three levels:

1. When possible, the electricity produced by the PV surfaces is directly used by the hut for immediate needs. These can include, for example, ventilation, pumps and lights. Furthermore, in winter conditions, the electricity generated by the PV surfaces not covered by the snow has the potential to be used to maintain a set minimum temperature and ventilation inside the building.
2. The second level would be the recharge of the existing batteries. Instead of disposing of them, they can be kept in use at the hut until possible. Energy stored in the batteries can be used for lighting purposes, and most importantly, can be used in the bivouac, the only part of the hut accessible throughout the year. Thanks to the energy stored in the batteries, possible winter visitors can better use the bivouac. In case of necessity and emergency, charge their devices to call for rescue.
3. Finally, the third and final level of energy use would be by its storage through hydrogen production. In this case, the rainwater collected can be combined with the electricity produced by the PV surfaces and thanks to the electrolysis split oxygen and hydrogen. Hydrogen would be then pressurised and stored in pressure tanks in the former diesel generators sheds, together with the batteries and about twenty meters away from the hut itself. When necessary, the stored energy can be recuperated through highly efficient fuel cells, generating heat and electricity covering the hut's needs in a period of high demands and when solar panels are not in use.

The scheme below shows the systems in their entirety, indicating the interconnections between the different technologies into one comprehensive

Energy System Scheme



Energy system scheme. The proposed system prioritises direct use of energy, followed by recharging the existing battery bank, and finally uses the available energy to produce hydrogen as main energy carrier.

system that takes full advantage of the local environment without harming it.
To conclude this section, a dimensioning approximation of the system is as follows: The average electricity demand of the refuge, according to the building management system is of approximately 6200 kWh per season of 100 to 120 days, with an average of 5o to 60 kWh per day.

Hydrogen stores approximately 33.33 kWh per Kg of usable energy, compared to the 12 kWh per Kg of usable energy stored in Diesel. In comparison, to cover an average of 55kWh per day, the refuge would need 1.65 Kg of Hydrogen versus the 5.7 Kg of diesel if both systems would work in perfect conditions. The current system is consuming around 20 litres of diesel per day of operation. To produce 1 kg of Hydrogen, 9 litres of water are necessary. Assuming a daily need of up to 1.7 Kg of Hydrogen, it can be estimated that the refuge would need 15.3 litres of water per day or 1836 litres per 120 days season. An amount of water easily collectable from the hut's roof surface.
To extract hydrogen from the water are necessary 55kwh per kg of product that will then need to be pressurised for storage. Considering just the extraction process, the requirement of harvested energy would climb up to 90.75 kWh per day.
Considering a seasonal demand of 11.000 kWh due to the high demand of energy necessary to extract the Hydrogen, and with a peak hour solar irradiation of 1.080 kWh/m2, the hut would need a PV surface between 100 and 150 m2.

Although precise calculations and engineering are necessary to implement the system, it can be speculated that the already existing roof surface of the refuge could suffice to produce the energy necessary to remove the need for the diesel generator. The production of Hydrogen, its storage, the production of the fuel cells necessary to use it are all steps that require energy, as well as the transportation of those elements to the site. However, this needs to be compared to the supply chain necessary to transport on-site 2500 litres of diesel from its source, refining transportation and final flight to the refuge, or in the scenario of using batteries to store the harvested energy, to the supply chain necessary and the scarce natural resources needed for the production of the batteries themselves. In conclusion, to follow the project's guiding principle of connecting the building to its local environment, making use of what is available, the system as the one presented appeared as the most convincing solution. A system that uses locally available resources of water and energy harvested by the existing roof surfaces.

Water Supply & Treatment

With regards to water usage, as mentioned, the refuge is currently taking its supply of water from a nearby spring. The water is then pumped uphill of the refuge, where a 17.000 litres underground tank is located. The spring water is used to cover all the necessities of the refuge, from cooking to sanitary needs. With the project's requirement of doubling the hut's receptivity and the intention of producing hydrogen on site, the supply of water needs to be reconsidered. As already mentioned in these pages, in high-altitude mountain areas, water is a rare commodity that needs to be carefully managed.
With these considerations made, the consequent proposal is of associating with the use of spring water, the collection of rainwater. In the project's intentions, along with being used as a primary source for the extraction of the hut's energy carrier, the rainwater will be used for sanitary purposes. It is within the project's vision to use rainwater for toilets and showers, as well as for cleaning purposes while reserving the use of spring water for cooking and drinking purposes.
Finally, the refuge requires an important intervention with regards to wastewater treatment. As of today, it remains unclear where exactly sewage water is discharged. The most recent information suggests that such waters are expelled from the refuge and discharged further downhill underneath the nearby scree. Wastewater from the kitchen instead goes through a degreaser before being discharged. An entirely new system needs to be implemented.

The project's proposal is to implement a wastewater treatment system based on the information retrieved from Lombardy's section of the Italian Alpine Club, which, in 2019, held a training module for huts care-takers regarding wastewater management at high altitudes (CAI Lombardia, 2019). Furthermore, the proposal is based on the lectures and work of Prof. Bruce Logan of the Pennsylvania State University, and the research group focusing on energy sustainable water infrastructures (Pennsylvania State University, n.d.).
The proposed system works as follows, downstream from the current degreaser installed at the refuge:

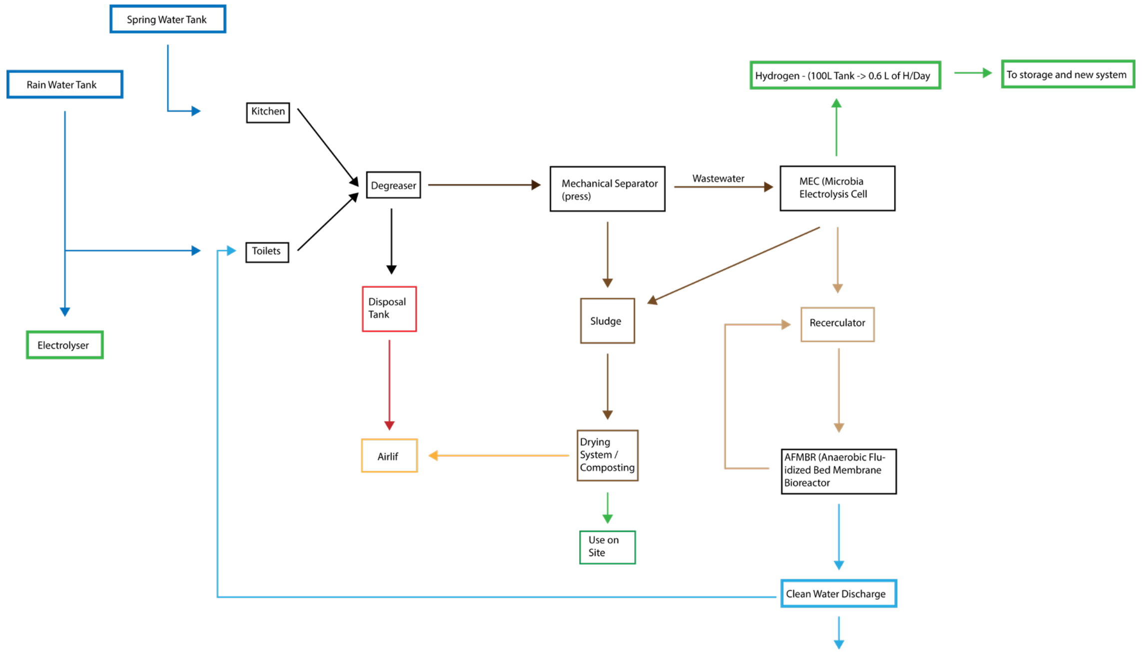
- A mechanical separator, or press, divides the solid (sludge) from the liquids.
- The wastewater is further treated in a Microbial Electrolysis Cell (MEC). At this, electricity and microbes further separate the wastewater and finer sludge. This process, according to the literature study, is currently in use to extract hydrogen (Heidrich, Edwards, Dolfing, Cotterill, & Curtis, 2014) (Fudge, et al.,

2021), further contributing to the hut's energy system functioning.
- Wastewater, at this point, would pass through a recirculating system and an Anaerobic Fluidised Bed Membrane Bioreactor (AFMBR), purifying water that can finally be discharged in the environment returning the collected water from spring and rainfall to the ecosystem.
- Finally, the separated sludge from the different cycles is collected in a bad filtering and drying system. Once the drying process is completed, the desiccated sludge can be further treated according to the municipality's waste treatment strategy.

In conclusion, the proposed water system concurs to the project's intention of integrating the hut into its ecosystem, using its available potentialities. In this case, collected water is given back to the natural environment in the cleanest possible form while, in the process, is concurring with the functioning of the refuge itself.

Materials Selection, Waste Disposal, And Supply Potential

This final section is aimed at addressing three more aspects of the project: how the study of the hut's system ecology guided the material selection for the renovation project; a short proposal on how to further optimise waste management at the refuge; and finally, a hypothesis on how to improve the supply of perishables to the refuge.



When it comes to materials selection, the architectural design phase focused on two strategies: reusing as much as possible what was available on site and use as much as possible locally sourced materials. The first strategy translated into the design goal of reducing to the minimum the demolition phase, using the existing structure, and where possible the existing layout. Furthermore, it was taken into consideration the thermal mass value that the existing solid rock wall has. For this reason, part of the materials recuperated from the demolition works and the excavations necessary to expand the refuge are reused for part of the internal wall, therefore, maintaining the advantages provided by the rock's thermal mass. More information on this is available on the project's drawings and details. With regards to the materials selected for the expansion of the refuge, the choice fell on the use of recycled aluminium as cover materials to the new built elements, while local larch is used for structural elements, wood fibre insulation boards, interior boarding, and external cladding. Larch is found in the forests of Cadore and has always been a driver of the local economy. Since the VAIA storm in 2018, many forest areas require extensive work. The storm knocked over nearly 8 million cubic meters of wood, a natural disaster that left many open cuts in the Dolomitic forests and forced the lumber industry to suffer from an over-supply of wood. Larch, and wood in general, is a perfectly suitable building material that can be sustainably sourced. Thanks to the use of mass timber prefabricated elements can be efficiently transported to the hut's construction site balancing weight and strength (Drexler, 2019).

The research touched many aspects of the hut and informed the design phase in several aspects. Finally, two more elements need to be considered when forming a strategy to make Rifugio Carducci more environmentally sustainable. As common for many human activities, operating an accommodation facility that provides shelter and restoration to the public will necessarily have to deal with waste management and disposal. While a reduction strategy is already in action, reducing to the minimum possible the use of disposal materials, the refuge still has to cope with waste storage. While reducing waste needs to remain an ongoing effort, further actions can be taken with the storage and consequent transportation of waste materials to the municipality's recycling facilities. As of today, waste bags are airlifted a few times per season depending on the demand. To optimise the ratio between volume and weight to be stored and transported, the use of a waste shredder would prove to be an effective integration in the hut's systems. Shredders and compactors are commonly used in the shipping industry, where storage onboard is required between harbours (Toneatti, Deluca, Fraleoni-Morgera, & Pozzetto, 2020), therefore a similar strategy can be used in high altitude areas to manage waste in between airlifts.

Finally, the last item to be addressed in this systems design proposal is the optimisation of supply deliveries to the refuge. As discussed, the helicopter is the primary mean of transportation for the hut's supplies, while some perishables are either transported by foot or via the small cableway that serves Rifugio Comici. While at the moment of this research, there is no viable alternative to the use of the helicopter, the energy system design for Rifugio Carducci has the potential to open the way to a new supply route. Without the need for a diesel generator and the potential for hydrogen as affordable and sustainable energy storage, part of the produced electricity can be used to recharge the batteries of a delivery Unmanned Aerial Vehicle (UAV). Although further research is necessary, the use of a drone for delivering low weight supplies to the refuge is to be considered as a viable option, as already tested by logistics companies, such as DPD in alpine villages (Willsher, 2019) and DHL (DHL, 2021). An adequately sized drone has the potential to further connect Rifugio Carducci to the local community, picking up fresh products from the producers in the valley and flying them to the hut. In this scenario, the hut would serve as a further point of contact between the high-altitude regions, visitors, and the local community.

Conclusions

This study presented in these pages started with the goal of designing a sustainable project for the renovation of the high-altitude alpine hut Rifugio Carducci. In the specifics, this paper focused on finding an answer to the following research question: How can the positive impact of a high-altitude alpine refuge to-wards its (eco)system be maximised?
To determine the hut's (eco)system, it was necessary to study Rifugio Carducci from different perspectives and at different scales, investigating how the high-altitude areas of Dolomiti work in general and how the specific refuge under study functions. This research developed a narrative strategy to be applied to the renovation of Rifugio Carducci, ensuring that each aspect of the project is in direct conversation and inter-dependency with the local environment. As a design principle, (eco)system thinking served to pinpoint and study the different components of the refuge system, looking at them in one image.

The subsequent step to studying the current situation and the existing interdependencies has been to optimise, reconnect, or rethink various elements and systems of Rifugio Carducci. With these pages focusing on the systems design rather than the architectural design, covered in another part of this research project, the positive impact of the refuge towards its (eco)system was maximised through the following actions:

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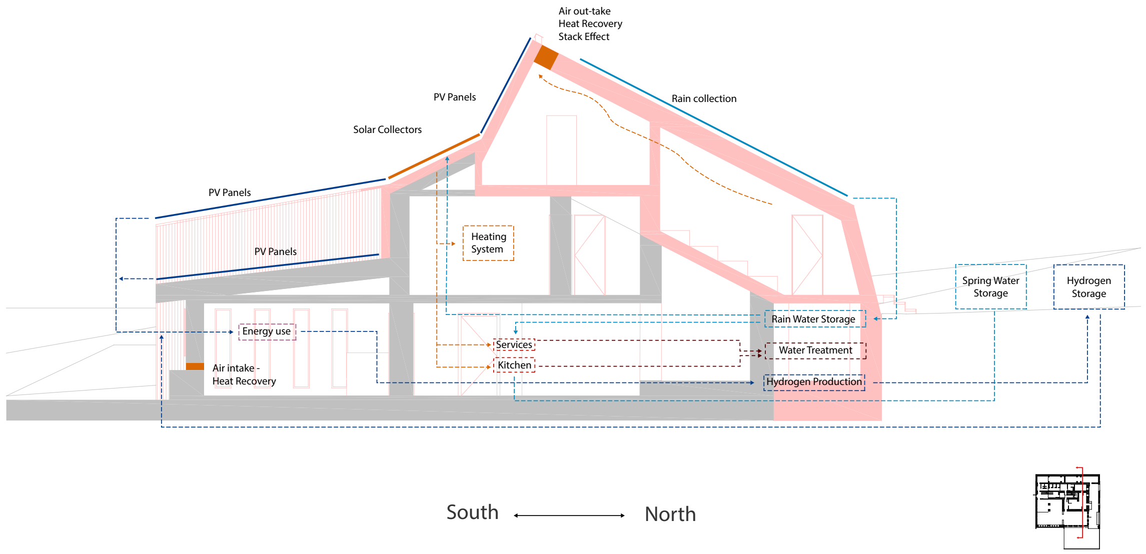
- Use of locally available materials.
- Optimisation of waste management and logistics cycles.
- Proposal of a wastewater treatment strategy to be implemented in the project's renovation.
- Design of an energy system based on the local environmental potentials that eliminate the need for fossil fuels while relying on several systems of energy harvest and carriers.

Finally, the study proposed in these pages is also to be intended as an attempt at using a method of study focused on understanding a building in its several and different layers. Considering a building as a specific node within an interconnected (eco)system has the potential of leading the design process towards the evaluation and implementation of solutions suitable to the unique and specific conditions of a built element. Starting from the realisation that, in the built environment, each project is unique, the study of the building's uniqueness becomes paramount when the intention is to develop an appropriate and fully integrated architecture.



Refuge system scheme. The proposed systems integrate and interact into one functioning refuge system.

In conclusion, the study of a built element as a node within an (eco)system allows the designer to better comprehend the building in its different layers and to develop adequate and appropriate solutions that integrate the building into a working environment without further damaging it. In other words, understating the building's (eco)system is the foundation of a more sustainable architecture.
In the context of this specific project, the research has proved that by studying the available resources and by considering the built element as a node, it is

possible to contribute to the positive impact of the building towards its ecosystem. In other words, the research and the renovation project have shown that the refuge can clean the wastewater before discharging it in the environement, it can be expanded with locally avaialble maiterials, it can continue to use the exisitng materials as thermal mass, and most importantly it has the potential to work without consuming fossil fuel. Thanks to the collection of rain water it doesn't weight on the delicate water balance of the area, and thanks to the height it makes a more effective use of solar power, storing it thorugh the on-site production of hydrogen. In numbers, renovating the refuge will extend the use of the 486.980 chilograms of Dolomia rock stored in the exisitng wall, and thanks to the 150 square meters of solar panels installed it will have the potential to transform at least 15.3 litres of rain water into Hydrogen each day, cancelling the need for the current consumption of over 22 litres daily of fossil fuel.
A more sustainable Rifugio Carducci is possible.

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Appendix A

Solar radiation data for the town of Auronzo for the year 2020. Table provided by ARPAV.

Day	GEN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
1	3.414	6.357	0.609	21.244	16.983	28.43	15.583	24.915	15.414	11.585	4.751
2	3.464	6.627	4.148	20.855	19.091	23.177	15.897	12.753	13.424	2.033	7.28
3	2.554	4.563	0.728	19.512	25.135	21.231	11.836	11.058	19.876	0.766	7.274
4	3.565	7.311	13.474	21.42	25.455	6.351	28.43	11.215	19.223	5.014	1.726
5	3.929	3.74	6.828	21.244	12.125	>>	28.361	12.332	19.468	5.629	7.318
6	4.82	7.952	10.914	21.476	23.491	16.211	20.453	21.194	11.014	7.876	6.841
7	4.161	7.945	10.443	21.633	27.212	5.008	29.302	26.334	2.466	10.663	6.797
8	4.826	8.065	14.88	22.505	24.639	8.196	28.273	24.231	18.57	12.301	6.847
9	3.916	7.393	9.539	22.217	23.509	11.209	26.396	23.34	19.305	11.027	6.169
10	4.211	4.236	6.954	21.62	10.123	12.533	26.12	22.762	13.336	11.623	6.194
11	4.293	9.081	14.981	21.087	10.826	16.813	5.692	20.34	15.577	1.393	6.433
12	4.97	9.125	14.472	21.533	18.363	28.587	30.143	20.441	18.338	11.56	6.063
13	5.215	8.372	9.878	13.594	4.632	29.095	26.384	14.623	17.114	11.654	6.106
14	5.14	9.784	3.452	24.244	24.175	17.905	19.436	9.991	17.208	12.232	5.78
15	5.253	9.125	14.805	23.767	11.968	9.144	15.796	16.411	17.786	1.801	5.88
16	4.23	7.776	16.7	20.152	13.424	14.253	16.073	15.238	13.179	8.09	2.228
17	4.814	3.991	16.518	22.499	16.317	13.983	20.246	8.272	14.259	7.65	5.473
18	2.379	10.117	16.688	18.225	24.639	18.526	11.121	16.995	17.008	7.111	5.284
19	5.447	5.391	16.694	15.407	5.416	9.972	14.799	20.861	16.273	7.136	5.366
20	5.329	10.851	14.259	3.847	14.504	21.181	26.465	19.775	14.064	9.044	4.657
21	5.742	9.997	10.468	16.675	28.643	17.459	22.449	21.03	10.016	9.313	5.134
22	5.843	10.882	17.058	25.047	25.279	27.388	19.085	20.924	6.182	8.667	5.272
23	5.899	6.973	19.418	24.225	22.838	29.264	19.631	13.499	7.544	3.081	2.843
24	5.799	9.075	15.024	22.235	26.49	27.589	10.286	15.269	6.897	4.889	4.688
25	4.418	1.462	11.516	15.771	23.102	5.837	17.98	21.62	3.728	9.659	4.795
26	2.918	5.868	4.023	18.941	27.921	18.897	16.468	17.334	7.205	2.115	4.45
27	5.95	10.016	5.391	13.976	30.181	23.578	21.25	20.478	9.37	3.891	4.5
28	1.512	13.041	17.095	7.016	15.721	17.786	25.348	7.631	4.864	6.069	4.299
29	6.32	7.355	13.882	5.648	19.154	13.248	22.392	11.428	12.169	6.1	4.374
30	7.073		3.615	13.782	12.376	18.351	23.547	7.38	14.943	7.958	4.343
31	5.868		16.731		17.208		25.405	6.778		7.933	
Sum	143.273	222.474	351.186	561.396	600.941	511.202	640.648	516.454	395.82	225.863	159.163
Average	4.622	7.672	11.329	18.713	19.385	17.628	20.666	16.66	13.194	7.286	5.305