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Integration of Renewable Technologies for Sustainable Development in an Alpine Heritage Village

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Abstract

In response to the undeniable reality of climate change, this thesis explores the pressing need for sustainable solutions, focusing on the revitalization of Querio, an abandoned historic village in the Alps between Turin and Aosta. Uninhabited for decades, it provides a distinctive setting to explore the integration of renewable energy and energy-saving systems, with a central emphasis on preserving its unique character. In fact, the thesis navigates the challenge of harmonizing the adoption of such systems while respecting the context's identity, showcasing how neglected territories can be revitalized using renewable energy resources and innovative technologies.

In the first section are explored the entities, regulations and initiatives safeguarding cultural and landscape heritage, concluding that recent efforts show a commitment to involving buildings with high heritage and landscape value in addressing climate change.

Then the recovery project for Querio is outlined, employing the innovative “diffused hotel” model, that guarantees minimal disturbance to the village's distinctive characteristics and allows to do an estimate of the town’s hourly consumption throughout the average year.

Next are presented sustainable insulation and heating systems integrated with circular economy principles using local by-products. In particular, the chosen method for producing thermal energy ensures both environmental and aesthetic harmony, involving a district heating system with a central biomass boiler fuelled with chipped wood, a renewable material derived from waste generated by local sawmills.

Subsequently, to sustainably meet the energy demand is proposed the installation of a photovoltaic energy production system. The analysis compares tools to obtain solar irradiance and different solar panel’s configurations, with a deep focus on their aesthetic impact and efficiencies. Economic aspects of various configurations are also assessed considering different energy management options, revealing that systems emphasizing aesthetics are more expensive. Nevertheless, they provide reasonable return on investment times, especially when considering the preservation of the area's rich historical and landscape value.

The research, while acknowledging limitations, demonstrates the feasibility of implementing renewable energy in valuable contexts. It showcases adaptability and resilience, shedding light on the potential to revitalize marginalized areas by transforming challenges into opportunities.

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Introduction

The effects of climate change are undeniable across the globe: unambiguous scientific evidence shows that the average global temperature has risen by about 1°C since 1880 and that the atmosphere's concentration of CO_2, the primary greenhouse gas, is currently higher than it had been in the last 800 thousand years. The Intergovernmental Panel on Climate Change (IPCC) reports that some recent changes are unprecedented over the course of millennia and lead to a wide range of impacts like sea levels rising, harsher heat waves, severe and frequent extreme precipitation events, decreased snow and icecaps, and the warming and acidification of the oceans. [1]

In this context, the Alps have proven particularly sensitive to climate change, with regional climate models predicting a 2°C increase in average temperature over the next 30 years, alongside a 10% decrease in precipitation and a seasonal shift marked by a notable rise in precipitation from late winter to spring. The impacts of climate change extend to a rise in extreme events, such as storms, floods, summer droughts, rockfalls and landslides, causing observable ecological, economic, and social damage. [2]

This underlines the urgent need to rethink our behaviours, especially in the most impacting sectors, like the one of energy production and use. In fact, the important consequences of the changing climate will condition the future on our planet and, rather than just adapting to its effects, it is crucial to mitigate its causes, first and foremost reducing greenhouse gases emission. [3]

The following thesis is centred on sustainably addressing climate change in the complex area of the restoration of a mountain town with both heritage and landscape value. Querio is a small village on the Italian Alps that, like many other rural realities, was abandoned during the last century and of which the cultural, environmental, and socio-economic values are at risk.

Through in-depth analysis of existing renewable technologies and information deriving from literature, is planned a feasible use of different sustainable techniques aimed at reducing energy consumptions and maximizing its production. In the process of searching for the best options it is always kept in mind the historical value of the town, and therefore a central objective is to alter as little as possible its original look to preserve the high heritage and landscape values. The thesis also aims to demonstrate that overlooked, marginalized, and complex territories can regain central significance, serving as exemplary instances of potential revitalization through the adoption of renewable energy resources and innovative technologies. Also, the implementation of renewable energy in sites with high value can have a substantial effect in limiting greenhouse gases emissions.

In the first part of the thesis are described the existing institutions and working principles aimed at protecting sites of interest like Querio, then are analysed specific case studies that contain exemplary choices followed in similar applications, and so directing possible approaches.

The following step involves an exploration of the town's history and layout, crucial for executing an effective and considerate restoration process with the ambitious goal of integrating renewable technologies and safeguarding the original identity.

Afterwards is searched a possible use for Querio to be compliant with the need of preserving its value and possibly to fuel the local economy, opting for the *diffused hotel*. It is an innovative hospitality approach that gives central importance to sustainability and the respect of the territory's peculiarities: in these hotels the tourist aims at living like a temporary resident, with special care to the genuinity of the experience. This model also proved to be particularly effective for depopulated towns' social and cultural recovery, boosting their popularity, attractiveness and economies. Finally, supposing the opening days, occupancy and uses for each structure of the town, it is possible to estimate the consumptions in terms of electricity, heat and water.

Given the central focus on thoughtful energy usage in this analysis, specific emphasis is given to incorporating technologies aimed at reducing consumption, planning the use of efficient electrical devices, water-saving tools, and environmentally friendly materials to achieve optimal insulation performances. Additionally, considerable attention is directed towards ensuring a high level of comfort, particularly relevant in the context of touristic applications.

From the estimated consumption of the town, it is then possible to design systems aimed at satisfying the demands of the town and compliant with the searched goals of sustainability and harmonious integration.

Regarding thermal energy production is considered a biomass boiler fuelled with chipped wood, a fuel strongly aligning with the sustainability objectives of the project because it is a renewable by-product from local sawmills, representing a good example of circular economy.

Electrical energy is supplied by a photovoltaic system placed on the best exposed roofs of the town. The dimensioning and design of the solar installation is markedly influenced by a strong emphasis on the aesthetic compatibility of the installations, ensuring they seamlessly integrate into the surrounding context. Multiple options are explored to present a comprehensive picture and facilitate a comparison of results obtained through the different techniques.

Then, knowing the lag between energy production and consumption, batteries and on-site energy exchange mechanisms are implemented to check their suitability. Finally, economic feasibility is assessed through analyses centred on the concept of payback time for investments.

In conclusion, the research showcases the integration of renewable technologies in an historically significant context, with the aim of sustainably revitalizing a marginalized and depopulated area challenged by climate change.

1 Bodies and political frameworks

Historical buildings represent 30-40% of the whole building stock in European countries [4] and have a priceless role in creating characteristic contexts and spaces enjoyed by both residents and tourists. Often functioning as notable features of high value within city ecosystems, these buildings, unfortunately, tend to feature low energy performances, contributing significantly to greenhouse gas emissions. In fact, renovating the existing heritage European buildings could have the considerable impact of reducing the EU's total energy consumption of 5-6 % and CO_2 emissions of 5%. Today's structures serve as examples of the effectiveness and usefulness of increasing energy efficiency in buildings because, thanks to stricter requirements, they consume about half the energy of typical buildings from the 1980s. [5]

1.1 UNESCO

A key step in defining the sites with high value and understand how they are preserved involves introducing the bodies that work to safeguard the locations with marked properties. One of the most representative entities in this regard is the *United Nations Educational, Scientific and Cultural Organization*, commonly known as UNESCO.

The Organization was born on the 16th of November 1945, counts 195 members and 8 associate members and among its missions is present the support towards the creation of a culture of peace, the eradication of poverty and sustainable development. It is recognized as a specialized agency within the United Nations that plays a vital role in fostering global cooperation to support education, culture, and the sciences, while also emphasizing the importance of cultural diversity and heritage. On the cultural side, the Organization strongly aims to preserve heritage, both tangible, such as monuments and sites, and intangible, like traditions and languages. [6]

The parameter used to define whether a property can be included in the World Heritage List is the OUV (Outstanding Universal Value), that represents the cultural and/or natural significance of the site, which must be so exceptional as to transcend national boundaries and be of common importance for present and future generations. Consequently, the permanent protection of this heritage is of prime importance to the whole international community, together with the safeguard of intangible cultural heritage, including traditions like performing arts, social practices, oral histories, or festive events. [7]

Regarding the interest of the Organization on the core-topic of this thesis, energy, it is underlined that the ongoing shift towards renewable energy production and the increase in the number of renewable energy projects have posed significant challenges for the preservation and administration of World Heritage sites. In fact, these impacts can extend beyond the boundaries of World Heritage properties and their buffer zones. A primary concern revolves around the anticipated adverse effects of renewable energy infrastructure on the Outstanding Universal Value (OUV) of these properties. [8]

It is also specifically remarked the urgence to act in reducing greenhouse gas emissions in alignment with the Paris Agreement, concurrently providing the economic and expertise support to ensure the long-term resilience of World Heritage properties. Achieving both these goals is of central importance, and, in fact, a growing body of knowledge, management guidelines and policies exists.

Among the guidelines, UNESCO's report on *World Heritage and Tourism in a Changing Climate* states that, in touristic context, efforts can be made to raise visitors' awareness regarding the significance of the sites they visit, how climate change affects these sites, and the measures that can be taken to protect them. Sustainable and aware tourism is, in fact, strictly linked to fostering responsible behaviours and practices in the general visitor to safeguard heritage assets, the surrounding environment, and support local communities. [1]

1.2 European Union

Within the objectives of the European Union, a pivotal emphasis is placed on revitalizing regions through cultural initiatives, encouraging the adaptive reuse of heritage buildings, and amplifying their positive impact to promote the adoption of sustainable cultural tourism. The emphasized idea is that, for historical constructions to endure, they must be lived and preserved, necessitating frequent retrofitting. This process extends beyond enhancing energy efficiency, also addressing structural protection, ensuring the comfort of occupants, and preserving potential collections.

Four pillars are defined by the European Commission regarding the actions that should be performed on cultural heritage:

- follow a holistic approach, looking at cultural heritage as a future resource with the people at its centre;

- use a uniform and shared approach towards cultural heritage across different EU policies;
- create policies based on experience;
- favour the dialogue between more actors when designing and implementing cultural heritage policies. [9]

The EU's commitment in assisting innovation in the cultural heritage sector reflects on the creation of the *European Framework for Action on Cultural Heritage,* with the aim to set a common approach for heritage-related activities, inspiring municipalities, cultural heritage organisations and networks when developing their actions on cultural heritage. [5]

A further virtuous example of the EU's attention towards heritage buildings is included in the Interreg Alpine Space: a transnational cooperation programme funded by the *European Regional Development Fund* (ERDF) under the *European Territorial Cooperation* objective that, since its foundation in 2000, has addressed common challenges and raised the standard of living for the 80 million people living in the alpine region, including Piedmont, where Querio is located. This macro-region in fact faces issues related to the delicate mountainous environment and the diverse cultures, in themes such as accessibility, biodiversity preservation, environmental and economic disparities. [10]

The main objective of the organization revolves around creating a resilient environment in the Alpine region in response to ongoing mega-trends like globalisation, climate change and digitalisation. Complex challenges that to be addressed require collaboration and teamwork between the seven Alpine countries to reevaluate their economies, communities, and growth plans.

The current acceleration of the previously mentioned mega-trends affects communities and economies, necessitating a prompt, coordinated response from international players, as these challenges know no borders. In the period 2021-2027 the central objective regards the transition of the region into a climate-resilient and carbon-neutral territory. [11] Figure 1 provides a summary of the Interreg Alpine Space Programme's objectives and priorities.

Figure 1 Objectives of the Interreg Alpine Space Programme [11]

Among the Interreg initiatives in the Alpine Space, the one most notably relevant for the analysis in this thesis is the ATLAS Project (*Advanced Tools for Low-carbon, high-value development of historic architecture in the Alpine Space*), which aims to improve the value of traditional Alpine architectures and re-discovering their functions. The project provides existing best practice solutions for building refurbishment and therefore paves the way for new sustainable development strategies for structures often beyond the level of protection, all while respecting their cultural significance. Its primary scope is to transfer a significant number of best practice examples to share experiences from construction detail to regional planning, and therefore simplifying and encouraging a boost in retrofitting historical buildings, with the pivotal focus on reducing carbon emissions, accompanied by a general increase in energy efficiency. [12]

1.3 IEA and HiBERatlas

Another organization dedicated to the preservation and sustainable development of historic architecture is the International Energy Agency (IEA), which started a collaborative research project called *IEA-SHC Task 59* centred on the preservation of heritage buildings. The task is part of the *Solar Heating and Cooling programme (*SHC) and involves organisations from academia and industry across different countries. Consequently, it is highly interdisciplinary and tightly connected to the sharing of existing knowledge and new findings, with the primary objective of supporting decision-makers involved in heritage building renovations. [13]

A key aim of Task 59 is the development of a historic building atlas, elaborated in close collaboration with the European Interreg Alpine Space project ATLAS. This collection aims to be an open database featuring numerous well-documented case studies of low-energy renovated heritage buildings, developed as part of collaborative research projects between the involved organizations. These lessons and information related to best practice examples of energy refurbishments are expected to assist in overcoming scepticism and prejudice against energy retrofitting in historical buildings. [14]

The collaborative efforts between the *ATLAS* project and *IEA-SHC Task 59* have resulted in the creation of the online database *HiBERatlas* (*Historic Building Energy Retrofit Atlas*), to which partners of both projects contributed to documenting best practice examples in the Alpine region, focusing on quality management of heritage buildings.

Launched in September 2019, HiBERatlas contains numerous real life examples of how heritage buildings have been renovated to achieve higher levels of energy efficiency while preserving their appearance and cultural significance. This valuable information has the added value of being accessible to the general audience, strongly simplifying the process of gathering information for the challenging yet crucial task of retrofitting buildings with historical value. The shared information covers aspects like heritage assessment, building materials, energy efficiency, building services as well as refurbishment solutions and products. [15]

2 Technical solutions

Integrating energy production technologies into high value sites poses a substantial challenge, demanding a delicate balance between heritage preservation and the adoption of sustainable energy solutions. Several current technologies and approaches address this challenge, including:

- integrating photovoltaic solar panels directly into historical or landscape structures to minimize the visual impact. As an example, applying them to roofs, walls, or even transparent windows;
- implementing customizable film covers to solar panels, improving their final aesthetic impact. These wrappings are light-permeable and therefore imply a minimal reduction in panels' efficiencies;
- using solar thermal to heat water, integrating them into existing heating systems without significantly altering the site's appearance;
- utilizing renewable fuels, such as biomass from sustainably managed forests for heating, or using highly efficient HVAC (Heating, Ventilation and Air Conditioning) systems employed to warm up buildings;
- adopting discreet energy conservation technologies to reduce overall energy consumption without significantly altering the site, such as low-energy LED lighting systems or highly efficient insulating materials;
- micro-hydropower systems could be implemented using small hydraulic turbines that minimise the impact on the surrounding environment;
- low-enthalpy geothermal energy systems could be implemented in suitable locations for heating or cooling without the need for visible installations;
- involving the local community and visitors through initiatives devoted to promoting the understanding and acceptance of energy efficient choices and their importance towards mitigating climate change;
- implementing advanced monitoring and control systems to optimise real-time energy usage and ensure compliance with the environmental conditions necessary for site conservation. [4]

Anyway, no *right* approach or technology exists, as the optimal solution strongly depends on the specific characteristics, available resources, and energy needs of the site: many variables regarding the single situation must be considered. In particular, for what concerns locations with heritage and landscape value, like the one object of this analysis, the evaluation is typically more challenging because of the commonly deteriorated conditions, stricter regulations linked to legal preservation and subsequent constraint to minimise the visual impacts on both the building and the context.

Regarding the methodology, as cited in the article *Integration of renewable technologies in historical and heritage buildings: A review* [4], the implementation in historic buildings of effective retrofit solutions usually starts from a preliminary diagnosis of the actual conditions related to the creation of an energy model of the building, followed by a simulation of the consumptions in an average year and leading to the proposal of new integrated configurations of the energy systems taking into account the building constrains. [4]

The first intervention usually considered when aiming to reduce the energy demand in historical buildings is the increase of the efficiency of the insulating and heating devices that, in fact, together with hot water production account for almost half of their global energy consumption. Looking for examples in literature, a combination that turned out to be the most effective for the case study of the Palazzo Ex-INPS (Benevento, Italy), was linked to the replacement of windows with less-emissive ones, the application of thermal insulation plaster and the implementation of new thermal insulation on the roof slab. Other commonly used solutions aimed at raising the energy efficiency of buildings are internal envelopes, cool coatings, multi-pane windows, upgraded control systems, LED lighting, efficient ventilation systems, thermal storage, and heat recovery. [4]

Regarding HVAC systems, heat-pumps are devices that remarkably increase the efficiency of heating systems. However, their implementation in heritage buildings poses challenges, leading to discreet placements due to their noticeable aesthetic and noise impacts. A virtuous application of a masked heat pump is present in the Castle of Zena (Piacenza, Italy), where a water-source heat pump is connected to a previously existing well. This was concluded to be the best choice for the retrofitting of the Castle, both for economic and environmental reasons, presenting a payback period of only 7 years. [16] Also, in an application at the Basilica di Santa Croce (Florence, Italy) was found out that ground-source heat pumps are good options, and that if joined with a borehole heat exchanger they are more efficient than air to air heat pumps or common gas boilers. [4]

The use of technologies aimed at producing renewable energy represents yet another challenge for heritage buildings and the approaches for their integration are widely different. They often consist in solar energy systems and presents issues mostly related to the lack of useful space and the need to preserve the original architecture of the buildings. However, a large variety of effective integration techniques for photovoltaic applications on roofs and facades exists.

An upstanding example of energy retrofitting is represented by the Palazzo Gallenga Stuart (Perugia, Italy), where the interventions that incremented the general efficiency of the building can be summarised in:

- disposal of the outdoor condensing units and maintenance of the existing radiators;
- substitution of the old methane boiler with a more efficient ground-source heat pump;
- installation of a system for heat storage composed 10 tank modules of 12 m^3 able to provide 170 kWt;
- simulation of the building's energy performance after the retrofit. [4]

Historical buildings are fundamental testimonials of ancient cultures and habits, representing the community's identity and giving priceless character to urban environments of cities and towns. Also, thanks to ancient passive systems like high thermal inertia and the air cavities often present throughout the opaque envelope system, they commonly can guarantee indoor comfortable conditions through the whole year, debunking the myth of being inefficient. Anyway, their importance is not only related to their aesthetics, because, as stated in the *International Charter for the Conservation and Restoration on Monuments and Sites*, they bring a message from the past reminding in our present days of their age-old traditions as living witnesses. Heritage buildings have a marked social importance in creating a sense of unity along citizens through the different generations, that have the common responsibility to safeguard them and their functionalities as trademarks of cities. [17]

3 Querio and Alpine depopulation

The work of thesis is centred on the requalification of the historic village of Querio: a small cluster of wrecked houses that were fully abandoned in the 1960s that sits at 1306 metres amsl in the Verdassa valley. More specifically, the area object of the analysis falls in the municipality of Ingria (TO), a depopulated rural town recently awarded as one of the *Most Beautiful Villages of Italy*. [18]

The village of Querio (or "*Borgata*", a local way to define a small rural town) has high heritage value and is immersed in an environment with high natural and landscape features but needs deep restoration to return to being usable and possibly represent a redemption for the territory. The current desolate conditions as pictured in Figure 2.

Figure 2 The Borgata Querio [19]

The climate of the area is typically alpine, and according to the Köppen-Geiger climate classification it belongs to the (Cfc) Subpolar oceanic climate, having also traits of the Subarctic climate (Dfc). The winters are cold, the summers hot and it is not much rainy, with rainfall mostly concentrated in spring and autumn. [20] A particularly relevant local climatic feature is the Föhn: a hot dry wind from the mountains able to quickly raise the temperature of the site. [21]

The landscape of the Verdassa valley is mountainous, featuring a sequence of peaks that include Punta Mionda (2784), Monte Giavino (2764m), Punta Bordevolo (2619m), Punta of Verzel (2406m) and Punta Rama (2437m). In 2022, a bivouac was built on the latter, reachable from Querio via a trail with a height difference of about 1300 metres. [22] An outline of the landscape of the area is reported in Figure 3.

Figure 3 Outline of some mountains of the Verdassa valley (photo by C. Dallere) [23]

The built space of the Valley is characterized by the research of the best exposition, water supply and stability of the terrain, and therefore distancing between towns is frequent. [23] The valley has a north-east/south-west orientation and on the best exposed side many clusters of buildings are present; among which Querio, Albaretto, Bettassa, Bech, Beirasso, Monteu, and Fraschietto are some of the examples.

Querio has the peculiarity of being on top of a big rocky ridge bordered by the stream Verdassa on one side and by the Rio di Querio on the other, it lies in an elevated position with respect to the road and has a wide open visual on the valley below. The small town's name can be traced back to its possible origins, believed to derive from the Celt *quer-cher-kar*, meaning village, rocky location or clearing [19]. Else, it may have its roots in the Latin *coverium*, that stands for hatch, highlighting the hamlet as a place suitable for shelter. [23]

The first records of a settlement in Querio date to the 13th/14th century and are supported by the finding in one of the houses of the village of a spear tip from the 1400, while the first official written documents attesting to the existence of the village are related to baptisms and marriages of the 1600s. [19] The buildings of the town did not face many changes throughout the centuries and so the village presents an unaltered valuable architectural heritage hidden by the many years of complete abandonment in the alpine environment led the built to the currently degraded conditions.

The phenomenon of depopulation, resulting in the total abandonment of the small town in the 1960s after reaching a record of 147 inhabitants in 1871 [23], was common in the region. To give an example, the municipality of Ingria, that also includes Querio, currently counts only 43 inhabitants within its 14 km^2 territory, after reaching a peak of almost 2000 at the beginning of the century [24]. This explains why in some texts the Verdassa Valley is defined as "*uninhabited mountain*". [25] The persisting decreasing trend is noticeable from the graph of Figure 4.

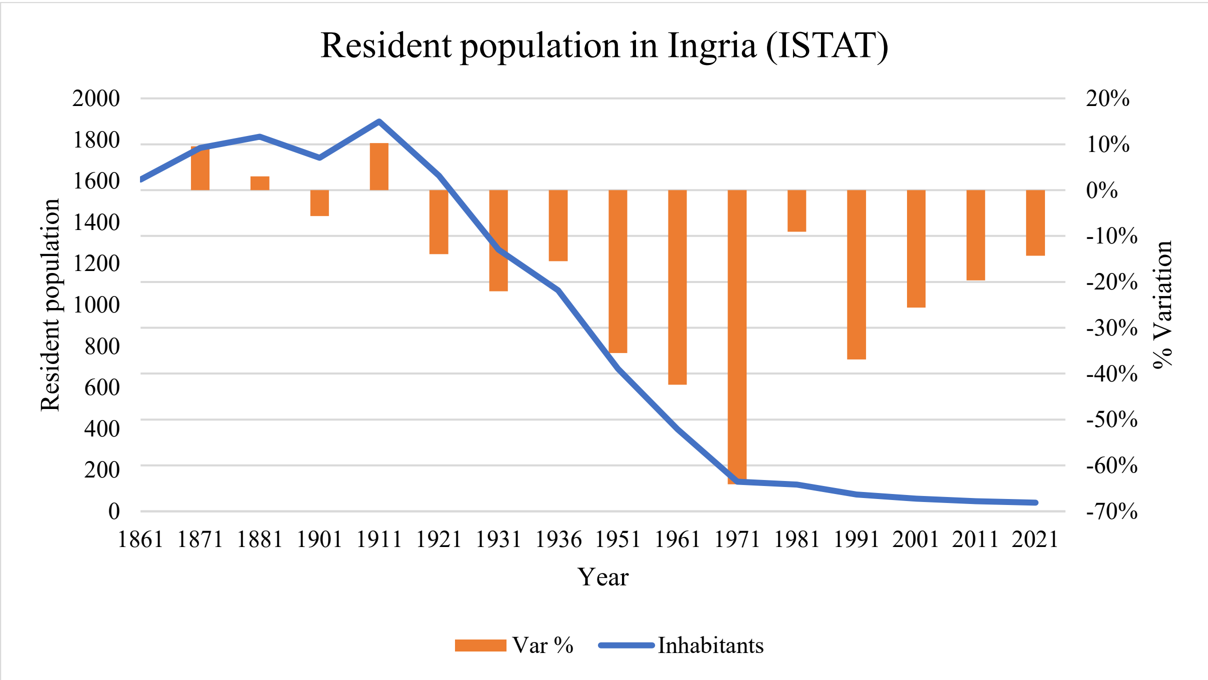

Figure 4 Demographic trend of Ingria (TO) between 1861 and 2021 [26]

The marked depopulation in the Soana, Orco and Verdassa valleys can also be justified by the local strong diffusion of itinerant professions and specifically almost all the men of Querio practiced the knife sharpener trade. It may be of interest knowing that, like other ambulatory workers of the Orco and Soana Valleys (chimney sweepers, tinsmiths, glassmakers), the knife sharpeners of Querio had developed their own jargon, different from the commonly spoken Franco-Provençal, deliberately incomprehensible to other people.

They used to leave the village between October and November to trade itinerantly, heading to other locations of North-Western Italy like Piedmont, Lombardy and Liguria moving from town to town with the mill on their shoulders until their return in their hometown at the beginning of spring, when they would reunite with their families and resume agricultural activities. [19] In Figure 5 is represented a knife-sharpener from Querio.

Figure 5 Antonio Querio, knife-sharpener (from Davide Querio's private collection) [23]

To give a wider perspective of mass emigration towards cities, it must be remarked that in Italy after the Second World War, as the rural areas' economic condition deteriorated and the strong process of industrialization needed many working hands in the cities, more and more people aimed at better living conditions moving along new migration routes that stretched from south to north, and from towns to cities. In fact, after the 1950s the common relocations of the knife-sharpener started being no more strictly seasonal and many of them decided to move permanently to bigger realities where the development of new commercial activities was easier and more profitable for artisans. [26] The process strongly impacted Querio, that by the 1960s became permanently uninhabited like many other alpine towns where people left deserted their hometowns, places before full of life and culture.

The small town, that can be reached only using a driveway followed by a long stone stairway, still conserves some distinguishable architectonical elements that suggest the town's road matrix and some characteristics of the buildings, like the presence of an internal street stretching throughout the town and leading to the heart of the village: the central square where the ancient bakery used to be located. [23]

Querio is built following the line of maximum tilt of the terrain, while looking at the buildings can be noticed that the village is composed of structures with the ridge beam parallel to the line of maximum inclination. The marked tilt of the terrain in some areas of the town also allowed to build structure up to three floors high, keeping a design coherent with the context. The town is surrounded on each side by wooden areas, while climbing the mountain some pastures areas can be reached. [23]

The economic condition of the territory is markedly influenced by touristic flows that, following a boom in the 1960s, supported important infrastructural projects that favoured a marked growth in the hospitality sector. In fact, the area offers a wide range of sport activities related to the mountains and at close contact with nature (ski, hiking and climbing). The unvaluable natural heritage of the Valley undoubtedly represents its most known value, but equal attention should be given to its fascinating history, mostly inherent the architectonic and cultural value of the towns, the gastronomic specialities, and the dialects.

The commitment to keep Querio alive is evident from initiatives like the one born in the summer of 2012, and reported in Figure 6. This activity regards an annual gathering of descendants from all-over the globe of those who used to live in the small town, usually surnamed Querio, to reconnect with their roots and keep alive the memories of a town that would otherwise risk being forgotten. [27]

IN ALTA VAL VERDASSA, A FRASSINETTO

La prima festa dei Querio fa rivivere una borgata

FRASSINETTO - Querio (Queer, in dialetto locale) è l'ultima borgata che si incontra salendo da Ingria o da Frassinetto lungo la valle del Verdassa: la frazione un tempo faceva parte del Comune di Frassinetto e, solo dal 1957, è stata conglobata con la vicina Monteu nel confinante Comune di Ingria.

Completamente abbandonata dai suoi abitanti alla fine degli anni Sessanta dello scorso secolo, oggi è purtroppo diventata una sequela quasi inestricabile di case in rovina. L'occasione per ricordare il passato di questa borgata, ma anche per disegnarne un possibile futuro, è certamente stata la prima festa-raduno dei "Querio" che si è svolta domenica 1° luglio all'Alpe Losa di Frassinetto, una distesa prativa situata ai piedi della rupe su cui ancora svetta quel che resta dell'abitato di Queer.

Querio è una borgata particolare, posizionata sul Rocco Menta quasi a volere scrutare tutta la sottostante vallata del Verdassa. E particolari erano i suoi abitanti, la cui vita ruotava attorno a un mestiere, quello dell'arrotino, svolto dagli uomini della frazione: per esercitarlo si spostavano in tutte le zone del Piemonte, ma anche in parte della Liguria e della Lombardia, e alcuni sconfinavano in Francia e Svizzera. "*Quindi, forse, per loro è stato anche più naturale che per altri emigrare* - racconta Davide Querio, giovane consigliere comunale di Frassinetto e uno dei più appassionati organizzatori del raduno -. *Sicuramente non è stato più facile, perché lasciare il proprio paese non è mai facile, anche se questo è povero. Fu così che i Querio emigrarono non solo nella pianura piemontese, ma anche all'estero, in Francia, Svizzera, negli Stati Uniti e in Sud America*".

"*L'idea di riuscire a incontrare tutti i Querio sparsi per il mondo non è nata ieri* - aggiunge Davide -, *ma ha iniziato a prendere forma quando, anni fa, parlando con mio padre della borgata Querio e del suo spopolamento, era nato il desiderio di avvicinarli tutti, di fare conoscere le proprie radici anche a chi non sapeva più quale fosse il luogo di origine della sua famiglia*". Il tutto ha incominciato a prendere concretamente forma grazie all'utilizzo dei social network come *Facebook*, che hanno permesso un po' alla volta a Davide di cercare tutti i Querio sparsi per il mondo, creando addirittura un gruppo chiamato "W Querio!".

Attraverso questo strumento, è riuscito a metterli tutti in rete tra loro, a scambiare materiale sulla borgata, sul territorio, sugli antenati, sulle tradizioni, insomma, a condividere tutto quello che si sapeva su borgata Querio e sui Querio. "*Poi, durante le ultime riunioni del Consorzio per la strada interpoderale Monteu-Querio-Fenoglia* - spiega ancora Davide -, *abbiamo deciso di organizzare la prima festa-raduno dei Querio, che si è svolta all'Alpe Losa, alpeggio di proprietà del tesoriere del consorzio, Flavio Querio*".

Dopo un lungo e paziente lavoro di preparazione dell'evento, domenica 1° luglio finalmente la festa, a cui hanno partecipato circa novanta persone, la maggior parte residenti nel Canavese, ma alcuni provenienti anche dall'astigiano e dalla provincia di Trento; c'era addirittura una famiglia di Querio emigrata negli Usa, giunta appositamente per partecipare alla festa. Al pranzo svoltosi all'alpeggio (il cui ricavato verrà interamente devoluto per realizzare la strada carrabile per raggiungere Querio), è seguita una passeggiata fino alla borgata, che per molti dei presenti è stata la prima occasione per vedere il paese delle loro radici.

"*E' stata una giornata piacevole, fatta di emozioni semplici ma vere, una giornata in cui è parso possibile riuscire a fare ancora qualcosa per Querio e per tutte le borgate che sono nelle sue stesse condizioni* - conclude il suo appassionato racconto Davide Querio -. *Anche se stiamo vivendo in tempi difficili, con una crisi economica che lascia poco spazio ai sogni, sono convinto che con la tenacia accompagnata da un lavoro fatto di piccoli gesti, ma costante, anche quelle che ora sembrano utopie possono diventare realtà concrete*".

marino pasqualone

Figure 6 Newspaper's extract describing the annual gathering in Querio [27]

The context in which Querio's rebirth is inserted regards the marginalization of peripheral territories, areas that often present resources not caught by the most but that, if understood, can transform into opportunities to create new economies, and become launch pads for new ways of living internal rural areas. Many alpine territories had a fate like the one of Querio, both because of the diffused demographical decrease, and owing to the detachment related to the inefficient and underdeveloped infrastructures that negatively affect the already complicated lives in peripheral areas. Anyhow, in the analysed territory interventions aimed at the socio-economic development of rural areas are supported through investments devoted to implementing, adapting and expanding basic infrastructure to serve rural businesses and communities. [28]

Also, in recent times the old trend of moving from small mountain towns to big cities is reversing and is often noticeable the birth of new economies and an increased interest towards small communities, fuelling a slow but progressive population growth. This choice is often related to the search of better climatic conditions and of more human-scaled realities than the ones of cities. [29]

4 Architectural project

Moving to a more applicative side, the aim of bringing the town of Querio back to life would potentially provide a long list of advantages to the territory, not only economical, but also social and cultural. Anyway, aiming at relieving a town with such peculiar features requires a thoughtful project towards the central need of preservation of the town's architectural and landscape characteristics. In this regard, the most suitable configuration for the town was identified in the one presented by Craveri Alessia and Dallere Cristian in their master's degree thesis in Architecture for Sustainability, which respected at best the original conformation and architecture of the old town. Their project focused on the use of mountain-therapy: a rehabilitation practice that bases on using the natural environment as an instrument to treat people with medical conditions. This involves doing hikes and living in the salubrious mountain environment, following the idea, supported by many studies, that creating a connection with nature can have a healing effect for some illnesses. The concept is reflected also in the name of the project: "*Re-Hab Querio*", underlying the deep connection of rehabilitation performed in comfortable habitations, able to sustain and enhance the recovery of the hosts. [23]

The aim of the project was also to create spaces able to tell the story of the town and so was inserted a museum dedicated to the enhancement of the cultural heritage of Querio, *the town of the blade-sharpeners*. The definition of such space would be the one of an ecomuseum: a space dedicated to showcasing the unique character of a location, with a strong emphasis on involvement and improvement of local communities. It would in fact be aimed at spreading the knowledge of the knife sharpener job that characterized the town and the architectural and cultural peculiarities of the area.

The core-idea at the base of the project for the new Querio was to find a way to live the mountain in the most respectful way possible, trying at the same time to absorb all the positive values present in such an invigorating environment and share it with as many people as possible, allowing them to feel a sense of belonging to a welcoming environment.

The functional program delineated on the project had a dual objective: on one side to be a place to host culture-related spaces, like promoting the knowledge regarding the *knife-sharpener's town*, and on the other to safely accommodate and promote social inclusion of people with different medical conditions. In particular, the project was centred in ensuring the highest possible usability, which often is a fulcrum to obtain effective peripheral territories regeneration. [23]

To be able to maintain the original conformation of the town, and therefore keep coherence with its history, were investigated the shape and conditions of the town's buildings from historical iconographic sources and from the remaining physical evidence of the buildings, that in the years of abandonment were strongly modified by vegetation and collapses. The actual town's outline and the conservation conditions present are reported in Figure 7.

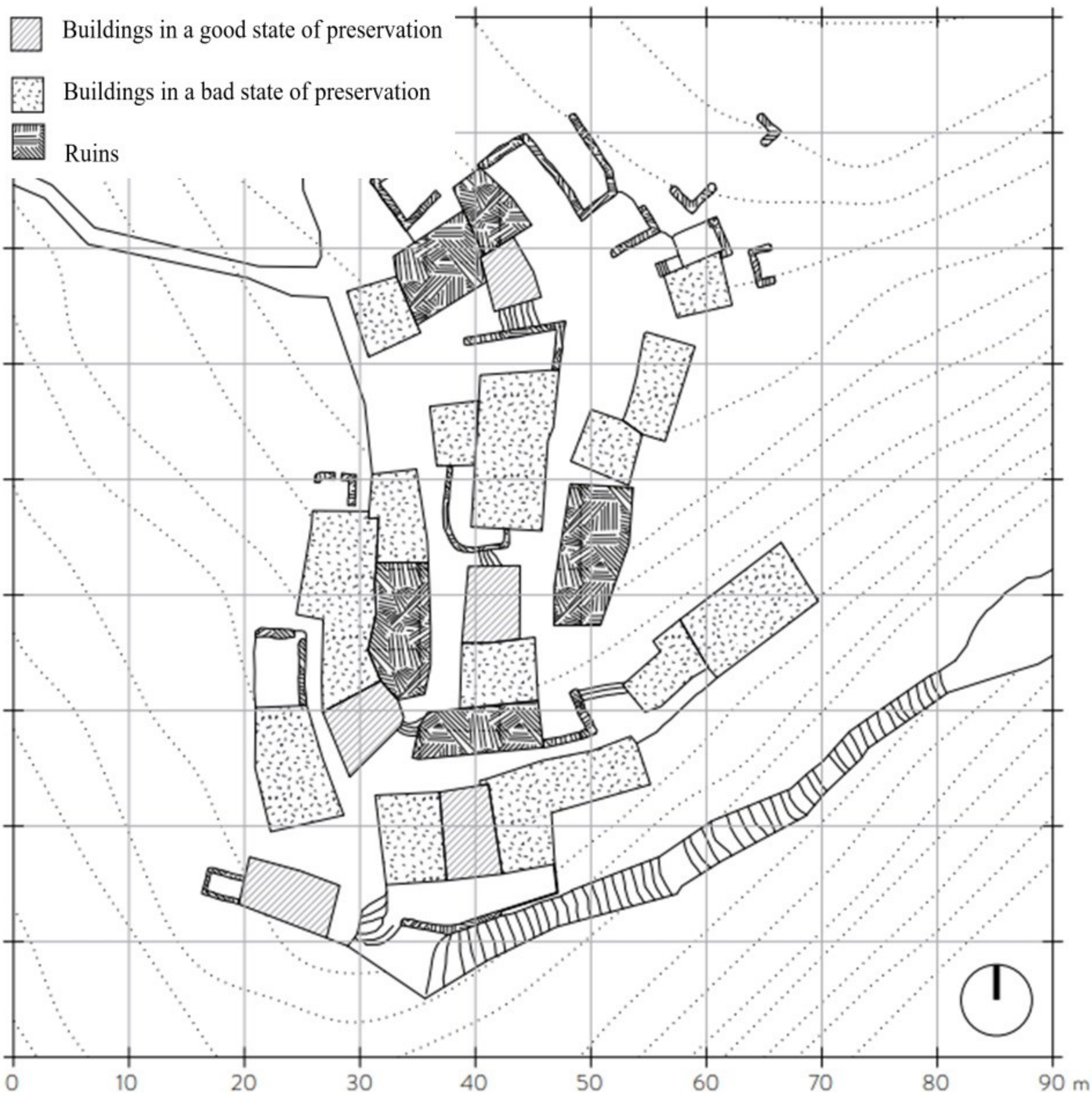

Figure 7 Map of the current conditions (architectural survey by A. Craveri and C. Dallere) [23]

The result of the project of restoration was based on the conservation of the town's identity and shape, and therefore were used components with colours as similar as possible to the original ones, with the result shown in the representation of Figure 8.

Figure 8 Rendering of the Re-Hab project (architectural design by A. Craveri and C. Dallere) [23]

In conclusion, the described project managed to design a possible technical configuration for the new town, carefully pondering the central aspects of identity preservation, society inclusion, and creating an ideal place for hosting, discovering, and socializing.

5 Predicted scenario of use of the town

The town of Querio presents many interesting features on landscape and heritage aspects, underlying its potential touristic attractivity and therefore suggesting the possibility of using it as an accommodation structure. Following this concept, a fitting option aligned with the peculiarities of the town turned out to be the one of a diffused hotel.

5.1 Diffused hotel

The main objective of a diffused (or scattered) hotel is to make the tourist feel as a temporary resident, giving central importance to the respect of the territory's peculiarities while having a strong attention towards sustainability. It is a niche of the touristic business where the attention is focused on the genuinity of the stay, outside of the main usual over-touristic routes, where is possible to live the holiday experience in a slower way. The authentic experiences provided to the public following this accommodation approach encourages the (re)discovery of traditions and places that would otherwise risk being forgotten. [30]

The components of a diffused hotel, as is suggested by the name, are not located in the same building, but rather are detached, scattered along the same town along a horizontal structure, different from the vertical one of traditional hotels. Therefore, the natural location of the widespread hotel often is focused on small centres, that can be referred to as hotel towns. The model was proved to be particularly effective in valorising uninhabited villages with artistic or landscape interest, expanding their offer of tourist accommodation.

According to the model all the traditional hotel services are offered, like in-room breakfast or restaurant and spa services, and the main differences with the common offer in the accommodation industry are related to the conformation of the structure, that is diffused and not centralizes, and on the vacation experience provided to the hosts, that is oriented towards the discovery of traditions and authenticity. [31]

In Italy are present many examples of this kind of tourist accommodations, and a virtuous one is Santo Stefano di Sessanio (AQ), a fascinating medieval town located in the Gran Sasso and Laga Mountains National Park characterized by the harmonicity of its architecture and the mountainous landscape (Figure 9). The town, not exempt from the previously described phenomena of mountain depopulation, was almost uninhabited in the second half of the 1950s but revived in 2002, when, thanks to the signature of the "*Carta dei valori per Santo Stefano di*

Sessanio" [32] by the Municipality, the Park Authority and the Sextantio Society, was allowed to develop sustainable tourism in the form of the diffused hotel. [33] Following this model the town turned from a place of marginality and abandonment into a site for experimenting an eco-sustainable development, becoming a destination for high-quality naturalistic tourism and a cultural hub for concerts and exhibitions. [34]

Figure 9 Santo Stefano di Sessanio [35]

To clearly identify the diffused hotel touristic model, the ADI [31] (Italian Association of Diffused Hotels) provided the following guidelines:

- the structure must be able to provide all the basic hotel services;
- the rooms should be in more pre-existing buildings detached one another but at a reasonable distance (no more than 200 metres between the units and the reception services);
- the management of the hotel should be integrated in the territory and its culture.
- there should be a living community interested on the town;
- social and cultural aspects should melt creating an authentic environment;
- a defined identity of the town should be preserved throughout the whole structure;
- common services should be provided in common areas;
- the structure should be managed unitedly.

It follows that Querio for its characteristics is a perfect candidate for becoming a diffused hotel, and, among the cultural activities, it could include an ecomuseum devoted to the traditionally local job of the knife sharpeners, where visitors could learn about the small town's ancient traditions.

Additionally, a bakery could be placed in the same building in the central square where was in the past, reviving the historical tradition and offering guests the opportunity to immerse themselves in an authentic experience of the town's past life.

Its operation would involve the use of locally supplied wood, with an estimated consumption of 7.15 kg/h, and assuming a daily functioning of 4 h/day. It is therefore estimated the daily consumption through the following formula:

$$Daily\ wood\ consumption\ in\ mass = 7.15\ kg/h\ * 4\ h/day = 28.6\ kg/day$$

Then, considering the wood's average density of 750 kg/m^3 [36], is obtained the required daily storage:

$$Daily\ wood\ consumption\ in\ volume = \frac{28.6\ kg/day}{750\ \mathrm{kg/m3}} = 0.038\ m^3$$

Finally, considering the 160 opening days of the hotel, the storage needed to recharge annually is obtained as follows:

$$Annual\ wood\ consumption\ in\ volume = 0.038\ m^3 * 160 = 6.10\ m^3$$

This value is considered suitable in the context of the town.

5.2 Allocation of town spaces

In the following part of the thesis, the previously presented architectural model was merged with the main features of a diffused hotel and, considering the available buildings it was possible to allocate the elements described in the following list.

Living spaces:

- 8 hotel rooms, with a total maximum capacity of 21 hosts;
- 1 house for the director, with a capacity of 2 workers;
- 1 house for the baker, with a capacity of 2 workers;
- 1 house for restaurant staff, with a capacity of 3 workers.

Food and recreation:

- 1 restaurant;
- 1 ecomuseum;
- 1 bakery;
- 1 recreation area;
- 1 sightseeing area;
- 1 sauna room;
- 1 playroom.

Storage rooms:

- 1 storage room of the restaurant;
- 1 storage room of the bakery;
- 1 snow equipment storage room;
- 1 common equipment storage room;
- 1 multipurposed storage room;
- 1 cleaning equipment storage room.

Service rooms:

- 1 laundry room;
- 1 biomass boiler room;
- 1 chipped wood storage room;
- 1 nursery.

The diffused hotel, considering the exposed configuration, could accommodate a total of 21 guests and 7 workers during opening days.

Considering the touristic peculiarities of the area, the opening period was designed to be mostly focused on summertime. This choice facilitates guests in exploring the numerous paths in the vicinity without dealing with the harsh alpine winter climate. Specifically, the hotel is planned to be open every day from the 1st of June to the 1st of September, and only from Friday to Sunday in April, May, September, October and December, totalling 160 days/year.

5.3 Electrical consumption

The electrical consumption of the town was estimated based on the previously listed configuration of use, projecting the following relationship between space and number of devices.

<u>Living spaces:</u>

- hotel room:
  - 6 lightbulbs;
  - 4 wall outlets;
  - 1 mini fridge;
  - 1 hairdryer.
- house for the director:
  - 6 lightbulbs;
  - 4 wall outlets;
  - 1 fridge;
  - 2 induction hobs;
  - 1 TV;
  - 1 microwave;
  - 1 hairdryer.
- house for the baker:
  - 6 lightbulbs;
  - 4 wall outlets;
  - 1 mini fridge;
  - 2 induction hobs;
  - 1 TV;
  - 1 microwave;
  - 1 hairdryer.
- house for restaurant staff:
  - 6 lightbulbs;
  - 4 wall outlets;
  - 1 mini fridge;
  - 2 induction hobs;
  - 1 TV;

    - 1 microwave;
    - 1 hairdryer.

<u>Food and recreation:</u>

- restaurant:
    - 15 lightbulbs;
    - 1 stereo system;
    - 2 fridges;
    - 5 induction hobs;
    - 2 ovens;
    - 2 dishwashers;
    - 1 coffee machine;
    - 1 juicer;
    - 2 hand dryers;
    - 2 cooker hoods.
- ecomuseum:
    - 20 lightbulbs;
    - 4 TVs;
    - 2 projectors;
    - 2 computers;
    - 3 stereo systems.
- bakery:
    - 6 lightbulbs;
    - 1 fridge;
    - 1 sandwich plate;
    - 1 microwave;
    - 1 backup electrical oven;
    - 2 mixers.
- recreation area:
    - 4 lightbulbs;
    - 1 router;
    - 3 wall outlets;

    - 2 projectors.

- area for sightseeing:
    - 2 lightbulbs;
    - 1 electric water heater.

- sauna room:
    - 4 lightbulbs;
    - 1 stereo system;
    - 1 mini fridge.

- playroom:
    - 4 lightbulbs;
    - 2 TVs;
    - 1 console;
    - 1 router.

<u>Storage rooms:</u>

- storage room of the restaurant:
    - 2 lightbulbs.

- storage room of the bakery:
    - 2 lightbulbs.

- snow equipment storage room:
    - 2 lightbulbs.

- common equipment storage room:
    - 2 lightbulbs.

- multipurpose storage room:
    - 2 lightbulbs.

- storage room for cleaning equipment:
    - 2 lightbulbs.

Service rooms:

- reception:
  - 8 lightbulbs;
  - 2 computers;
  - 1 router.
- laundry room:
  - 4 lightbulbs;
  - 3 washing machines;
  - 2 dryers;
  - 1 ironing machine;
  - 2 vacuums.
- biomass boiler room:
  - 3 lightbulbs;
  - 1 chipped wood boiler.
- chipped wood storage:
  - 1 lightbulb;
- nursery:
  - 4 lightbulbs;
  - 1 computer.

Outdoor:

- 20 streetlamps working only on opening days;
- 4 streetlamps always working;
- 1 pump for an always flowing fountain.

Finally, following this scenario, each device's estimated power was correlated with its supposed daily time of use, allowing for the calculation of daily electrical consumption as reported in the following formula.

$$E_{day=}\sum_{i=1}^{n} P_i * t_i$$

Where:

- E_{day} is the daily electrical consumption;
- P_i represents the power of device i;
- t_i is the daily usage time of device i;
- n corresponds to the number of devices.

Then calculations were performed considering the real-market average consumptions of the specified devices, obtaining an average hourly consumption of 11.15 kWh (267.5 kWh/day) on opening days, and of 0.325 kWh (7.8 kWh/day) for the base consumption every hour of the year, which includes the external lighting provided by 4 streetlamps and the presence of a small traditional always flowing fountain. By multiplying the values of daily consumption by the respective operating days (respectively 160 and 365), the annual electrical consumption of 42.80 MWh/year for working days and of 2.85 MWh/year for constant consumption throughout the year was obtained. Finally, the total estimated consumption for Querio was computed as the sum of the two values and amounted to 45.65 MWh/year.

5.4 Water use

Considering the water consumption, the presence of the following elements was estimated:

- 15 toilets;
- 10 bidets;
- 15 sinks;
- 10 showers;
- 1 always flowing fountain.

The possible total water requirements were obtained following per capita estimations that underline that in the hospitality industry the consumptions are much higher than common residential ones and amount to about 645 litres per day per capita. [37] Considering the maximum number of hosts and workers of 28, the estimated daily water consumption is 18060 litres/day.

To reduce the water consumptions in tourist accommodation it is suggestable to adopt devices like air flow reducers, low consumption shower heads or latest generation taps to reduce the flow rate of water per minute. Other solutions are related to the inclusion of timed taps with manually operated buttons for dispensing limited quantities of water, touchless electronic taps, and double flush cisterns for toilets. [38]

All these interventions, joined with a more informed use of water could lead to reductions in water use of up to 20%, significantly bringing down the water demand to 14448 litres/day, which, considering the 160 opening days of the hotel, corresponds to 2311680 litres/year, approximately the volume of an Olympic pool.

Finally, considering the demand required for the constant flow of the small fountain is estimated a consumption of 1 litre per minute, and therefore its consumption in one-year amounts to 525600 litres/year, bringing the total consumption to 2837280 litres/year.

The substantial volume required underlines the current necessity for a connection to the local water distribution network, but, for instance, the use of rainwater harvesting systems may be considered for possible sustainable future developments.

6 Thermal insulation

Improving insulation performance stands as one of the primary strategies considered when aiming at lowering a building's energy demand. Therefore, a deep analysis is required, especially considering that heritage buildings are often bonded with degraded or inefficient materials associated to low insulation performances. The thermal capabilities in historical buildings are often improved through thermal insulation enhancing systems placed in roofs or internally, together with the replacement of windows and the renovation of the heating systems. External interventions are generally not considered because operating on facades may undermine the identity of the buildings.

6.1 Guidelines

The complexity of the matter is understood by the European Union that, through the RIBuild project, aimed at increasing the overall thermal performance of the European building stock to reach high indoor climate quality and energy efficiency. In particular the EU-funded project offered the most recent findings on how and when to install internal thermal insulation in historic buildings without compromising their architectural and cultural value and put them on a shared database. The database and its tools are used when planning the renovation of buildings with heritage value, and particularly for the retrofitting measures relative to internal thermal insulation without compromising the architectural and cultural value. [39] RIBuild also developed specifical guidelines aimed at addressing all the tangle of specific conditions and situations in which historical buildings can be found. [40]

In this way building owners can understand the steps to take and decide what to do and how to do it in the most informed way. Anyway, a certain risk is always involved when renovating a building and is mostly related to the absence of detailed knowledge about the building materials used. Knowing the unknowns and providing as much information as possible the building owners would encounter a simpler process and therefore be more open to considering the implementation of internal insulation. [41]

6.2 Project in Querio

For the following analysis have been considered the materials and setting reported in the rebuilding project delineated in Chapter 4, which is characterized by a strong use of concrete for the requalification of the site in the most conservative way. The final aim was in fact to obtain a new artifact inspired by the history of the town, and so were the method of overlapping the pre-existent ancient elements, mostly composed of natural stone, with a new concrete box. [23]

The foreseen interventions on the town's structures are reported in Figure 10, where is noticeable the variety of conditions of the artifacts, that are all marked by a generally degraded state, and the subsequent different approaches for the interventions.

Figure 10 Foreseen interventions (architectural design by A. Craveri and C. Dallere) [23]

6.3 Autoclaved Aerated Concrete

The chosen material for the structure is autoclaved aerated concrete (Figure 11), to which is added glass fibre to have a further diffused insulation effect. To give a more precise information, the ASTM C1386 Standard Specification for Precast Autoclaved Aerated Concrete (AAC) Wall Construction Unit defines AAC as "*a cementitious product based on calcium silicate hydrates* *in which low density is attained by the inclusion of an agent resulting in macroscopic voids and is subjected to high pressure steam curing...*". [42]

Figure 11 Block of Autoclaved Aerated Concrete [43]

This composite material proved to be both compliant with the structural needs, and adequate on the aesthetic side: in fact, through the combination with the natural stone already present in the town, as shown in Figure 12, AAC contributes to keeping the original character of the hamlet.

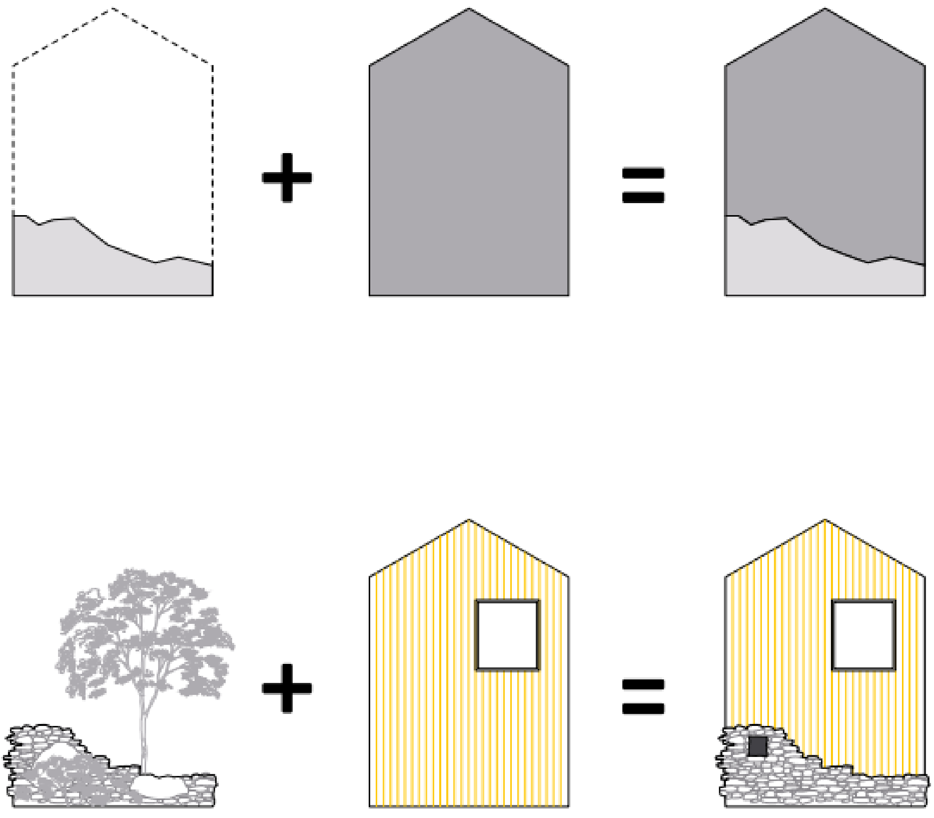

Figure 12 Projected aspect of the town's buildings (architectural design by A. Craveri and C. Dallere) [23]

The material also has good thermal and acoustic insulation characteristics linked to its remarkable porosity, that can make its air content rise to almost 80%, while being lightweight (~20% the weight of concrete). It is in fact denominated aerated because of the many small air bubbles it contains. [44]

Considering the worksite aspect, crucial for the complex area object of interest characterized by a particularly complicated topography, the Autoclaved Aerated Concrete shows extremely flexible characteristics: it is almost self-compacting and can easily adapt to specific shapes. In fact, to further enhance the fusion between the new structure, the old remaining elements and the natural context on which are locates, during the concrete casting sandblasted wooden boxes can be used to highlight a wooden texture to additionally characterize the walls, while pigments in a ratio lower than 5% can be used to obtain a hot colouring following the one of local stones. [23]

6.4 Thermal properties

Focusing on the property related to the searched energy savings, are introduced two central parameters to help understanding the thermal characteristics of materials.

- Thermal conductivity λ [W/mK]: represents the ability of a material to conduct heat. It quantifies the amount of heat flowing perpendicularly to a surface because of a temperature gradient.
- Thermal transmittance U [W/m²K]: denotes the rate of heat transfer through materials. It represents the amount of thermal power flowing through an element of the building, like a wall, because of a temperature difference between the two sides.

To summarize, thermal conductivity reflects the features of a materials independently of the wall's thickness, while thermal transmittance is influenced by both the wall thickness, its surrounding environment, and therefore can account for the overall heat transfer through a structure. [45]

The thermal conductivity of the AAC has been estimated to a value of 0.08 W/mK [46], while for stone masonry the λ value is of 2.3 W/mK [47].

The thermal transmittance U is calculated starting from the thermal resistance R of the elements constituting the building component object of interest. It represents a material's ability to resist heat transfer at a certain thickness and is calculated according to the following formula:

$$R = \frac{d}{\lambda}$$

Where:

- R is the thermal resistance [m^2K/W]
- d is the thickness of the material [m];
- λ (lambda) is the thermal conductivity of the material [W/mK].

The higher the R value, the better when searching for an insulating material.

The U Value is instead obtained as the reciprocal of all resistances of the materials composing the building element considered as reported in the following formula.

$$U = \frac{1}{R_{tot}}$$

Where:

$$R_{tot} = R_1 + R_2 + \cdots + R_n$$

In assessing the thermal performance of building elements, and in particular insulators, various parameters are useful. Recognizing an insulator as a material impeding the flow of heat, the ideal characteristics involve low conductivity, high density, resistance to water, minimal thickness, and low costs. It's crucial to acknowledge that finding a material meeting all these criteria is challenging, and therefore is crucial to evaluate among the multitude of existing insulators to identify the most suitable one for the specific application.

Focusing on the subject of the thesis, two producers were analysed in the following paragraphs, both because of their proximity to the site and because of their strong environmental vocation.

6.5 Ricehouse (RH-P)

Ricehouse S.r.l. is a business based in Biella focused on the use of by-products from rice processing. It is acknowledged as an innovative startup since 2016 and is deeply committed to the development, production, and promotion of bio composite materials characterized by high energy and acoustic efficiency, eco-compatibility, and derived from a short supply chain. [48]

Considering the application examined in this thesis, the most interesting Ricehouse product was the *RH-P* [49], a natural insulator that consists of pre-compressed dried rice-straws block, whose main characteristics are:

- optimal breathability, preventing surface condensation;
- effective acoustic insulation;
- biodegradability;
- ease of handling on-site;
- compatibility with other natural building materials;
- CO_2 absorption capacity that contributes to reducing atmospheric emissions.;
- low thermal conductivity;
- renewability, as it is composed of rice straws, which are produced yearly and generally discarded;
- high resistance to decay and mold growth due to its chemical composition and high silica content.

In Table 1 are reported some quantitative information about the properties of the RH-P insulator. [49]

Table 1 RH-P datasheet [49]

Thermal conductivity	0.44 W/mK
Density	120 kg/m3
Specific heat	1900 J/kgK
Resistance to water vapor diffusion	3.09

The performance in terms of thermal conductivity λ is remarkable and makes of RH-P a great candidate for an application in Querio.

To confirm the hypothesis have been analysed real life examples of the use of the material in the alpine context, finding of interest the application at the B&B Alchemilla, an accommodation facility in the Aosta Valley where the use of the RH-P insulant led to the creation of a highly performing and welcoming-looking envelope, in great harmony with the mountain environment in which it is located, as reported in Figure 13.

Figure 13 B&B Alchemilla, Tache (AO) [50]

6.6 Davifil-Bioisol (Cartonlana)

This business, like the previous, is located in the Biella province and aims at using sheep wool for sustainable architecture following the research project *Cartonlana* conducted by Politecnico di Torino's Department of Architecture and Design. [51]

The Cartonlana material is a novel sheep wool-based product designed for thermal insulation in buildings, with the purpose of obtaining a resource from waste. From the research conducted on the economic and social aspects of the wool production chain in the Piedmont region some crucial points turned out:

- sheep are not selected for the quality of their wool, which cannot be used by textile industry;
- sheep farming is primarily focused on producing milk and meat;
- wool is a special waste and is typically disposed of improperly: buried or burned, with a negative effect on soil and air pollution;
- sheep wool building products are typically imported from other nations. [51]

The Cartonlana project aimed to overcome these criticalities by producing panels totally composed of locally recycled sheep wool natural, hygroscopic, recyclable, semi-rigid and with excellent soundproofing and thermal insulation performances. The cited properties were evaluated through physical and chemical analysis reported in the study *Sheep wool for sustainable architecture* focused on thermal conductivity, thermal transmittance, sound absorption coefficient. [51]

The results showed that Cartonlana (Figure 14) performed competitively if compared to other fibrous insulating materials (such as fiberglass and rock mineral wool), giving outstanding results in terms of thermal conductivity (λ=0.040 W/mK), thermal transmittance (U~0.42 W/m^2K and acoustic absorption (absorption coefficient of α_w = 0.55). The thickness of the panel is 4 cm, has a density of 110 kg/m^3 and its standard dimensions are 52 x 90 cm [51].

Figure 14 Cartonlana panels [52]

The upcoming Chapter explores the applicative side of these insulant materials, evaluating their effectiveness through a comprehensive approach aimed at verifying their compliance with the existing regulations.

7 Quantitative analysis of thermal insulation

In the following paragraphs are numerically estimated the performances of different configurations of the town's buildings' insulation systems and their compliance with the existing normative. This is a crucial analysis when aiming for the highest energy efficiency in buildings.

7.1 Wall configurations

In the project were followed two configurations of wall thickness depending on the preservation status of the structures:

- when dealing with a bad conservation state or a thin remaining layer the new structure in concrete incorporated a portion of the previous wall, reaching a total thickness of ~50 cm (0.4 AAC + 0.1 stone blocks). In this case the stone blocks represented a sort of skin, simply aimed at improving the final aesthetic result;
- if the pre-existing wall had a good conservation state the intervention was centred on the insertion of an internal consolidating structure, reaching an overall wall thickness of ~0.9 m (0.4 m AAC + 0.5 stone blocks).

To obtain quantitative information regarding the thermal performance of the configurations the following formulas were performed:

- firstly, the thermal resistance of each layer was calculated as the ratio between its thickness and its thermal conductivity.

$$R_{layer} = \frac{d}{\lambda};$$

- then, the summation of the different layers' resistances was performed.

$$R_{wall} = \sum R_{layer};$$

- finally, was obtained the thermal transmittance of the wall.

$$U_{wall} = \frac{1}{R};$$

The U values were calculated in absence of the insulant materials, and to the previous configurations were simply added the following finishes by Ricehouse [48]:

- a layer of thermal base plaster (RH-100) thick 1.5 cm;
- a 4 mm coating of natural lime and rice husk-based 00000of white colour (RH-210);

- a 4 mm sheet of natural finishing composed by lime and rice husk mass-coloured (RH-220).

Finally, the total U value without any insulating material il calculated obtaining that:

- for a stone wall thickness of 0.1 m U_{wall} is 0.1897 W/m^{2}K;
- for a stone wall thickness 0.5 m U_{wall} is 0.1836 W/m^{2}K.

The described structures already provide good levels of thermal efficiency, but aiming to increase the efficiency to higher levels, in the next paragraphs is planned the use of additional insulating materials.

7.2 RH-P (dried rice-straws)

Aiming to increase the thermal performance of the wall, to the two wall configurations described was added a RH-P insulation layer following the scheme reported in Figure 15. [53]

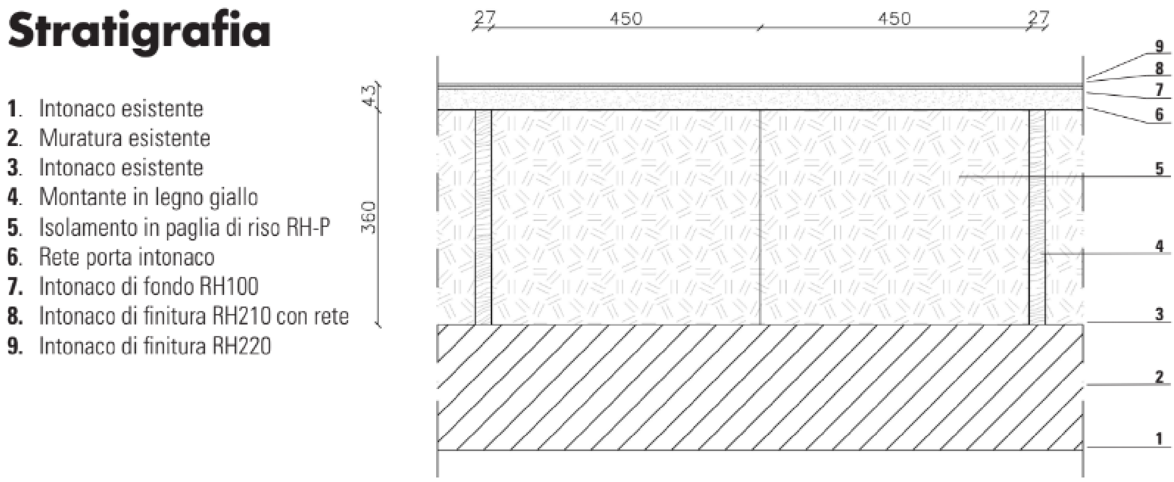

Figure 15 Stratigraphy for the application of RH-P [53]

Then, utilizing the known material's performances ($\lambda = 0.044$W/mK and d = 0.35 m), was obtained that:

- for a stone wall thickness of 0.1 m U_{wall} is 0.0756 W/m^{2}K;
- for a stone wall thickness of 0.5 m U_{wall} is 0.0746 W/m^{2}K.

Proving a marked increase, of about 60%, in the thermal performance of the buildings following the implementation of the thermal insulant. Anyway, the improvement related to the thicker wall emerges to be not particularly relevant in terms of thermal insulation, and therefore is considered the conservation of only 10 cm of stone wall independently of the preservation conditions. This would give a very similar aesthetic result, while keeping the thermal performance at a very high level and increasing the walkable area.

7.3 Cartonlana (sheep wool)

The same calculations of the previous paragraphs were followed to obtain the U_{wall} values implementing the Cartonlana insulant (λ =0.040W/mK, d=0.04 m), obtaining that:

- for a stone wall thickness of 0.1 m U_{wall} is 0.1594 W/m^{2}K;
- for a stone wall thickness of 0.5 m U_{wall} is 0.1551 W/m^{2}K.

Showing a U value higher than the one of the rice-based insulant, but also a smaller impact on walkable surface, being ~30 cm thinner than RH-P. Consequently, making an informed decision for the analysed application necessitates finding a balance between achieving higher thermal performance and maximizing available usable space.

7.4 Normative

Finally, to check the compliance of the projected structures with the Italian normative and perform a prediction of the town's heat consumptions, the climatic zone of the area was retrieved from Italian official tables. Figure 16 presents a thematic map reporting the normed classification in the Peninsula, placing Querio in the F class [54]. This category includes the coldest areas of the country and therefore requires optimal thermal performances.

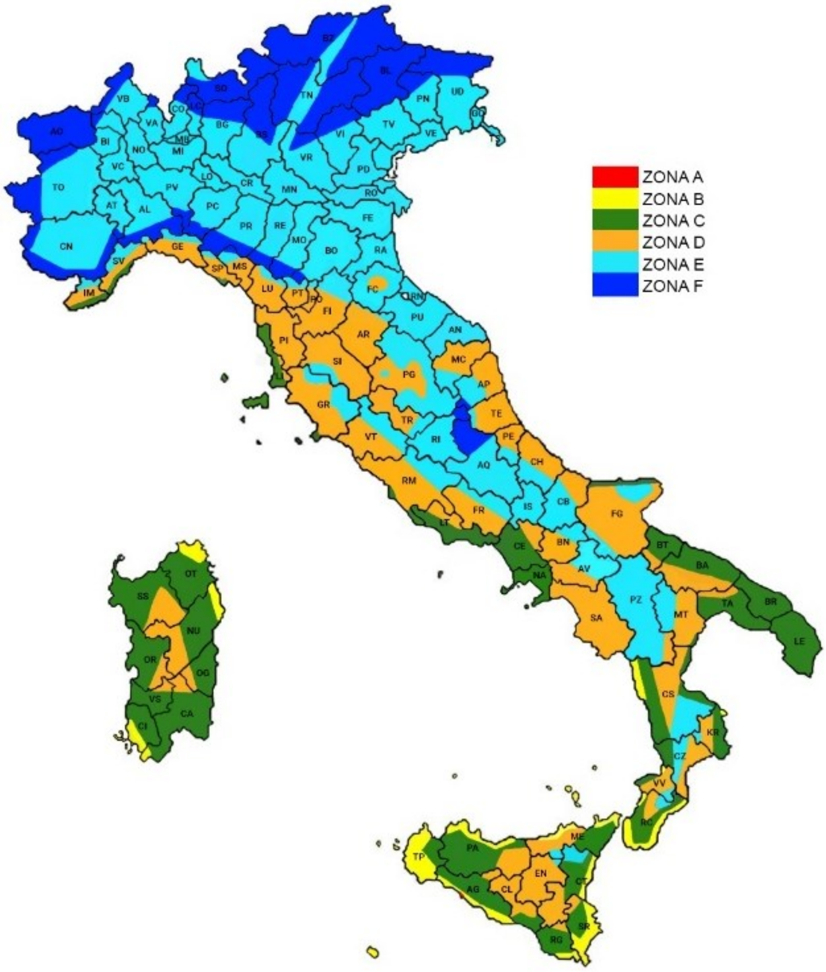

Figure 16 Italian climatic zones classification for indoor heating [55]

Then, were found the U-values required for the buildings' external surfaces from the Italian regulation tables (norm *UNI EN ISO 6946*). The values relative to the climatic area F, as reported in Table 2, indicate a threshold for external walls of 0.22 W/m^{2}K [56], and therefore all the configurations previously projected comply with the requisite.

Table 2 Thermal transmittance requisites in the Italian normative [56]

	Walls	**Roofs**	**Fixtures**
Climate zone A	≤0.38 W/m^2K	≤ 0,27 W/m^2K	≤ 2,60 W/m^2K
Climate zone B	≤0.38 W/m^2K	≤ 0,27 W/m^2K	≤ 2,60 W/m^2K
Climate zone C	≤0.30W/m^2K	≤ 0,27 W/m^2K	≤ 1,75 W/m^2K
Climate zone D	≤0.26 W/m^2K	≤ 0,22 W/m^2K	≤ 1,67 W/m^2K
Climate zone E	≤0.23 W/m^2K	≤ 0,20 W/m^2K	≤ 1,30 W/m^2K
Climate zone F	≤0.22 W/m^2K	≤ 0,19 W/m^2K	≤ 1,00 W/m^2K

Similar considerations were followed for the roof structure, that can still feature the presence of both RH-P and Cartonlana insulants. For the calculations, the thickness of the structural component of AAC is supposed to be of 0.2 m, while the rest of the structure is considered equal to the one of the external walls, resulting in:

- considering the RH-P insulant, U_{roof} is 0.0936 W/m^2K;
- considering the Cartonlana insulant, U_{roof} is 0.2682 W/m^2K.

Knowing that in this case the normed limit is of 0,19 W/m^2K (Table 2) only the first insulating material meets the specified condition.

While, regarding the fixtures, the minimum requirement for the climatic zone F is 1,00 W/m^2K (Table 2). To optimize thermal insulation while complying regulatory standards, a practical choice was the use of windows with triple glazing, consisting of three sheets of glass and two air chambers. An example of such windows is represented by the Oknoplast Prolux Vitro windows, that, with a U_{win} of 0.7 W/m^2K, thereby adhering to the requirement. [57]

7.5 Thermal comfort

In addition to energetical considerations, the thermal properties of buildings are also related to the crucial topic of thermal comfort, which refers to the state of being in which a person feels satisfied within the thermal environment surrounding them. This concept is influenced by various factors, including temperature, humidity, air movement and other environmental terms. In indoor settings, achieving conditions that fall within the range perceived as comfortable by individuals is fundamental to ensure overall satisfaction and well-being.

The concept of thermal comfort takes into account both objective environmental factors and subjective individual preferences, recognizing that different people may have different comfort preferences. Considering the application object of the analysis, which is related to hospitality, the standard is to set a temperature to 20°C. Achieving thermal comfort holds significant importance, not only for promoting well-being but also for enhancing productivity and satisfaction in closed environments. This relevance is particularly pronounced in the hospitality industry, where the guests' comfort is a primary concern. [58]

8 Thermal demand

As exposed in the previous paragraph, thermal comfort is a crucial aspect when planning the construction and use of buildings, and particularly hotels. In fact, many heat-transfer processes occur in buildings and can condition their thermal performance and comfort, as presented in the Figure 17.

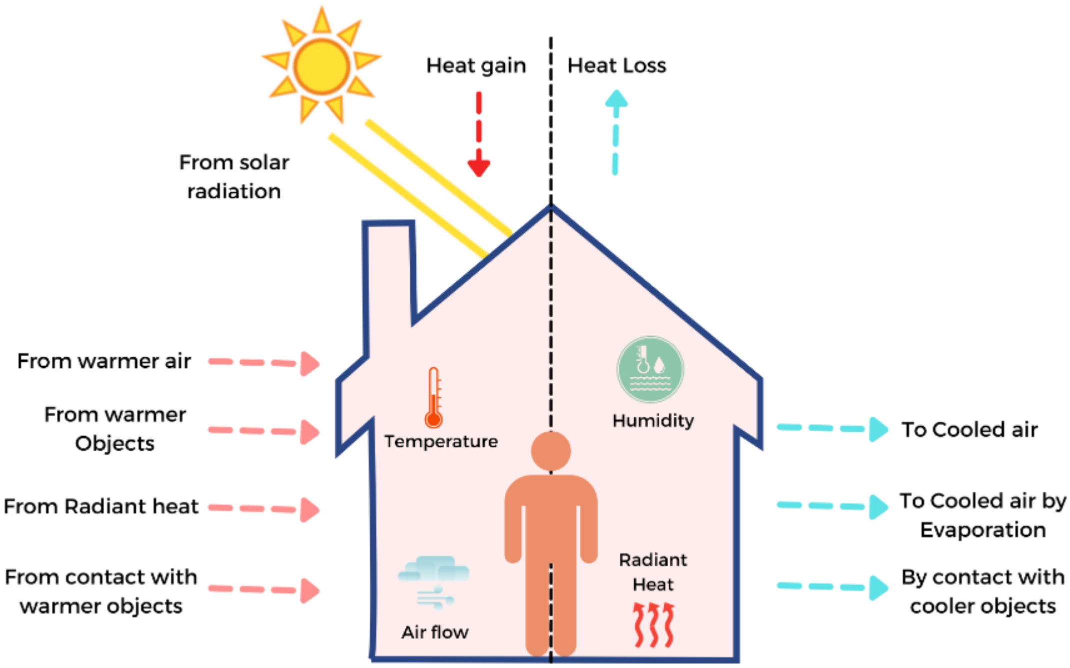

Figure 17 Aspects related to thermal comfort in buildings [59]

The parameter used to know the heat requirement of a building is the design thermal demand ϕ_d, which represents the thermal flow needed to maintain a given temperature inside of a building depending on its size, insulation and external climate. The used formula to calculate such fundamental parameter is the following:

$$\phi_d = r * V * (T_{in,D} - T_{out,D})$$

Where:

- ϕ_d is the design thermal demand: the information needed to properly design the heating devices;
- r is volumetric heat transfer coefficient: a parameter that measures a structure's ability to transfer heat per unit volume. Lower values of r are associated with better thermal performances, and in fact it usually ranges between 0.85 W/m^{3}K and 0.95 W/m^{3}K for old buildings and between 0.35 W/m^{3}K and 0.45 W/m^{3}K for buildings of recent

construction. For the considered case-study, knowing the analysed rebuilding techniques and high-efficiency insulating materials, the value is selected to 0.35 W/m^3K;

- V represents the heated volume. For the town was estimated to 2547.12 m^3, which was approximated to 2800 m^3 to have a safety margin and include the possibility of adding new structures or sustain an increase of thermal demand in the future;
- $T_{in,D}$ is the design temperature of the indoor spaces that, to comply with thermal comfort standards, is set to 20°C (293.15 K);
- $T_{out,D}$ is the design temperature of the outdoor. It represents the worst conditions of the outside. For the considered territory it can be estimated to -10°C (263.15 K).

Performing the previously reported calculation with the exposed values, is finally obtained a value of ϕ_d of 29400 W.

Then, to include the presence of a health and wellness area, where guests could unwind and de-stress during their stay, were considered the thermal consumptions related a small Finnish sauna (160 x150 x 210 cm operating at 90°C [60]). The calculation of its thermal demand was performed using the same formula previously described:

$$\phi_{\mathrm{dsauna}} = r_{sauna} * V_{sauna} * (T_{in,\mathrm{D}} - T_{\mathrm{out,D}})$$

with the updated parameters reported below:

- $T_{out,D}$ = 15°C (288.15 K);
- r_{sauna} = 0.45 W/m^3K;
- V_{sauna} = 5 m^3;
- $T_{in,D}$ = 90°C (363.15 K).

Using these coefficients, the additional consumptions related to the presence of the sauna amounts to about 170 W. In conclusion, summing the thermal requirements related to indoor warming and the sauna's operation, it was obtained a value of required thermal power of 29.57 kW.

Another thermal requisite is the production of domestic hot water. An estimation of its demand was retrieved from the following table (Table 3), that indicates its share on the total heat demand in different building types.

Table 3 Share of domestic hot water on total heat demand [61]

Building type	Share of domestic hot water
Single family house (before 1918)	9%
Office (after 1995)	10%
Hospital (>1000 beds)	20%
Hotel	22%

This ratio is a characteristic parameter that can markedly vary between different kinds of buildings: it is rather low in old buildings with low insulation standards, and it grows steadily with increasing thermal efficiency performances. [61]

The value corresponding to hotels is rather high and represents the 22% of the total heat demand required. Then, to obtain the relationship between domestic hot water demand (DHW) and space heating (SH) is used the following formula:

$$\frac{DHW}{DHW + SH} = 0.22$$

That, reversed and considering the previously obtained value of SH, allows to estimate the required power for domestic hot water production: 8.34 kW. Finally, is obtained the total heat power demand (DHW+SH), that is equal to the summation of the power demands related to space heating and domestic hot water production.

$$SH + DHW = 29.47 + 8.34 = 37.81\ kW$$

In the following chapter is analysed how this demand can be satisfied in the context of Querio.

9 Heat production

Knowing the required heating power to keep the indoor temperature of the diffused hotel at a level compliant with the guests' comfort and to fulfil the demand for domestic hot water, it was possible to design a heating system for the small town. In fact, the focus of this section is on the functionality and advantages of implementing a biomass boiler fuelled with chipped wood, a pivotal component for the sustainable development of the scattered hotel in Querio. The produced heat would then be dispatched to the whole town through a district heating network.

9.1 District heating

A district heating system operates with a central device producing heat, which is then distributed through a network of water pipes to reach substations where, through heat exchangers, is used to supply both heating for the internal environment and domestic hot water to the final users. After transferring the heat, the cooled water then returns to the central device through a separate set of pipes (Figure 18) to be reheated and restart the cycle. [62] The set of pipes that moves hot water from the boiler to the rooms is defined *primary*, while the one returning the colder water to the boiler is called *secondary*.

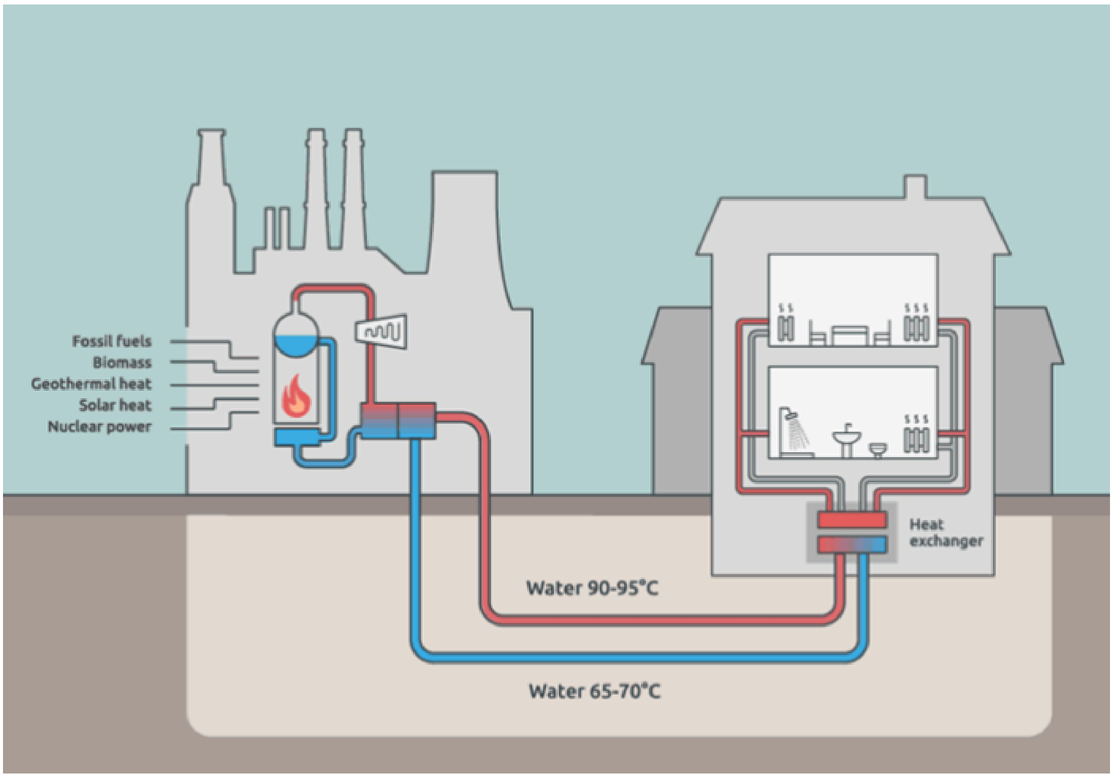

Figure 18 General functioning of a district heating system [62]

The advantages of using a centralized machine include a reduced need for maintenance and a lower probability of malfunctions, implying economic benefits. Also, the use of a unified device contributes to mitigating the aesthetic impact on the town by avoiding the installation of many individual devices, like heat pumps, which could negatively affect areas with heritage and landscape importance. [4]

9.2 Piping system

The piping system serves as a fundamental component of a district heating network, serving as the backbone through which hot water stretches across the serviced area, providing the necessary amount of heat. These devices are thermally insulated, buried underground and their correct dimensioning is of paramount importance.

Their size strictly depends on the mass flow rate required by the buildings, which is calculated through the following formula:

$$\dot{m} = \frac{\phi}{c(T_{m-}T_r)}$$

where:

- $\dot{m}$ is the mass flow rate of the water in the pipes;
- ϕ is the previously calculated heat demand of the town (37.81 kW);
- c is the thermal capacity of water (4184 J/(kgK);
- T_m is the supply temperature of the network (90°C equal to 363.15 K); [63]
- T_r is the design return temperature of the network (60°C equal to 333.15 K). [61]

Then, performing the calculation with the displayed values, the resulting $\dot{m}$ is 0.30 Kg/s.

This value can then be inserted in the next formula, which is based on geometrical relationships to obtain the value of the required diameter.

$$D = 2\sqrt{\frac{\dot{m}}{\pi * \rho * v}}$$

Where:

- $\dot{m}$ is the preiously obtained mass flow rate in the pipes;
- ρ is the density of water (1000 kg/m^3);

- v is the design velocity of the pipe (supposed to be of 1 m/s).

Using these values, the obtained value is of 1.95 cm. Looking for existing pre-insulated steel pipes' typologies, the most similar one is found to have an inner diameter of 26.9 mm. [64]

Subsequently, considering the commercial diameter, the effective velocity is calculated inverting the previous formula, obtaining 0.528 m/s. While this value is smaller than the initial one, it is still acceptable in prevision of potential future expansions of the network or increases in demand.

This approach also involves a compromise on the pipes' diameter: increasing D, the velocity of the water decreases, limiting also the operative costs related to pumping, but implying higher initial investments related to the excavations. [65]

In conclusion, a balance between initial and operational costs must be made, knowing that the selected diameter is suitable for the considered application.

9.3 Chipped wood

The choice of fuel becomes a pivotal factor when aiming at a sustainable energy generation approach. In the search of a material to heat the Borgata, the following qualities were sought:

- abundance;
- affordability;
- minimal environmental footprint;
- high energy yield;
- renewability;
- local sourcing;
- supporting to the local economy;
- ease of supply.

After research in the territory, the most adequate option turned out to be chipped wood (Figure 19), which consists in pieces of wood cuts from logs and wood pieces left over from the manufacture of woodworking products. [66]

Figure 19 Chipped wood [67]

Chipped wood, widely available locally because of the strong presence of sawmills, serves as a great example of circular economy. Derived from a potential waste, it not only supports the local economy but also aligns with sustainable practices being locally harvested, renewable and, if managed sustainably, carbon neutral. In fact, chipped wood can be a net zero fuel (NZF) if the CO_2 emitted during its combustion is balanced by the amount absorbed by trees during their growth. Therefore, the main condition for chipped wood to be a NZF is that the harvested wood used for its production is replanted following sustainable forestry practices, creating a relatively short and closed loop in the carbon cycle, unlike fossil fuels, which release carbon that was sequestered millions of years ago.

The environmentally positive impacts of exploiting wood chips are also related to the maximum exploitation of the available biomass, rather than letting the wood remains decompose and release carbon into the atmosphere. In fact, the process is estimated to allow the recovery of 15-20% of the biomass that would otherwise be abandoned in the forest as residues, not only increasing the yield per hectare and avoiding decomposition emissions, but also mitigating the thorny risk of wildfires in forests, an increasingly prevalent issue exacerbated by the changing climate. [1] [68]

The process of producing chipped wood, known as chipping, takes place in a woodchipper, an instrument that transform the waste resulting from the processing and cleaning of the woods into chips of wood. Finally, the resulting material is deposited in storages for about two years to dry and produce an efficient combustion.

In fact, the calorific value of wood chips mostly depends on the essence of the wood and its degree of humidity, ranging between 2 kWh/kg and 4.5 kWh/kg. Generally raw freshly cut wood chips have a water content of 50% and generate a calorific value of approximately 2.0 kWh/kg, while the same material dried naturally in the sun have a water coefficient of 30% and generate a calorific value of 3.5 kWh/kg. Through advanced in-plant drying processes the coefficient of humidity can be further lowered to 10%, enhancing the calorific value of chipped wood to 4.5 kWh/kg. [68] [69]

9.4 Biomass boiler

Biomass boilers are devices that function burning organic matter, such as chipped wood, to generate the thermal energy employed to produce steam or hot water for heating purposes.

These instruments can be fed automatically with fuel using flat spring arms able to catch the stored chipped wood that, thanks to a progressive screw, is conveyed through valves and devices devoted to preventing burn-backs until reaching the combustion chamber. Here through a system aimed at optimizing the fuel use, chipped wood is burned inside the heater to produce hot flue gases. These gases, through heat exchangers, heat up the water that is then conveyed through the piping system to provide the town with sustainable heating. [63] (Figure 20)

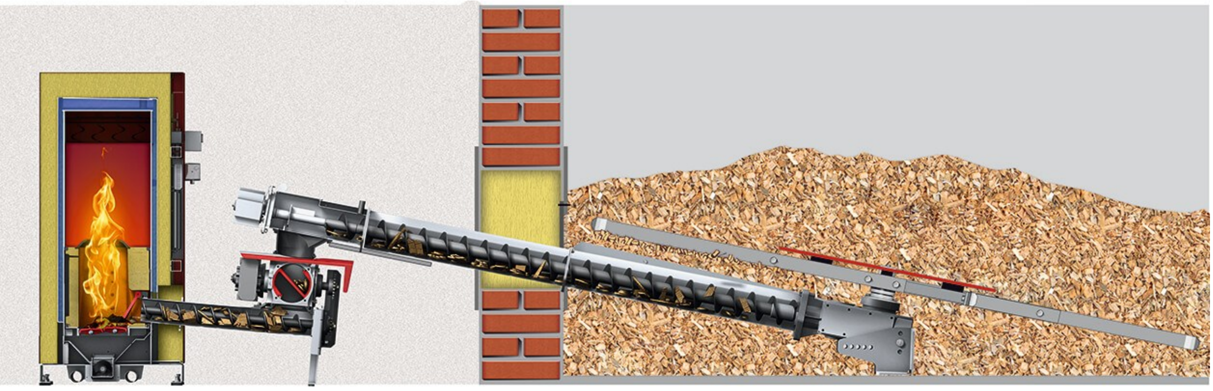

Figure 20 Functioning mechanism of chipped wood heating systems [70]

To properly size the heating required for the town, the thermal power demand calculated in the previous chapter (37.81 kW) was taken into consideration. Then, to ensure sufficient power coverage with a safety margin, the ETA eHack 45, capable to provide up to 45 kW, was selected. Its technical specifications are reported in Table 4.

Table 4 eHACK wood chip boiler 45 datasheet [63]

Suitable fuels	-	Chipped wood and pellet
Dimensions	mm	2700 x 2300 x 2400
Rated capacity of wood chips M25 BD 150 (W25-S160)	kW	7.6-45
Energy efficiency class	-	A+
Efficiency with wood chips at partial/full load	%	92.9/94.7
Water content	L	153
Ash box volume	L	52
Flue draught required at partial/full load	Pa	>2/>5
Electrical power consumption with wood chips at partial/full load with integrated precipitator	W	76/141
Electrical power consumption in ready mode	W	12
Maximum permissible operating pressure	bar	3
Temperature adjustment range	°C	70-85

The biomass boiler can be positioned in a room devoted to the scope, which should be adjacent to the one used to store the chipped wood, as shown in Figure 20. The next paragraph explores further this option.

9.5 Required storage estimation

As the initial step in determining the total space required to store the annual thermal energy consumption of the town, is necessary to consider the amount required for space heating (SH) and domestic hot water production (DHW). This is calculated using the following formula:

$$E_{tot} = E_{SH} + E_{DHW} = P_{SH} * t_{SH} + P_{DHW} * t_{DHW}$$

Where:

- E is the energy needed;
- P represents the power required;
- t is the duration of the request.

The estimated operating times are reported in Table 5. The days requiring space heating are estimated to 40 and corresponds to the diffused hotel's opening days between September and December. Anyway, thanks to the optimal insulation of the buildings presented before, this estimation could also be lower.

Table 5 Operating times for space heating and domestic hot water production

	Space heating	Domestic hot water production
Requested days/year	40 days	160 days
Requested hours/day	6 hours/day	4 hours/day

Considering the power obtained previously, the total demand for space heating is obtained following the next calculation:

$$E_{SH} = 29.47 \text{ kW} \ * \ 6 \text{ h} * \ 40 \text{ days/year} = 7073 \text{ kWh/year}$$

While total demand for domestic hot water production is obtained as:

$$E_{DHW} = 8.34 \text{ kW} * \ 4 \text{ h} * 160 \text{ days/year} = 5338 \text{ kWh/year}$$

Then, calculating their summation is obtained the total annual requirement for heating:

$$E_{tot} = 12410 \text{ kWh/year}$$

That, divided by the lower heating value of dry chipped wood (4.5 kWh/kg [69]) gives:

$$Chipped\ wood\ yearly\ request = \frac{E_{tot}}{LHV_{CW}} = \frac{12410 \text{ kWh/year}}{4.5 \text{ kWh/kg}} = 2758 \text{ kg/year}$$

Finally, considering the average density of chipped wood of 380 kg/m³ [71] was determined the required storage volume:

$$Storage\ space = \frac{2758\ \text{kg/year}}{380\ \text{kg/m}^3} = 7.26\ m^3/\text{year}$$

Concluding that this amount could be easily accommodated in an available room within the town, adjacent to the one hosting the biomass boiler (Figure 20). Therefore, in one year of operation one refill of the needed amount is necessary. In case of longer self-sufficiency needs, storage systems with bigger capacities could be considered.

9.6 Puffer

For domestic hot water production, it is advisable to couple the boiler with puffers, water storage tanks capable of speeding up hot water availability and ensure heat autonomy for several days.

Puffer storage tanks are ideal for heating in autumn or spring and for hot water preparation in summer because, in these seasons, the required energy is often lower than the boiler's production. Consequently, the energy stored in the puffers can be provided at need, saving fuel and preventing the boiler from switching on and off multiple times.

This approach enables the provision of domestic hot water and heating independently of the boiler's operation status. Considering its compatibility with ETA eHack 45 boilers, the ETA-S puffer was chosen for the application in Querio (Figure 21). [72]

Figure 21 ETA-S puffer [72]

Finally, taking into account the town's hot water requirements, the tank capacity, and the town's configuration, was supposed the need of 7 puffers, one in each building.

10 Photovoltaic energy production

This section of thesis is dedicated to estimating the photovoltaic energy budget for the town of Querio, allowing considerations regarding the use of solar energy for on-site clean energy production. The analysis was carried out comparing different instruments to obtain precise projections, aiming to improve the consistency of the considerations.

10.1 SolarEdge-Designer

As a first step of the analysis, the entire town was modelled using SolarEdge-Designer, a free web-based tool developed to assist in the design photovoltaic systems. This web application provides values for the inclination and azimuth of the roofs, allowing to estimate the irradiance hitting their surfaces and, consequently, their potential solar energy production. The 3D model of the town was recreated on SolarEdge-Designer using maps, sections and models created by Alessia Craveri and Cristian Dallere after measurements obtained during on-site campaigns. The main software used to retrieve the characteristics of the projected town were Rhinoceros 3D (Figure 22) and Autocad. (Figure 23)

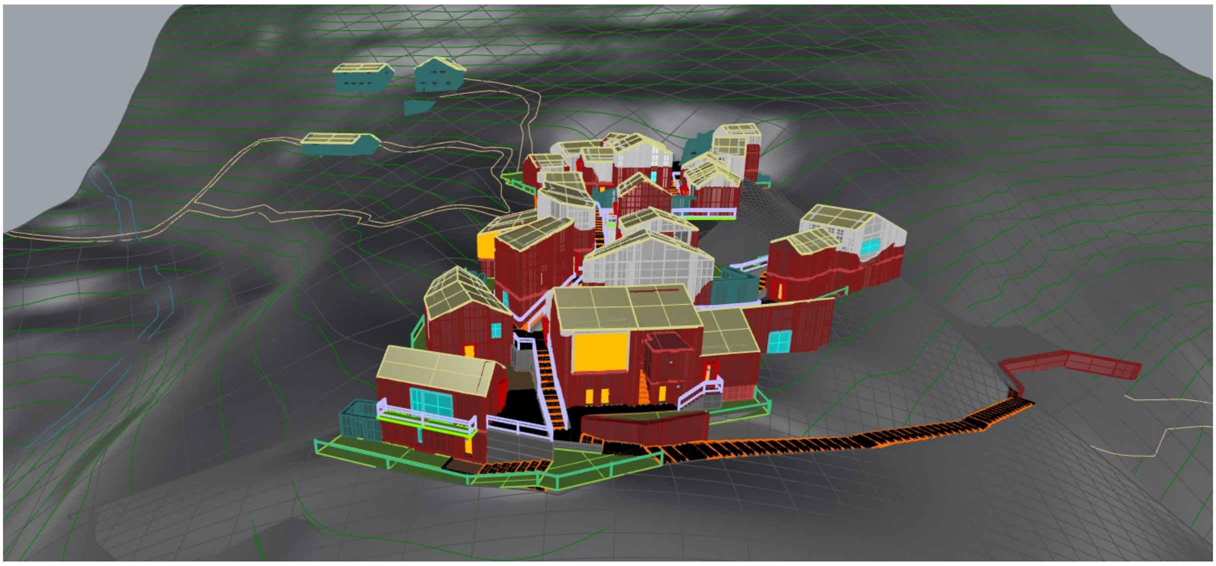

Figure 22 3D model in Rhino (architectural design by A. Craveri and C. Dallere)

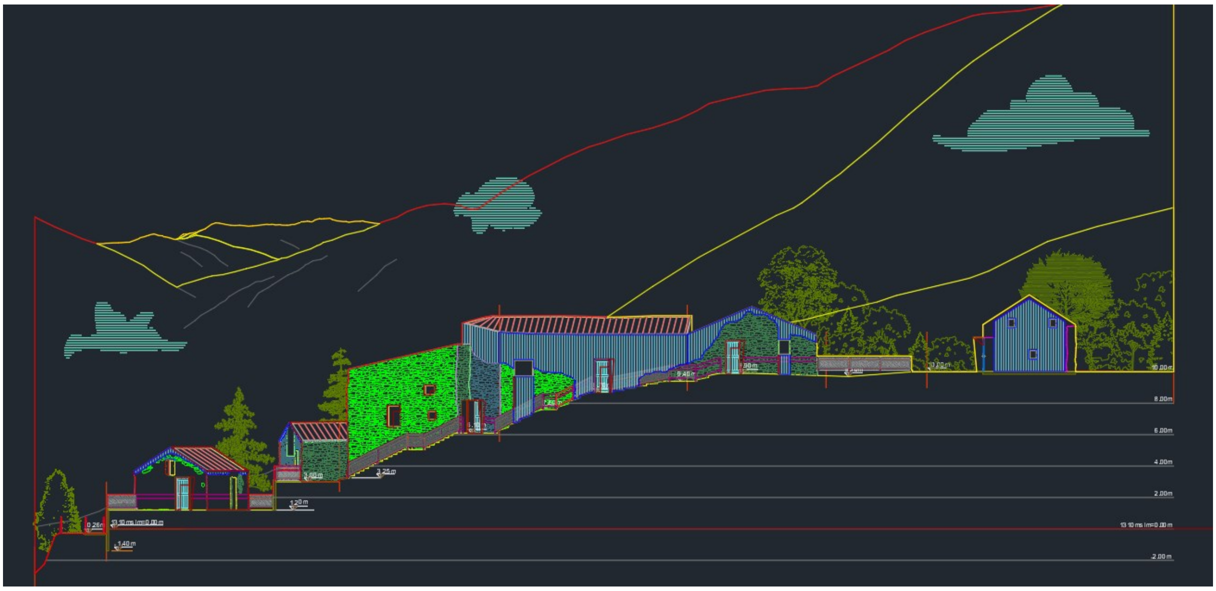

Figure 23 Section of the town in Autocad (architectural design by A. Craveri and C. Dallere)

However, SolarEdge-Designer does not automatically account for the topography of territories. To address this, it was integrated with the height of the buildings, resulting in the outcome presented in Figure 24.

Figure 24 Rendering of the town on SolarEdge- Designer [73]

Next, using the Perez model [74], the software computed and reported the irradiance values corresponding to each roof (Figure 25). This allowed a quick selection of the most sun-exposed covers for photovoltaic energy production.

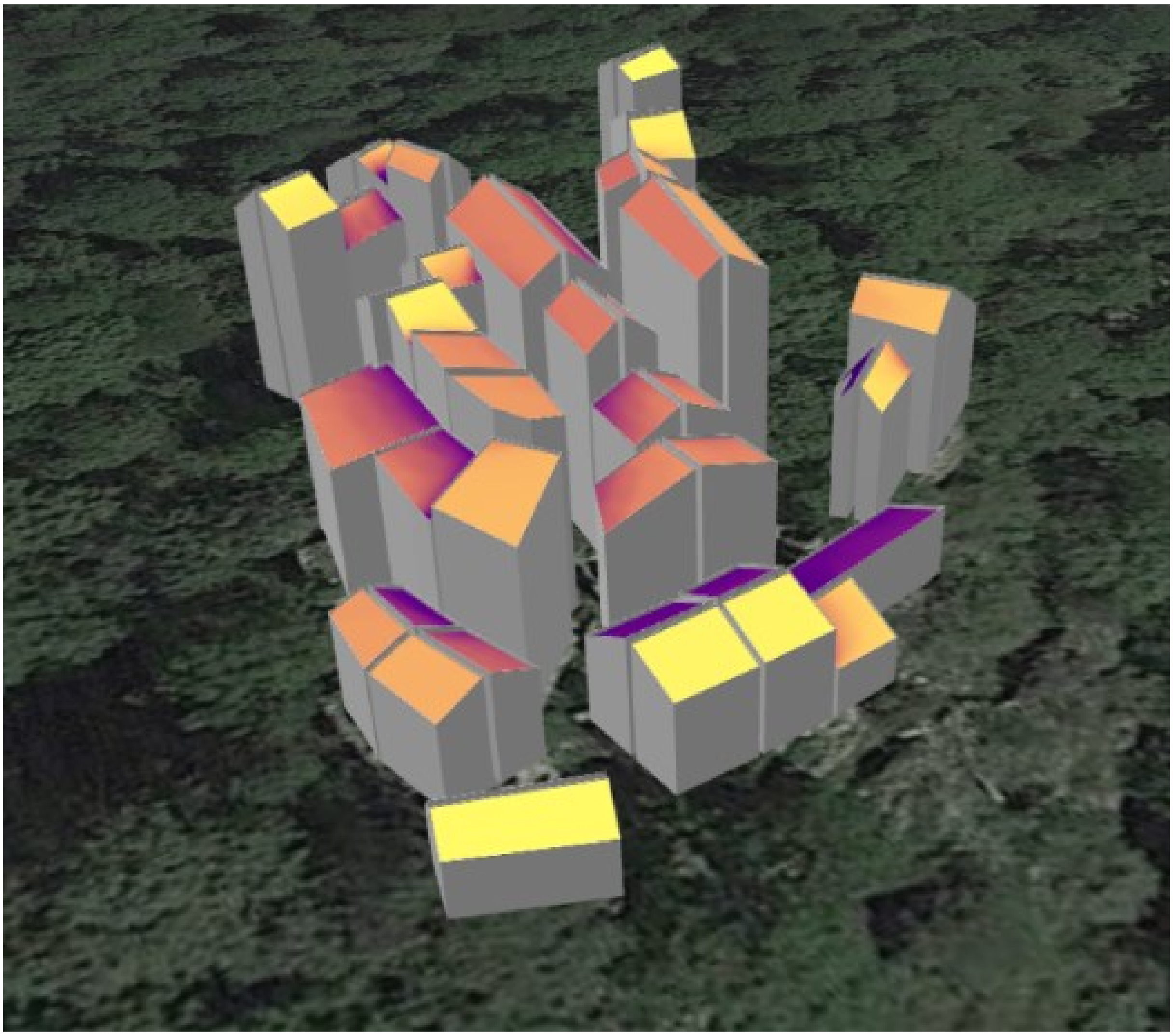

Figure 25 Rendering of the town on SolarEdge- Designer showing the irradiance [73]

Additionally, the SolarEdge-Designer model was used to retrieve the exact azimuth and tilt values for each roof of the town. Table 6 outlines the twelve roofs identified as the most suitable for the installation of solar panels, chosen based on their high solar irradiance values.

Table 6 Characteristics of the considered roofs

ROOF_ID	Azimuth	Tilt
1	176°	25°
2	168°	32°
3	207°	28°
4	155°	37°
5	176°	34°
6	176°	25°
7	181°	25°
8	233°	34°
9	202°	46°
10	140°	47°
11	236°	14°
12	165°	23°

Following this, by utilizing a function integrated into the software that allows to place solar panels on the roofs, various configurations and models were tested. The most efficient arrangement was achieved using the SunPower Maxeon3 430 in the set-up reported in Figure 26 and in Table 7. A total of 76 photovoltaic panels were considered, and SolarEdge-Designer estimated a potential energy production of 50.42 MWh/year, as noticeable from the Figure below. [73]

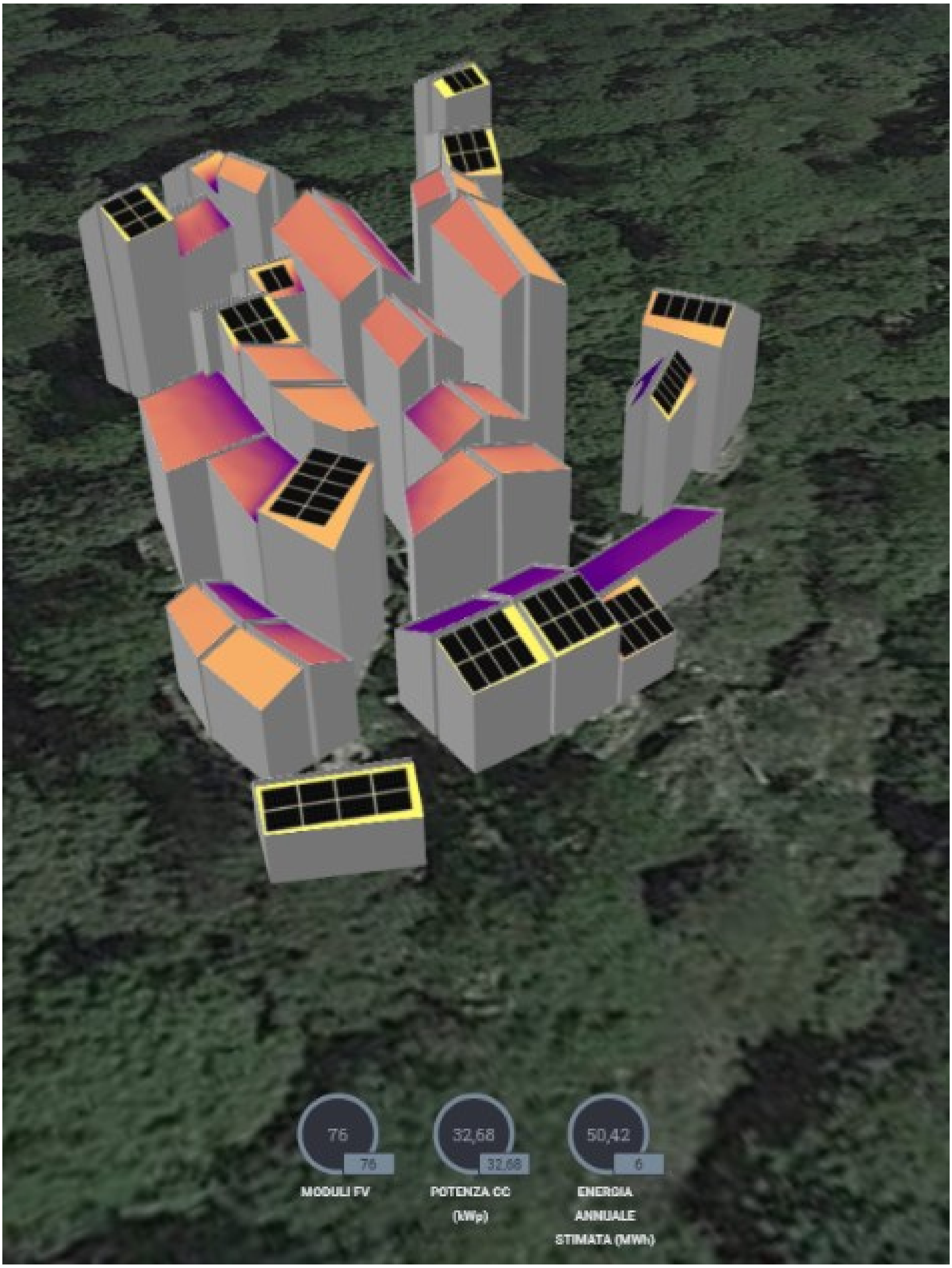

Figure 26 Rendering of the town on SolarEdge- Designer showing the irradiance and the solar panels [73]

Table 7 Number of panels per corresponding roof

ROOF_ID	N. of modules
1	8
2	3
3	6
4	6
5	2
6	8
7	6
8	5
9	8
10	6
11	10
12	8

Subsequently, to test multiple providers of irradiance data and obtain a consistent estimation of the producible energy from the solar resource, two widely recognized computational tools for solar irradiance were employed: PVWatts and PVGIS.

These online platforms are free, relatively simple to operate, flexible and commonly used when looking for general estimates, even though in certain simulations can give results as accurate as the ones from more professional applications.

The two software have recently grown in precision and nowadays are widely utilized for various reasons [75], especially the ones listed below:

- flexibility: PVWatts and PVGIS include a wide range of options that allow users to customize the calculations to their specific needs;
- generality: these tools are suitable for providing a quick general overview of the solar energy potential in a given location;
- accessibility: they have no cost and are user friendly, with tools that are relatively simple to operate, making them available to a wide user base. Additionally, there is widespread access to extensive documentation on these tools;
- reliability: these tools have demonstrated their reliability and effectiveness in various scenarios throughout time;

- professional level results: PVWatts and PVGIS in certain simulations can deliver results comparable to more advanced, professional and expensive tools.

10.2 PVWatts

PVWatts is an online tool designed by the American National Renewable Energy Laboratory (NREL), primarily focused on providing solar energy assessments for locations in the United States, but also used for other regions. It is widely applied for estimating electricity production from photovoltaic applications and is designed to be user-friendly and provide quick assessments of solar energy potential for specific locations. Anyway, PVWatts does not provide full data on location outside of the United States, and in remote areas, like the Verdassa valley, some information may not be available. [76]

In fact, regarding the origin of the data used to describe the conditions at the system's location, PVWatts comments that for countries other than USA, the software obtains solar resource data from one of the following databases, depending on location:

- Solar and Wind Energy Resource Assessment Program (SWERA);
- the ASHRAE International Weather for Energy Calculations Version 1.1 (IWEC);
- Canadian Weather for Energy Calculations (CWEC). [75]

While in the USA is available a set of weather data prepared from the NREL National Solar Radiation Database (NSRDB). [75]

The tool operates by using the typical meteorological year weather data of the selected area to estimate, for each hour of the year, the solar radiation incident on the photovoltaic array. Its output consists in hourly typical meteorological year data, which incorporates a comprehensive representation of solar irradiation over a long-ranging time.

Regarding the application object of the thesis, it was not possible to set the location in Querio as the small town was not present in the database, and therefore the data was obtained from the closest available position: Monteu, a Borgata about 350 metres away. Then, the solar resource data used is the one of the closest meteorological station, that in this case corresponded to the one of Turin, at about 18 miles (~30 kilometres) of distance (Figure 27).

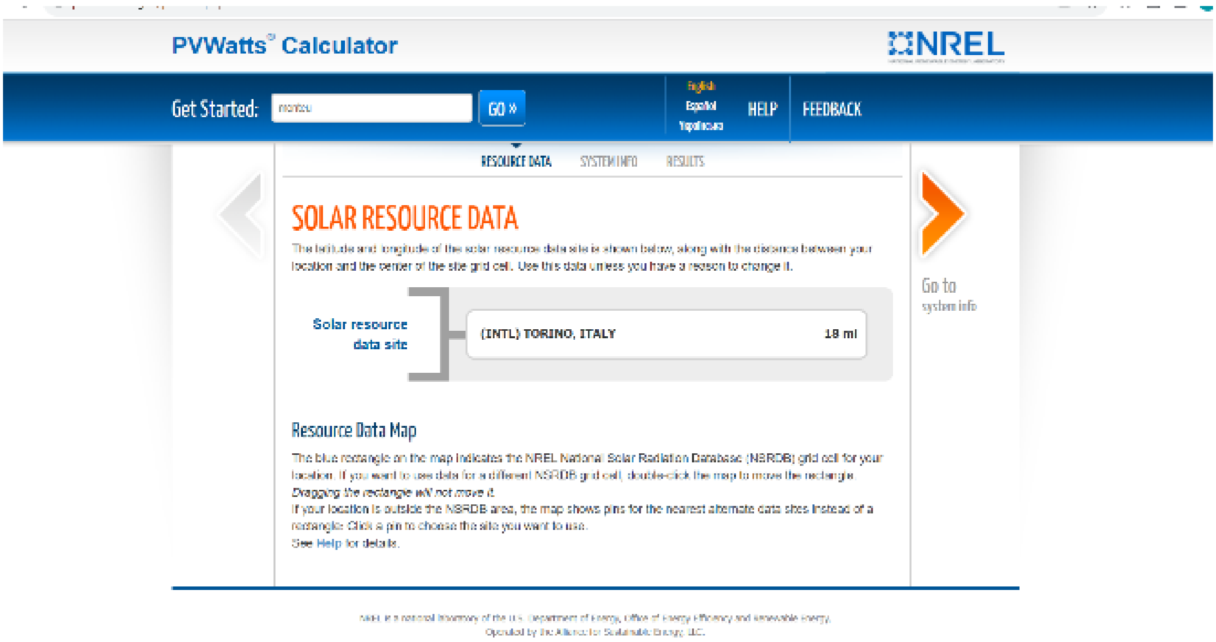

Figure 27 Screenshot of PVWatts Calculator [76]

Then, inputting the values relative to inclination and azimuth, a *.csv* output file was generated, containing hourly irradiance values along the average year. After repeating the process for each of the twelve roofs previously selected, calculations were performed to derive the final energy budget estimation. Assuming the use of the SunPower Maxeon3 430, with an area of 1.895 m^2 and efficiency of 22.7% [77], the amount of energy obtained on each roof was calculated using the following formula:

$$E_{roof} = I * A_{pan} * n_{pan} * \eta$$

Where:

- E_{roof} is the amount of energy produced on one roof;
- I stands for the solar irradiance in the average year;
- A_{pan} represents the area of one solar panel;
- n_{pan} stands for the number of panels on the considered roof;
- η is the efficiency of the photovoltaic panel.

Finally, to calculate the total annual electricity production in the village, the energy generation from each of the 12 roofs covered with solar panels were summed:

$$E_{tot=} \sum_{id=1}^{12} E_{roof\_id}$$

Obtaining a final estimation value of producible energy of 41.54 MWh.

10.3 PVGIS

PVGIS is an online free instrument implemented by the European Commission to give access to a large and accurate solar radiation database, especially for Europe but also Africa, the Mediterranean Basin and South-West Asia. It is available in five languages and is used for standalone or connected to the grid photovoltaic systems. It is also associated with Google Maps, simplifying the phase of the search for the location of interest. [78]

The efficient functioning of the tool in Europe is supported by a dataset served by 566 ground stations measuring in the last 10 years global and, in some cases, diffuse radiation. Similarly to PVWatts, distinct solar radiation datasets are used for different locations [75]. Their correspondence is shown in Figure 28.

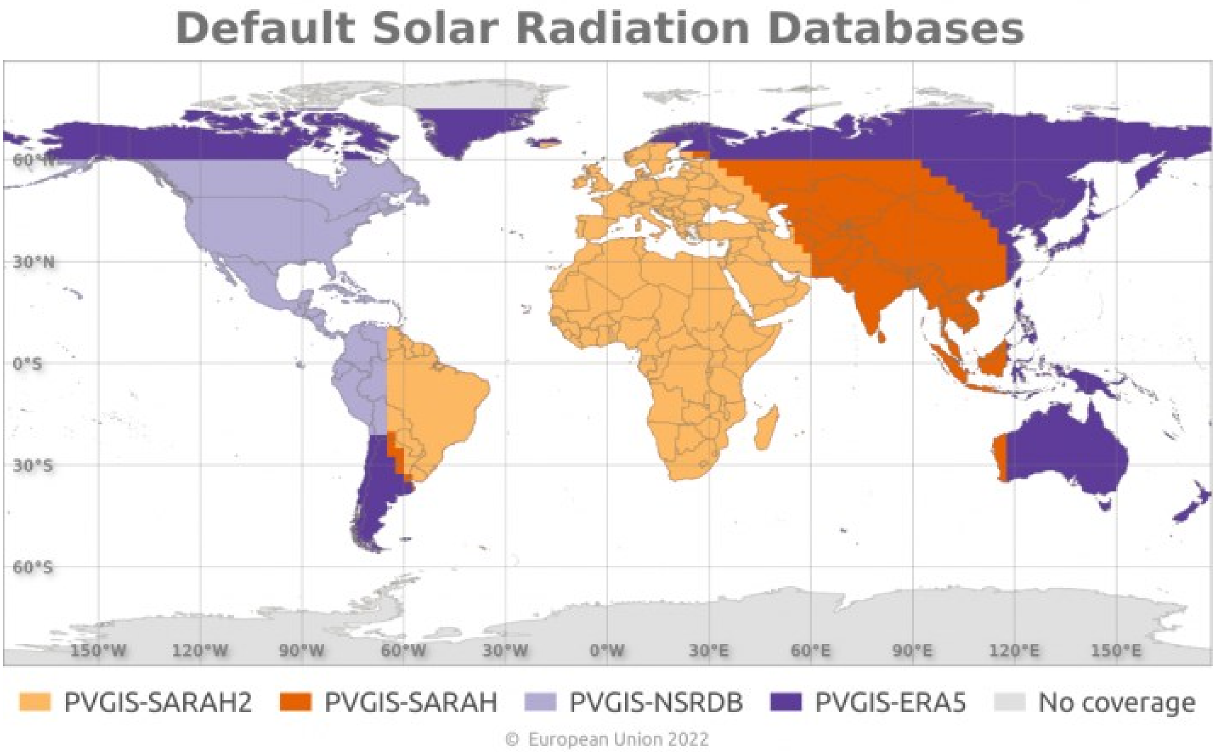

Figure 28 Solar Radiation Databases in PVGIS 5.2 [79]

In general, PVGIS is user-friendly and features a powerfully detailed database that, allowing a professional use (Figure 29).

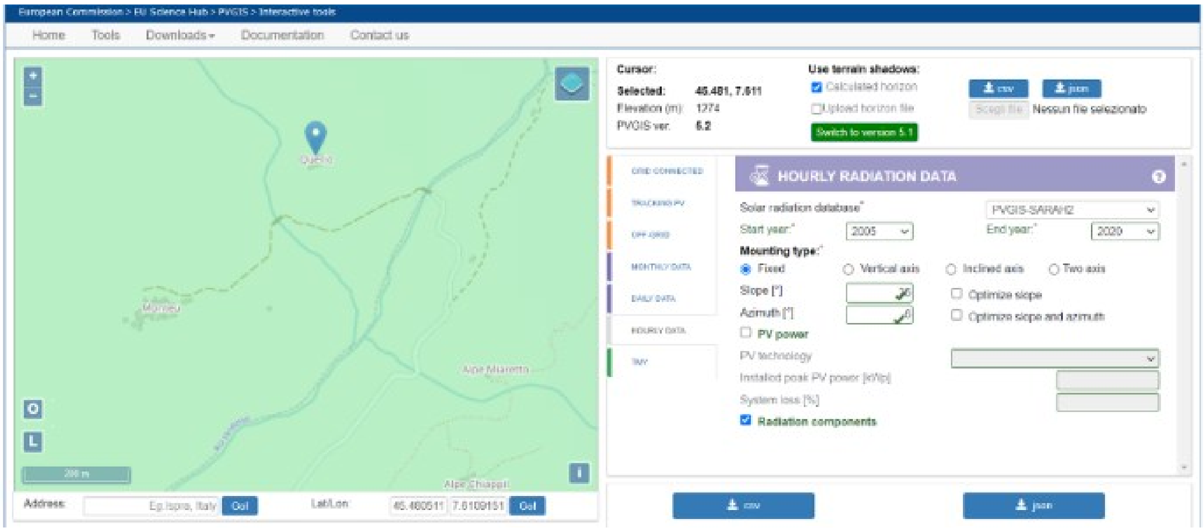

Figure 29 Screenshot of PVGIS [80]

Regarding the application object of the thesis, the path followed to obtain the solar irradiance data was similar the one previously described for PVWatts, requiring the location of interest, that was set to Querio, and the inclination and azimuth of each set of panels. One notable difference between the two tools relies in the south direction: in PVGIS it corresponds to 0°, while in PVWatts to 180°.

Another significant distinction is related to output of the hourly solar irradiation data, which is presented not as an average year but as time-series data [81], consequently requiring a conversion into an averaged format. To perform the most precise analysis, the largest amount of data available was selected, covering the period between 2005 and 2020, that was then converted into an average year.

Differently from PVWatts the output data from PVGIS features a useful differentiation of the components of the radiation impacting the panel's surface [W/m^2], that was in fact divided in:

- G_b direct, representing the solar radiation intercepted unimpeded in a direct line from the sun;
- G_d diffuse, corresponding to the radiation scattered by atmospheric constituents on its path from the sun;
- G_r ground-reflected, which is the radiation reflected from surface features.

The elements of our interest are the direct (G_b) and the diffuse radiations (G_d) [81], and so their summation relative to the same panels' configuration previously exposed was used to perform the calculation of the total energy produced.

As a final result, considering the SunPower Maxeon3 430, was obtained the estimated value of 47.66 MWh/year of energy produced, a value sensibly higher (+12.8 %) than the one obtained with PVWatts, and smaller (-5.8%) than the one estimated by SolarEdge-Designer.

10.4 Comparison

To further understand the differences between PVWatts and PVGIS was analysed the article *A Comparative Evaluation of Photovoltaic Electricity Production Assessment Software* (*PVGIS, PVWatts and RETScreen)* that performed a comparison between 24 months of real measurements of existing PV parks installed in Greece and the relative estimations by PVWatts, PVGIS and RETScreen. [75]

The study considered three different applications in distinct spots of Greece:

- a PV installation of 9.6 kW in the area of Athens;
- a PV open field array of 105.6 kW in Asopos, Lakonia (Southwest Greece);
- a 98.4 kW array featuring a 2-axis tracker in Amyntaio, Florina (Northwest Greece).

In the end PVGIS proved to be the most accurate tool, providing estimations closest to the real measures for each case. In fact, its averaged annual deviations from the measured values were around 3%, significantly smaller than those of PVWatts (~8%) and the Canadian RETScreen (~9.6%). This result is likely related to the use of more precise databases for the specified location: PVGIS was able to calculate the energy produced from the exact location while PVWatts used the general location of Athens for all the installations. [75]

In conclusion, both PVGIS and PVWatts are rather convenient tools for untrained users, with easy to fill in forms and relatively simple to obtain and comprehend results that are quite accurate on an annual basis.

The strength of PVWatts is mainly confined within the U.S. borders, while PVGIS is strongly validated for Europe and seems to generally estimate the produced energy with higher accuracy with small variations from real data. [75] So, from the analysis performed, the most reliable tool to estimate the solar irradiance in Querio is PVGIS.

11 BIPV

An effective approach to integrating renewable energy into buildings with high value involves the use of Building Integrated PhotoVoltaics (BIPV), a technique that consists in incorporating photovoltaic modules into the external envelope of the buildings, be it the roof or the façade. In doing so, the modules serve a dual-purpose functioning both as outer building material and as power generators. This innovative solution not only enhances material and electricity cost savings but can also introduce architectural interest to the buildings.

In fact, differently from the more commonly used Building Applied Photovoltaics (BAPV), which involves the usual fitting of the modules onto existing surfaces via superimposition, Building Integrated PhotoVoltaics (BIPV) goes a step further by replacing traditional construction element with materials incorporating solar modules. This gives to the architectural product an active function, and, because of the avoided cost of conventional construction materials and labour, the overall expenses of the application are reduced, and the life-cycle costs can be significantly smaller than the ones of traditional photovoltaic applications. [82]

An interesting case study regarding applications of BIPV is represented by the Chalet La Pedevilla in Marebbe (BZ), a mountain chalet immersed in a conservation area characterized by the impressive scenery of the South Tyrol dolomite mountain ridges. It is a virtuous example of integration of photovoltaic technology with the tradition because in its design melt the traditional South Tyrolese farm design inspired by the local *Paarhof* with the use of a photovoltaic system. [83]

Figure 30 Chalet La Pedevilla [83]

The BIPV panels, as is noticeable from Figure 30, are placed on the roof as if conventional roofing components, blended into the dark painted oak wood boards integrated on the wooden roof of the chalet.

This photovoltaic system is estimated to produce 6,592 kWh /year and is composed of twenty-five Aleo Solar S_79 SOL photovoltaic modules mounted with special aluminium Solrif profile frames and fixed to the substructure with special mounting clamps, to obtain a roof covering able to optimally replicate the classical one and assure weather tightness. In particular, the system can cover the building's electric consumption for the HVAC and 80% of the produced photovoltaic electricity is self-consumed, contributing with other energy-efficient building solutions to make the Chalet a *nZEB* (nearly Zero-Energy Building). [83]

The example of the Chalet La Pedevilla highlights the high potential in energy efficiency and aesthetic quality reachable when integrating renewable energy resources in applications located in mountainous conservation areas. It also suggests that with care for details, sensitivity to the surroundings and a careful design, BIPV can represent an incredibly satisfactory solution for restoration.

Another example of the application of BIPV is the Intesa Sanpaolo Headquarters skyscraper in Turin, where the southern façade (Figure 31) is covered by 1600 m^2 of BIPV *LOF Stone Elegance* solar cells. The skyscraper is 167.25 m high and is an example of green architecture: in fact, in normal operating conditions the whole complex does not emit any pollutant. To reach this ambitious objective, on top of the BIPV panels, the building features a HVAC system that uses groundwater, an illumination system almost totally LED, and on the eastern and the western facades has a "double skin" of steel and glass able to open in a way to optimize temperature and lighting of the internal environments. [84]

Figure 31 Southern façade of the Intesa Sanpaolo skyscraper (06/03/2024)

Thanks to the numerous environment-oriented features, the Intesa Sanpaolo building obtained the LEED platinum level of certification from the Green Building Council, the most authoritative international body to rate buildings according to their energy and environmental performances. [84] The example of this Turinese building proves that the application of BIPV and other virtuous green applications is doable also when facing ambitiously big projects, and therefore suggests that also challenging applications like the ones related to landscape and heritage protection contexts are possible.

11.1 Aleo Solar S_79 SOL-T 315

The procedure performed using the SunPower Maxeon3 430 in the previous chapter was followed also considering the BIPV Aleo Solar S_79 SOL-T *315* panels, which, being integrated in the roofs, can give better aesthetic results.

The irradiance data used was the same as for the other estimation, with the only differences in the calculations related to the panel's efficiency and size, that respectively amounted to 18.2 % and 1.71 m^2. [85] The different size of the panels implied a distinct fit in the roofs and therefore the configuration on the roofs obtained in SolarEdge Designer are slightly different. In fact, the total number of panels using Aleo Solar S_79 SOL-T *315* panels is of 78 (Table 8), two more than using SunPower Maxeon3 430.

Table 8 Comparison between configurations with MAXEON and Aleo Solar panels

ROOF_ID	N. of modules using SunPower Maxeon3430	N. of modules using Aleo Solar S_79 SOL-T *315*
1	8	8
2	3	4
3	6	6
4	6	6
5	2	2
6	8	8
7	6	6
8	5	5
9	8	8
10	6	6
11	10	11
12	8	8

A visual representation of the described configuration in SolarEdge-Designer is reported in Figure 32, together with the production estimated by the tool, which amounts to 37.11 MWh.

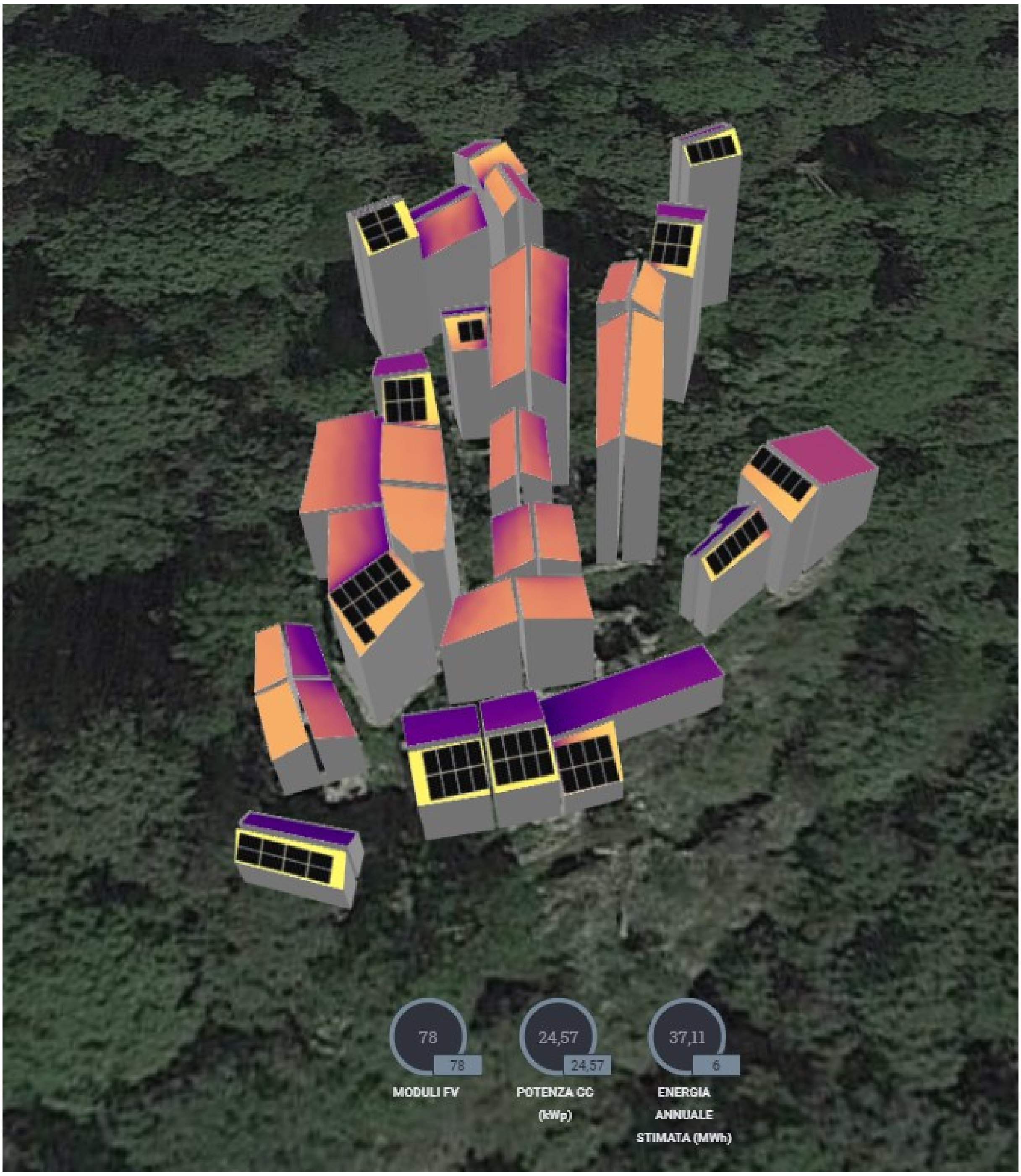

Figure 32 SolarEdge estimation considering Aleo Solar S_79 SOL-T panels [73]

Then, the following formula is used to compute the expected values of produced energy by the roofs covered by the BIPV panels:

$$E_{roof} = I * A_{pan} * n_{pan} * \eta$$

With the following parameters:

- area of one panel (1.71 m^2 [85]);
- efficiency of the photovoltaic panel (18.2 % [85]);
- number of panels on the considered roof (Table 8).

Obtaining that the total energy production in the town, estimated based on PVGIS irradiation data, amounted to 35.81 MWh. In conclusion, considering the total demand of the town of 45.65 MWh, the configuration utilizing *Aleo Solar S_79 SOL-T 315* panels did not meet the required annual energy needs.

11.2 Solitek BLACKSTAR 420 W

To gain a comprehensive understanding of potential Building-Integrated Photovoltaic (BIPV) solutions available in the market was considered a panel manufactured by Solitek, the business that also produces the Solrif structure used to integrate BIPV panels to the roofs.

The chosen model was the BLACKSTAR 420 W, a new EU-made solar panel with high efficiency thanks to its innovative bifacial design for optimal energy capture, durability, and an appealing aesthetic.

The panel has an efficiency of 21.51% and an area of 1.953 m^2 [86] and, following the same calculations done above and considering the same 76 panels configuration used with SunPower Maxeon3 430, was obtained an annual energy production estimation of 46.53 MWh considering PVGIS' irradiation data.

This panel therefore constituted an interesting option because of its high performance and aesthetic value, particularly in its compatibility with the Solrif roof-panel integration structure. [87]

12 Electricity management

The following section focuses on the crucial topic of obtaining a sustainable energy strategy for Querio, concentrating on energy storage and management using representative hourly energy surplus values. The final goal is to formulate a resilient plan that aligns with the town's unique requirements.

12.1 Inverter

Fundamental components for the operation of a photovoltaic system are the inverters: devices able to transform direct current into alternate current. The proper sizing of these devices was based on the maximum total power of the system, which, considering the configuration of the SunPower Maxeon3 430, amounted to (430 W * 76 panels) 32.68 kW.

The best option for the application in Querio is to use hybrid inverters that can both sell the produced electricity to the national grid or send it to batteries for storage and self-use. A device able to satisfy the described needs is the Huawei SUN2000-5KTL-L1, which can cover 5 kW of power per unit [88] and costs about 850 €. [89]

Finally, to align with the total power produced in the SunPower Maxeon3 430 configuration, was considered the presence of at least 7 inverters.

12.2 Surplus

The method followed to analyse the optimal size of the energy storage was based on the surplus values obtained hourly, which correspond to the difference between the energy produced by the panels and the town's consumption. In particular, throughout the whole average year the total annual production of electrical energy considering SunPower Maxeon3 solar panels was of 47.66 MWh, while the total consumption amounted to 45.65 MWh.

The surplus is an indicator of the energy not immediately used, and so available for other purposes like being stored for self-use or injected in the national grid to obtain revenues, while the deficit represents the situation when the energy consumption exceeds the generated amount. The discrepancy of energy is reported in Figure 33 as the cumulative difference between produced and consumed energy.

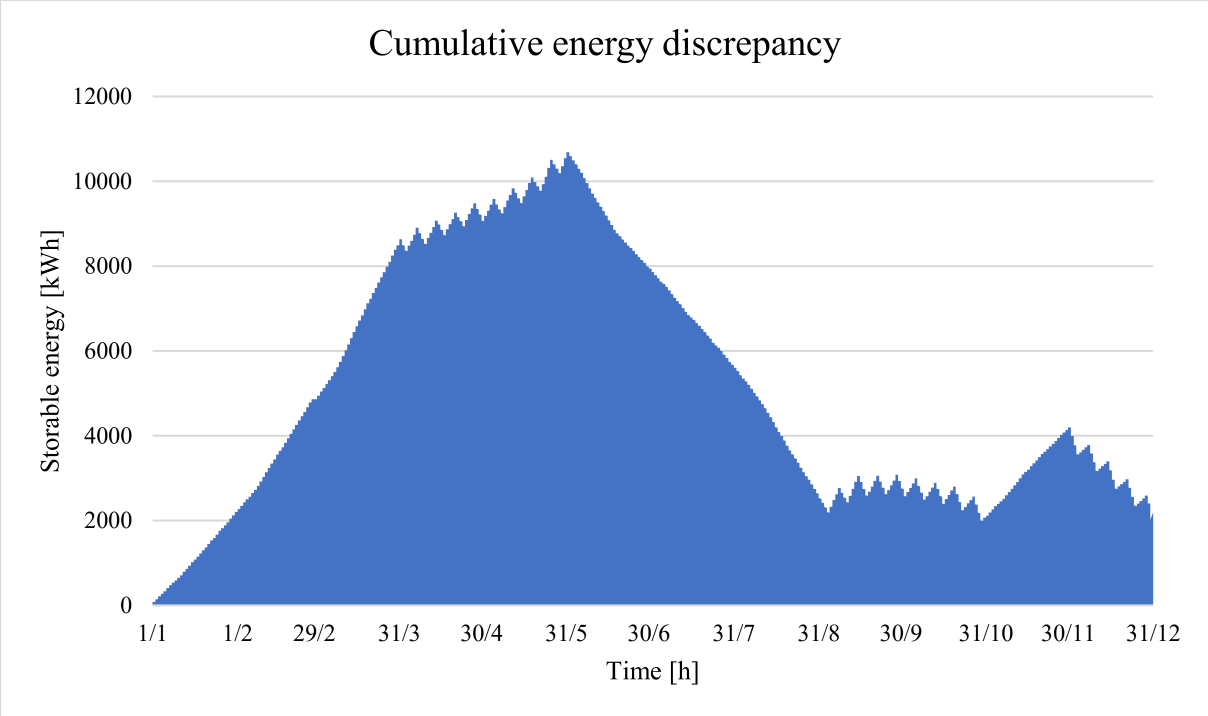

Figure 33 Cumulative energy discrepancy

This value represents the amount of energy that could potentially be stored.

From the graph a strong increasing trend of available energy was noticeable in the first months of the year. It was related to the panels producing energy without any consumption because of the closing of the diffused hotel until the first weekend of April.

Between April and June was present a growing trend denoted by frequent ups and downs associated with the opening of the hotel only between Friday and Sunday.

Conversely, between June and August an evident decreasing trend could be found, it was characterized by an energy consumption higher than the production, as the diffused hotel was open every day.

Then, September and October presented a mostly stable behaviour with ups and downs related to consumption concentrated in weekends, and a good electricity production.

Followed a growing trend in November linked to the closing of the hotel.

Finally, in December the cumulative surplus tended to decrease because of the weekends' consumptions and the low energy production related to reduced irradiance.

To give a more precise representation of the foreseen scenario, was also reported the difference between the daily surplus and the daily consumption not immediately covered by the photovoltaic energy (or *deficit*), as show in Figure 34. This graph illustrates the daily contribution to the energy balance: a positive value indicates that more energy was produced than needed during the day, while a negative value signifies that the energy demand throughout the day was higher than the generation.

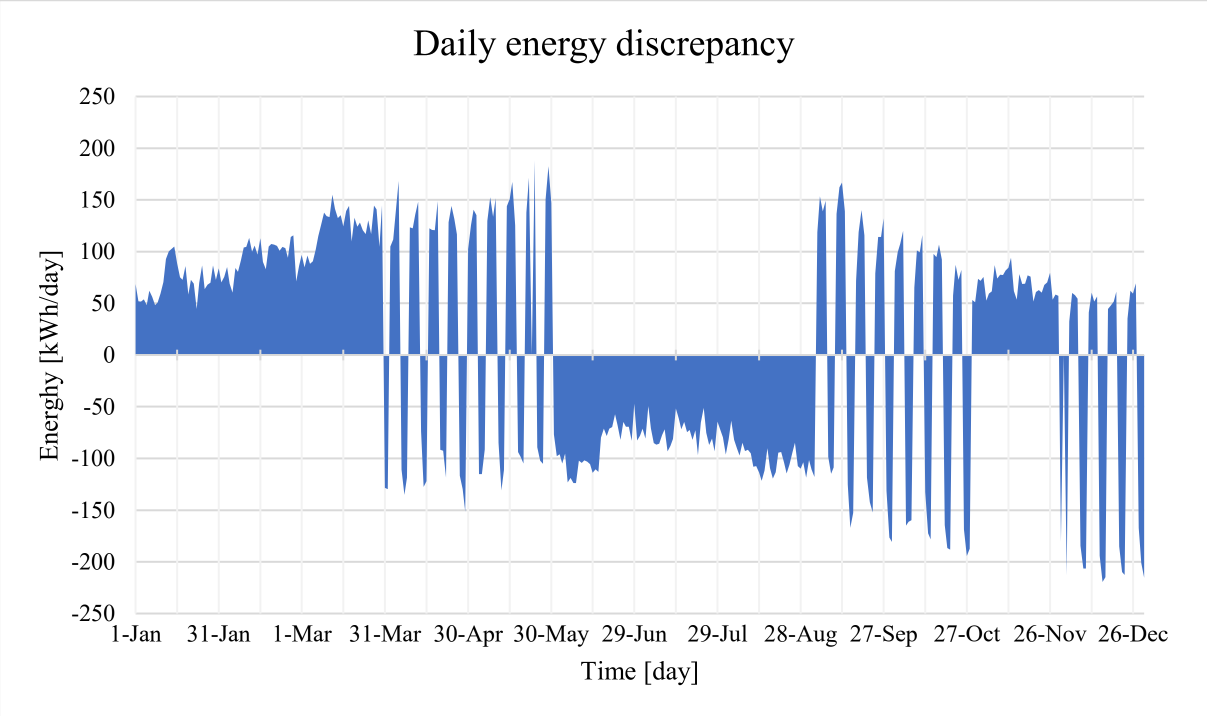

Figure 34 Daily energy discrepancy

The graph confirmed the previously described positive contribution of the closing days, while also highlighting the negative impact of the opening periods. Additionally, the effect of the solar pales was evident, as the daily demand in spring and summer is visibly reduced.

From the obtained values was noticed that the day with the highest value of discrepancy was the 24th of May, a closing day for the hotel characterized by high solar irradiance. In that day 212.45 kWh/day of electricity were produced in excess to the demand. In Figure 35 is reported the trend of the energy production and estimated average consumption throughout the 24th of May.

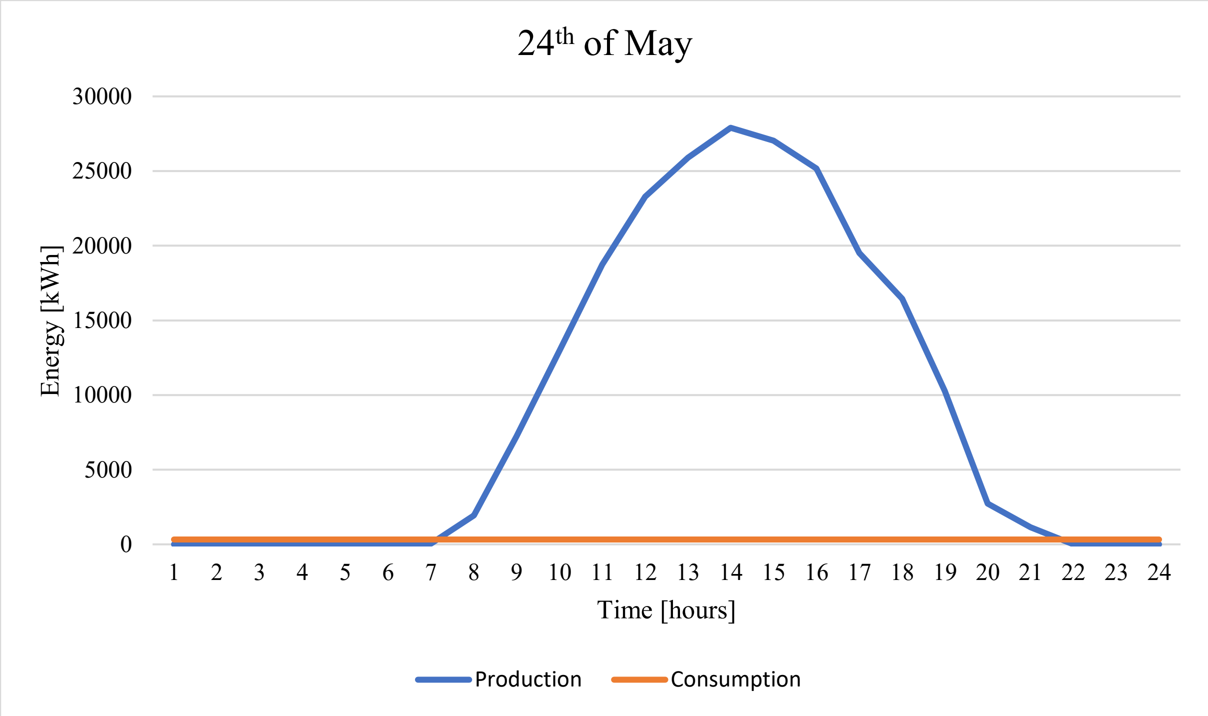

Figure 35 Energy balance of the 24th of May

From the graph was noticeable the big difference in production and consumption, which, as predictable, was higher in the early afternoon. The excess energy produced could be injected in the grid or stored.

The lowest value of the discrepancy between surplus and excess consumption occurred on December 2nd, a winter opening day for the diffused hotel, characterized by a net daily request of energy of -222.03 kWh.

In Figure 36 is represented the difference between the produced energy and the estimated average electrical consumption of opening days.

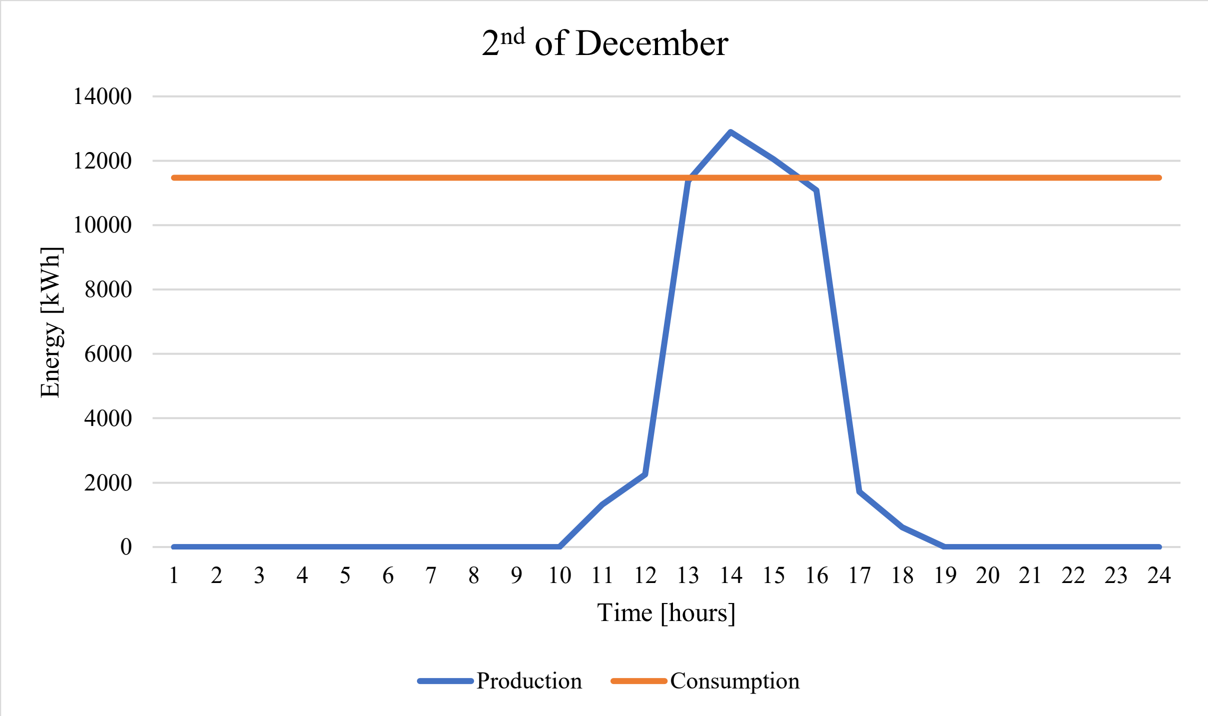

Figure 36 Energy balance of the 2nd of December

It was noticeable that for the biggest part of the day the production curve was below the production one, indicating that energy should be extracted from other sources, like the grid or a storage system.

12.3 Batteries

Aiming to analyse the different scenarios, was searched the possibility to maintain the town off-grid, and so not extracting energy from the national electrical network using batteries for its storage. To do so were retrieved the values of highest and lowest storable energy (Figure 33) after the opening of the hotel and calculated their difference, which corresponds to the lowest amount of energy necessary to keep the town off grid over the average year. These values corresponded to 10687 kWh (on the 31/05) and 1987 kWh (on the 30/10). Their difference is equal to the substantial amount of 8700 kWh.

The batteries considered for the analysis were the Huawei LUNA2000-15-S0 that use LFP cells, cost about 7000 € per unit [90] and can easily be paired with the previously described inverters. They can store up to 15 kWh each and provide energy at a maximum power of 5 kW, while, when connected in parallel, their capacity doubles reaching up to 30 kWh. [91]

Considering these batteries in the attempt of keeping Querio off grid would imply installing 580, a quantity not sustainable both for aesthetic impacts and cost, that in this case was estimated to the unfeasible amount of 4060000 €.

A projected configuration for the case of Querio foresees batteries distributed in some buildings of the town to partially cover the local energy needs. Also, in this case the energy surplus not storable would be sold to the national grid generating revenues, while, to meet on-site demand during high consumption times, electricity would also be purchased from the national grid.

A design approach consisted in dimensioning the storage system considering the day with the highest demand in excess to the production which, as stated above, was the 2nd of December. The relative net demand amounts to -222.03 kWh/day and, to be supplied by batteries, 148 Huawei LUNA2000-15-S0 would be necessary. This solution still was unapplicable because of the Borgata's preservation objectives and because of the big investment required, that would be of 1036000 €.

Another possible strategy was considering the daily demand of a closing day, and so related only to the external lighting and the water fountain's pump, that amounts to 7.8 kWh/day. Therefore, one storage unit with a capacity of 15 kWh complied the request, costing 7000 € and covering the small demand for numerous days of the year. Anyway, this solution didn't have a substantial impact on economical savings.

In conclusion, batteries turned out to be not compliant with the needs of the town, underlying the need to consider exchanging electricity with the national grid. In fact, the amount of energy necessary to keep Querio independent from the national net is high, and storages of such big size are difficultly integrated in contexts with significant heritage and landscape value.

In the following section was in fact explored the possibility of exchanging electricity with the national grid, not considering the presence of batteries.

12.4 Exchange with the grid

A hypothesis to handle the excess energy produced by the diffused hotel was to operate the *on-site exchange* managed by GSE (*Gestore dei servizi energetici*), which is a form of self-consumption that allows offsetting the electricity produced and fed into the grid at a certain moment with that taken and consumed at a different time. [92]

Exchanging electricity on-site could bring economic and environmental advantages and is linked with the definition of a renewable energy community: an association that generates and shares cost-effective renewable energy autonomously, reducing CO_2 emissions and energy waste.

The economical balance relative to this solution was performed using the following unitary costs:

- 0.25 €/kWh relative to the standard consumption of energy from the national grid; [93]
- 0.15 €/kWh as an average revenue from the energy withdrawn from the net after being previously introduced; [93]
- 0.08 €/kWh for the surplus energy introduced in the network. [93]

The annual self-consumption, considering the utilization of Maxeon3 430 panels, was estimated at 18024 kWh by calculating the sum of the lowest values between each hour's consumption and production.

Then was computed the amount of energy injected in the net as the difference between the total energy produced and the energy produced by the panels immediately consumed by the diffused hotel (or "self-consumed").

$$prod - selfcons = 47658 - 18024 = 29634\ kWh/year$$

The annual energy extracted from the national network was instead obtained as the difference between the total consumed energy and the self-consumed.

$$cons - selfcons = 45653 - 18024 = 27629\ kWh/\text{year}$$

While the exceeding energy injected and not extracted from the national net was calculated as the difference between the annual production and consumption.

$$prod - cons = 47658 - 45653 = 2005\ kWh/year$$

Subsequently it was possible to estimate the savings and revenues coming from the installation of the system. In the following formula is reported the calculation relative to the revenues linked to the energy withdrawn from the net after being previously injected. The value of the annual energy extracted from the national grid is multiplied times the average revenue from the energy withdrawn from the net after being previously introduced. [93]

$$Revenues_{withdraw} = 27629 * 0.15 = 4144.34\ \text{€/year}$$

Then, the savings relative to self-use were calculated as the self-used energy multiplied by the unitary cost that would otherwise have been paid to get a unit of energy from the grid. [93]

$$Savings = 18024 \; * 0.25 = 4505.94 \text{ €}/year$$

Finally, were obtained the revenues relative to the excess energy injected in the net as the product between the excess energy injected not withdrawn from the national net and the respective unitary revenue.

$$Revenues_{excess} = 2055 \; * 0.08 = 160.42 \text{ €/year}$$

The sum of these values represented the economic benefit linked with the installation of the solar photovoltaic system, which corresponded to 8810.70 €/year.

Finally, considering the annual cost of maintenance the benefits linked with the installation of the solar photovoltaic system must be reduced of 600 €/year.

$$Benefit = 8811 - 600 = 8211 \text{ €}$$

12.5 Economic analysis

Moving to the estimated costs considered for the creation of the system, the examined expenses were related to the panels, inverters, cables, labour, maintenance and the connection to the national net, as follows:

- 76 SunPower Maxeon3 430 panels costing 550 € each; [94]
- 7 Huawei SUN2000-5KTL-L1 hybrid inverters costing 850 € each; [89]
- 320 metres of wirings, estimated to cost 15 € per meter;
- Electrical connection to the grid, estimated to 1000 €;
- Labour cost estimated as the 5.5% of the total cost, and so equal to 2767 €; [95]
- Maintenance costs estimated 600 €/year. [96]

Leading to a total starting investment of 56459 €. The value was then reduced thanks to the non-repayable contribution of 40% of the total costs provided by the Italian government as incentive to the creation of new renewable energy communities [97], and therefore the estimated expenses became 33897 €.

To obtain the payback time of the investment it was performed a division between the total initial cost for the yearly benefits.

$$Payback\ time = \frac{33897\ \text{€}}{8211\ \text{€/year}} = 4.13\ years = 1507\ days$$

The return time value underscores the economic viability of the analysed photovoltaic system.

13 Aesthetic improvements

Given the central importance of preserving historical and heritage sites, this chapter focuses on existing and innovative applications aimed at improving the aesthetic effect of the solar panels and their performances.

In this context, the jurisprudence concerning the installation of renewable energy production facilities becomes pivotal when considering their introduction in complex contexts like the one under consideration in the thesis. The normative qualifies these installations as public utility works and therefore the Italian Government generally encourages them for environmental protection purposes, but in some situations the required analysis on their adequacy with the surrounding context leads to contrasting outcomes in legal judgments. In some cases, in fact, landscape authorization for solar panels may not be granted despite the national interest in renewable energy, with common rejections not always clearly justified. [98]

This underscores the importance of promoting better solutions aimed at minimizing the impacts on landscape interests. To do so, the methods followed nowadays to mitigate the visual impact of photovoltaic panels are mostly related to:

- hiding them in non-visible surfaces;
- masking them in the context in which the panels are located. [4]

13.1 SunPower Maxeon3 and SUNSPEKER wrapping

This focus regards the solution of masking the solar panels using special wrappings aimed at covering the panels and camouflaging them in the context in which they are located.

SUNSPEKER is a Turinese start up that produces fully recyclable graphic covers for photovoltaic applications that make the panels impact less aesthetically, while maintaining a very high efficiency energy production (~80% of the initial efficiency). [99]

An application is shown in Figure 37, where is evident how, thanks to the wrappings, the photovoltaic system smoothly blends with the surroundings, featuring intricately designed leaves.

Figure 37 Application of SUNSPEKER covers [100]

In this way “the photovoltaic modules adhere to Italian regulations protecting the landscape and artistic heritage in Italy, thanks to their aesthetic characteristics. Consequently, they facilitate the installations where it would normally be challenging”, as emphasized by Fabrizio Chiara, CEO of SUNSPEKER. [100]

In the case of Querio, the pattern would replicate the typical stone slabs, known as *“lose”* in Piedmontese. This material is locally extensively used for housing roofing and constitutes an important part of the architectural identity of the region. (Figure 38) It is also valued for its thermal and insulating efficiency, as well as its remarkable resistance and durability. [101]

Figure 38 "Lose" stone slabs roof [101]

Considering the predicted efficiency of the panels after the laying out of the film the total annual energy production was of 38.13 MWh, differently from the 47.66 MWh of the same configuration without covers.

Regarding the reduced energy production of the wrapped solar panels, the amount of total self-consumed energy decreased from 18.024 MWh to 16.98 MWh, while the energy extracted from the grid increased to 28.67 MWh from the 27.629 MWh of the condition without covers. Finally, the total annual surplus was of -7.53 MWh instead of +2.005 MWh without covers, representing a reversal in the trend, with a net annual extraction from the grid.

The economical balance pertinent to the solution was performed using the following unitary costs:

- 0.25 €/kWh relative to the standard consumption of energy from the national network; [93]
- 0.15 €/kWh as an average revenue from the energy withdrawn from the net after being previously introduced. [93]

Then the annual economic balance for the operation of the panels with the additional aesthetic wrapping resulted in a total saving of 6665 €/year. After deducing maintenance costs, the net savings amounted to 6065 €/year.

Then, considering the same system previously described with the addition of 76 SUNSPEKER layers with a supposed unitary cost of 100 €, the total price of the system amounted to 64513 €, that, reduced of 40% thanks to the Italian Government's incentive [97], became 38708 €.

To estimate the payback time was finally performed the following calculation:

$$Payback\ time = \frac{38708\ €}{6065\ €/\text{year}} = 6.38\ years = 2329\ days$$

Therefore, the solution with the added layers implied a substantial payback time increase of 2.25 years, which anyway is reasonable considering the importance of providing a good aesthetic result, limiting the impact on the original aspect on the buildings and simplifying the process of acceptance and authorization of the system.

13.2 BIPV Aleo Solar

To check the feasibility of as many options as possible was checked also the functioning of the system using Aleo Solar S_79 SOL-T 315 panels integrated with the houses' roofs.

The estimated value of produced energy using PVGIS irradiation data amounts to 35.81 MWh/year as previously calculated, a value not able to satisfy completely the town's yearly demand of 45.65 MWh. Anyway, the installation of this system could have a positive impact both on economic and environmental sides thanks to on-site exchange of the produced energy not immediately used, as shown also in the previous paragraphs.

Considering the estimated solar production matched with the consumption of the town were obtained the following values:

- self-consumed electricity: 16.63 MWh;
- electricity extracted from the grid: 29.02 MWh;
- total annual surplus: -9.84 MWh.

These values were then used to compute economical evaluations using the same energy costs reported in the previous paragraph [93], obtaining a yearly saving value equal to 6050 €.

Then the installation costs were computed as described earlier, with the modification of taking into account the following:

- 78 Aleo Solar S_79 SOL-T 315 panels, each estimated to cost 250 € and generate a total power of 24.57 kW;
- 5 Huawei SUN2000-5KTL-L1 hybrid inverters costing 850 € each. [89] Their number is lower than in the previous configuration because of the decreased power of the system;
- 1 Solrif BIPV integration structure in every roof covered by panels, with an estimated cost of 60 €/m^2 that, after estimating in Autocad the covered area as 200 m^2, gives a total of 12000 €.

The final expenses amounted to 43835 €, but after the 40% discount [97] became 26301 €. Finally, the obtained time of return of the investment is:

$$Payback\ time = \frac{26301€}{5465\ €/\text{year}} = 4.81\ years = 1757\ days$$

13.3 BIPV Solitek BLACKSTAR 420 W

The BIPV technique was also followed with Solitek BLACKSTAR 420 W panels, implementing them with the roof using the Solrif BIPV structure and producing 46.53 MWh/year as previously calculated.

Following the same procedure as before, was calculated that:

- the amount of energy injected in the grid amounted to 28.60 MWh/year;
- the annual energy extracted from the national network was 27.73 MWh/year;
- the exceeding energy injected and never extracted from the national network was equal to 874 kWh/year;
- the annual revenue from the installation of the system considering the savings related to self-consumption and the ones relative to the exchanges with the net was 8710 €/year, that, subtracting the costs related to maintenance became 8110 €.

Subsequently, the costs relative to the installation were estimated, considering the following differences from the previous case:

- 76 Aleo Solar S_79 SOL-T 315 panels, each estimated to cost 250 €;
- 7 Huawei SUN2000-5KTL-L1 hybrid inverters, priced at 850 € each. [89].

Then, the total cost, comprehensive of panels, the Solrif structure, inverters, wiring, connection with the national grid, labour cost and maintenance, amounted to 45903 €. Finally, applying the 40% discount provided by the Italian Government [97], the total cost reduced to 27542 €.

In conclusion was obtained the payback time with the following formula:

$$Payback\ time = \frac{27542€}{8110\ €/\text{year}} = 3.40\ years = 1240\ days$$

13.4 BIPV Solitek BLACKSTAR 420 W and SUNSPEKER wrapping

Aiming at testing the most effective solution to produce renewable energy while minimizing the visual impact, was explored the feasibility of implementing both techniques exposed in this chapter and dedicated to achieving the best aesthetic result. Specifically, the solution involves the integration of solar panels into building elements (BIPV) and the use of adhesives (or "skins") with patterns designed to camouflage the systems within the environmental context.

Therefore, the following implementation hypothesis was performed considering SUNSPEKER wrappings covering Solitek BLACKSTAR 420 W panels inserted in the building's roofs through a Solrif frame. The estimated annual production of this configuration is of 37.22 MWh, representing 80% of the condition without the wrapping.

Then, following the same process previously exposed were obtained the following values:

- energy injected equal to 20.37 MWh/year;
- annual energy extracted from the national network of 28.80 MWh/year;
- exceeding energy extracted the national grid equal to 8.43 MWh/year.

Finally, the yearly revenue from the installation of the system was calculated using the same unitary costs of the paragraphs above obtaining 6425 € that, subtracting 600 €/year related to maintenance costs, became 5825 €/year.

Subsequently, the costs relative to the initial investment were estimated as reported in the following list:

- 76 Solitek BLACKSTAR 420W panels costing 260 € each; [102]
- 7 Huawei SUN2000-5KTL-L1 hybrid inverters costing 850 € each; [89].
- 320 metres of wirings, estimated to cost 15 €/m;

- electrical connection to the grid, estimated to 1000 €;
- labour cost estimated as the 5.5% of the total cost, and so equal to 4429 €;
- 76 SUNSPEKER covers costing 100 € each.

The total cost reached 53921 €, but with the 40% incentive provided by the Italian Government [97], it was reduced to 32353 €.

Finally, the payback time was calculated using the following formulation:

$$Payback\ time = \frac{32353€}{5825\ €/\text{year}} = 5.55\ years = 2027\ days$$

This resulted in a value higher than the ones obtained for the other configurations.

13.5 Comparison and environmental considerations

The configurations discussed in this chapter underscores the substantial potential for implementing photovoltaic technologies in the analysed setting, proving that renewable solutions can be adopted even in complex environments.

Photovoltaic systems were proven useful in enhancing energy security, promoting economic development, and, most importantly, mitigating emissions of greenhouse gases. Generating energy from the sun is a means to avoid relying totally on the national grid, which in Italy is mostly fuelled using natural gas (Figure 39) and therefore emits significant amounts of CO_2. [103]

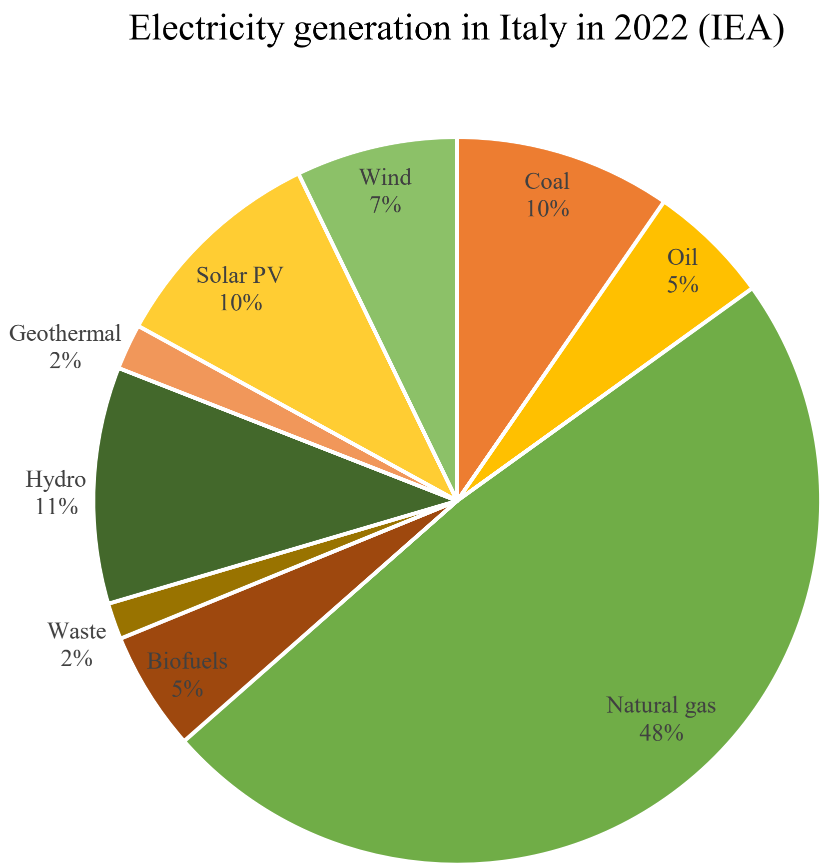

Figure 39 Electricity generation in Italy in 2022 (IEA) [103]

In this context, a comprehensive comparison of the environmental performances of the presented solutions is facilitated by taking into account the 2023 average CO2 emissions per kWh of electricity from the Italian national grid, recorded at 319 g CO_2eq/kWh. [104]

The quantities of emissions avoided for each configuration are reported in Table 9, together with key parameters crucial for evaluating economic and aesthetic performances. These three aspects are of pivotal importance in the analysis of applications like the ones presented above.

Table 9 Economic, environmental and aesthetic performances of the considered configurations

CONFIGURATION	ECONOMIC	ENVIRONMENTAL	AESTHETIC
	Payback time [years]	Avoided emissions [tons of CO_2eq]	Masking [1-3]
SunPower Maxeon3 430	4.13	15.20	1
SunPower Maxeon3 430 + SUNSPEKER film	6.38	12.16	2
Aleo Solar S_79 SOL + SOLRIF (BIPV)	4.81	11.42	2
BLACKSTAR 420 W + SOLRIF (BIPV)	3.4	14.84	2
BLACKSTAR 420 W + SOLRIF (BIPV) + SUNSPEKER film	5.55	11.87	3

The table above underlines that each configuration comes with its set of advantages and drawbacks. For each specific use case, conducting comprehensive analyses is essential to strike a balance among the most relevant objectives and requirements. It is reassuring to note that, driven by technological advancements, there is optimism that each of these aspects will yield even better results in the near future. [105]

Conclusion

The central theme of this thesis revolved around the use of renewable energy and energy-saving systems in a context of historical and landscape preservation. Specifically, it focused on the complex task of integrating the adoption of such systems in Querio, a small historic village in the Alps between Turin and Aosta that has been significantly depopulated, remaining uninhabited for 60 years. Special attention was given to respecting the identity and character of the environment, considering that, as suggested by the analysed literature, it should be preserved as closely as possible to the original.

The first part of the thesis described the institutions, regulations, and initiatives that define and protect places with cultural and landscape value, emphasizing that recent efforts are driven by a commitment to involve buildings with historical and landscape value in actively addressing the urgent issue of climate change.

Subsequently, the phenomenon of depopulation in the Italian rural area considered was explained, and the recovery project was presented, outlining the reconstruction of the village from its current ruins.

For the village's recovery, the choice was made to follow the model of the "diffused hotel": a hospitality system that has proven successful in revitalizing other Italian depopulated villages, and that aims to make the guest feel like a resident. This model avoids strongly altering the unique characteristics of the location and, on the contrary, supports the presence of distinctive elements and, among these, the future village is envisioned to have an ecomuseum and a typical historical bakery.

By combining the model's traits with the unique aspects of the area, the village's hourly consumptions were averaged over a year, translating to requirements of 45.65 MWh/year for electricity and 12.41 MWh/year for heating. Additionally, water use was estimated at 2837 thousand litres/year, but further analysis could be performed, especially regarding the possible implementation of devices attentive to sustainable water use and procurement.

An in-depth analysis was then conducted on possible insulation and heating systems for the village, which are among the main interventions in the redevelopment process of historical buildings. The analysis considered various innovative materials united by a high level of efficiency, sustainability, and proximity to tradition. For instance, the insulation materials analysed have low values of thermal conductivity and are composed of waste materials from local agriculture and livestock.

The exploration of circular economy principles, which involves the potential reuse of waste materials, was also applied to the evaluation of fuel options for heating the village. In fact, the selected option for the heat generation system was based on using chipped wood, a by-product from the numerous sawmills in the area. The system, implemented through a centralized biomass boiler connected to a district heating network, would fulfil the estimated power demand of the village of 37.81 kW with minimal impact on both aesthetics and the environment.

Ultimately, a comprehensive analysis was conducted to meet the energy needs of the village, leveraging a locally abundant renewable resource: solar energy. To estimate the energy budget the average annual irradiance was assessed using and comparing two useful tools: PVGIS and PVWatts. Then, the obtained data was used to estimate the electricity production from different types of panels in different configurations, aiming to meet the annual demand while preserving the village's identity. Indeed, among the various options, particular attention was given to the use of aesthetically unobtrusive systems, such as BIPV or wrappings designed to mask the panels' presence.

The configurations utilizing SunPower Maxeon3 430 panels and Building Integrated PhotoVoltaic SOLITEK BLACKSTAR 420 W panel emerged as the most efficient, respectively yielding 47.66 MWh and 46.53 MWh. Both configurations were also tested with the addition of a SUNSPEKER film, which improved the final result's aesthetic but reduced the efficiency, resulting in respective total annual production of 38.13 MWh and 37.22 MWh.

Then, considering the lags between demand and production, was considered the possibility of using batteries as energy storage systems, but they were deemed too expensive and aesthetically impactful. Therefore, the on-site exchange energy management model was preferred, involving the immediate injection and withdrawal of electricity into and from the grid.

The study, however, does not consider the degradation of solar panels and batteries, which were deemed as not of central importance for the primary research objectives. Also, performances and costs related to the installation of the wrapping films were not available in literature, and therefore were supposed. Nevertheless, these boundaries provide opportunities for future in-depth investigations and refinements of the study.

Finally, the costs associated with the different configurations and the corresponding savings linked to electricity production were considered to draw economic conclusions. It emerged that systems more attentive to the aesthetics of the village were generally more expensive than the others, but that the differences in terms of time of return of the investment were still manageable.

The analysis could be expanded by considering real-case bills to better estimate the consumptions and their distribution throughout days and months, providing a more empirical understanding of the energy needs within the given context, thus increasing the overall consistency of the study.

In conclusion, this thesis has demonstrated the feasibility of employing a range of renewable technologies in complex and vulnerable contexts associated with high historical and landscape value, exacerbated by the challenges of climate change, while indicating the adaptability of renewable energy resources when consciously managed. Significantly, the study also proved that, through an attentive, holistic, and sustainable approach, it is possible to increase the attractiveness and revitalize marginal places, representing the concept of resilience, intended as the ability to adapt and overcome difficulties, turning them into resources.

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