Master of Science program in Architecture For Sustainability

Thesis of Master’s degree

Transformation of rural areas into nearly-zero energy communities - The case village of Toiano in Italy

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Politecnico di Torino

A.Y 2023/2024

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Abstract

To be prepared for the opportunities and challenges presented by the new world, rural areas, especially villages, must adapt as attention gradually shifts to sustainability and energy efficiency. This category's historic conventional villages are distinguished by a large number of historically significant buildings, inadequate transportation and infrastructure, and low levels of energy efficiency. On the other hand, these kinds of villages offer enormous potential for change in the direction of greater environmental sustainability, energy efficiency, and economic vibrancy.

Renovating the village for energy efficiency is relevant not only to mitigate climate change but also to improve the standard of living for residents. In another way, it means bringing life back to forgotten communities and extending a warm welcome to newcomers. By reducing energy use and optimizing the exploitation of renewable resources, villages will gain autonomy, reduce energy costs, and even take a small step toward becoming smart. Such energy-efficient renovations can ensure sustainability and continued vibrancy for these communities, along with the preservation of their cultural and historical significance by maintaining historic details.

This study focuses on the renovation of Toiano village as an example of a rural area, aiming to transform it into a near-zero energy community by adhering to Italian legislation. The primary objective is to enhance the energy efficiency of buildings, with a particular emphasis on reducing the thermal energy required for heating and cooling. To achieve this, CitySim Pro will be utilized as the simulation tool to model and optimize energy consumption. Photovoltaic (PV) panels will serve as the main source of renewable energy, supporting the village's transition to near-zero energy status. The proposal and master plan of the project will be presented in two alternatives.

The achievement of near-zero energy in a village requires consideration of several complementary issues within the energy infrastructure. Improvement of building infrastructures for insulation and purposes of heating and cooling, installation of complementary renewable energy systems such as photovoltaic panels or wind turbines, and education on the use of sustainable practices like energy-efficient appliances are means to do so, while smart grid technologies are a means to achieve that goal. Further, unique village traits should be reflected upon so that energy performance enhancement is not done at the cost of the cultural and architectural heritage that defines the community.

Key words: nearly-zero energy village, smart village, energy efficiency, urban energy simulation

Dedicated

To my dearest family, your unwavering support and endless encouragement have been my greatest source of strength. Despite the distance that separates us, your love has remained a constant presence in my life, guiding me through every challenge. This achievement is as much yours as it is mine, and I am forever grateful for the love and guidance you have provided me along the way.

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Introduction

Background and context

Applying Toiano as the primary point of study, this thesis aims to explore the viability and possible approaches for creating a sustainable smart village in the Italian context. With a focus on its potential as a tourist destination, the goal is to create creative solutions that can turn Toiano into a model smart village in Italy, especially in underutilized or abandoned areas.

Location

Toiano, nestled in the heart of Tuscany, Italy, stands as a quaint village within the administrative control of the commune of Palaia, part of the province of Pisa. Its roots trace back to the medieval era, marked by its role as a contested castle among the prominent city states of Lucca, Pisa, and Florence. Set among the rolling hills of the Tuscan countryside, Toiano is about 50 kilometers away from Pisa and only 8 kilometers from Palaia.(Chiozzi & Latini, 2015)

History and background

Toiano, nestled in the enchanting Val d'Era, offers a captivating blend of natural splendors and historical significance. Situated approximately three miles southeast of Palaia, within the diocese of Volterra and under the jurisdiction of Sanminiato, this charming village boasts a modest parish church dedicated to San Giovanni Battista, and a splendid castle. Formally a part of the Florence district, Toiano stands out as a hidden nature, awaiting discovery owing to its unique character and rich history. In the rolling hills of marine sandstone tufa, its medieval fortress, Castelvecchio, commands the highest point, while the picturesque village center lies just below.

Although loyal to the diocese of Volterra, Toiano has a convoluted history, filled with multiple changes in leadership. Around the year 1000, it was under the rule of the Lucca bishops until Florentine occupations and the Pisans' eventual restoration in 1364. Notably, the walls of Toiano's castle were ordered to be demolished by the Florentine authorities, reflecting the region's turbulent history of territorial disputes and political power struggles. Toiano remains a monument to tenacity and its ancient walls resonate with stories of conquest and resilience. Tucked away from the serene splendor of the Val d'Era, Toiano welcomes guests on a voyage over time, where the sounds of the past meld with the beats of the present, providing a window into the spirit of Tuscany's legendary landscapes. (Chiozzi & Latini, 2015)

FIG. **1**-Toiano village

FIG. **2**-Toiano,via princinpale

FIG. **3**-Toiano village

Historically, the landscape surrounding Toiano has been characterized by expansive farmland and agricultural plots dominated by cereal crops, interspersed with uncultivated areas and pastures primarily used for cattle breeding. However, the current view of the area surrounding Toiano shows crowded and broken terrain, with forests intermingling with farmed land in various forms, including patches, scrublands, and solitary groves. Orchards, vineyards, and arable fields now constitute the agricultural landscape, which is dotted with patches of coniferous reforestation interspersed with broad-leaved forests, mainly found in ridge areas.

Toiano's topography is closely entwined with its landscape, giving rise to the first impression that embodies a typical Tuscan hilltop village. The internal arrangement of buildings reflects the region's agricultural past, shaped by land cultivation customs and traditions. The most common agricultural system is sharecropping, which is suited to mixed cultivation methods requiring constant labor and care from farmers. Within farmsteads, residential buildings are usually integrated with agricultural facilities, acting as centers for various agricultural activities.(Chiozzi & Latini, 2015)

Built with native materials and methods, these rustic buildings radiate simplicity and authenticity, reflecting the peaceful coexistence of human habitation and the surrounding landscape. The urban fabric of Toiano follows a linear pattern, with buildings arranged along the north–south axis facing a single thoroughfare named Via del Castello. These structures, typically two or three stories tall and made mostly of masonry, have pitched tile-covered roofs. External staircases, which frequently lack protective canopies, facilitate access to the upper floors. The buildings along the northern and southern fronts are of uniform depth and width, although there are differences in architectural details.

At the heart of Toiano lies its sole communal space, the "threshing floor," which historically served as a hub for processing agricultural produce. Residents also had access to a crucial water supply thanks to a shared cistern. The sensible arrangement of Toiano's residential, commercial, and recreational areas coexisted harmoniously in this town plan, capturing the spirit of Tuscany's rural life.(Chiozzi & Latini, 2015)

FIG. **4**-Toiano village

Statement of the problem

Among Toiano and other surrounding villages, there has been a decline in population and an increase in abandoned areas in rural Italy. This is part of the overall counter-urbanization trend in Europe that requires immediate investigation into how these historic places can be sustained and what their future holds. Restoring these villages goes beyond repairing the built environment; it also involves enhancing the social environment to accommodate today's lifestyles. An essential but often neglected dimension of such an enterprise is energy sustainability. It is critical for revitalization efforts to include sustainable measures to meet the energy requirements of these villages.

Research questions

Some research questions may include:

- What are the present-day energy usage and need patterns for rural Italian communities like Toiano?
- What are the key hurdles in achieving energy sustainability for rural settlements as opposed to cities?
- What are some examples of good practices and successful rural energy sustainability initiatives globally, and how applicable are they to Italian townships?
- What are the most viable approaches for promoting asset savings through the renovation of buildings aimed at conserving energy in the context of Italy's countryside?
- What would be the impacts on the economy, society, and environment if one were to embrace alternatives to fossil fuels?

Limitations

Among other things, Toiano faces the challenge of having little knowledge about its past residents, building techniques, and historical background. The extensive damage sustained by numerous buildings compounds this, making it even more difficult for historians to provide an accurate consideration. The largest obstacle facing researchers and historians trying to piece together the village's past is the lack of data. The municipality's rules, which occasionally forbid positive business partnerships, will also cause challenges with preservation and restoration. These rules provide financial difficulties in addition to conservation. The problem with Toiano's past is made worse by the lack of precise data, and the economic and regulatory issues are still unresolved. Even though promoting energy sustainability in the Italian countryside is a worthwhile objective, the effort is hampered by these overwhelming barriers. A successful approach is needed, one that includes the historical aspect, economic viability, and the community's interests as well.

- **lack of detailed data on building structures**

In most rural villages, like Toiana Small, there is no complete information available on the existing building stock. Historical data, technical construction data, and architectural drawings are often partial or not available at all. This information deficit inhibits the elaboration of accurate renovation strategies and the evaluation of the possibility to integrate modern energy solutions.

- **Insufficient information on past and present occupants**

Understanding building occupants' usage patterns and needs is critical for developing effective energy solutions. However, in rural Italian villages, information on previous and current occupants is frequently scarce or out of date. This lack of occupant information limits the ability to tailor energy renovations to actual user needs and behaviors, potentially reducing the efficacy and acceptability of suggested interventions.

- **Destruction and degradation of existing structures**

A great deal of the buildings in these rural areas have been severely damaged or destroyed. Because of their deteriorated condition, renovations are made more difficult and require a substantial investment in restoration before energy-saving measures can be taken into account. Since these projects can only be financially and practically restored, their potential for energy sustainability is limited.

- **Municipal regulations and constraints**

The municipalities that are responsible for these rural villages frequently show strict regulations on building interventions. Following these regulatory landscapes, meticulous planning and frequent compromises can limit the scope and ambition of sustainability projects. These rules are intended to protect historical and cultural heritage, but they can be restrictive and may conflict with economic and sustainability goals.

- **Economic constraints and funding limitations**

Financial constraints are a significant barrier in rural areas. The cost of extensive renovations and the installation of renewable energy systems can be prohibitively expensive, particularly in economically depressed areas. Furthermore, funding opportunities and incentives for such projects may be limited or insufficient, limiting their potential for widespread adoption.

- **Technological and logistical challenges**

Implementing modern energy solutions in rural areas can face technological and logistical challenges. The availability of skilled labor, modern construction materials, and advanced renewable energy technologies may be limited in these abandoned locations. Additionally, logistical issues related to transportation and infrastructure can pose significant hurdles to the timely and cost-effective completion of projects.

Significance of the study

This thesis is interesting for performing a comprehensive approach to energy sustainability in rural Italian villages by integrating renewable energy sources with building renovations. To present different scenarios and develop detailed strategies for sustainable technical and social solutions, the research takes into account factors such as urban energy needs, economic feasibility, and diverse design elements.

In this thesis, developed concerning international standards including EN ISO 52000-1 and the Energy Performance of Buildings Directive (EPBD), a strong structure will be established for analyzing energy efficiency and performance as it pertains to rural village settings. With an interdisciplinary method, this structure will not only suit various international best practices but also integrate dimensions of engineering, architecture, economy, and sociology. This is necessary for addressing the multiplicity of energy sustainability and enabling the development of new ideas that would be technically viable but community-oriented.

Moreover, concentrating on remote rural locales presents a rare chance to delve into the confluence of heritage conservation, community rejuvenation, and sustainable growth. This research explores the specific hurdles and opportunities in such places, offering important information to the overall dialogue on rural viability. It is vital to note this concentration as it highlights how rural neighborhoods can be educated on sustainable living principles that meet modernization necessities while maintaining cultural and historical identities. The aim of the thesis is also to change theoretical knowledge into practical actions by offering functional recommendations and guidelines for policymakers, planners, and practitioners who are concerned with revitalizing Italian countryside villages. This study aspires to facilitate a more sustainable and resilient future for Italy’s rural communities as well as other regions facing similar challenges from both the social engagement and technical innovation standpoints. By utilizing a comprehensive and integrated approach, this thesis intends to significantly contribute to sustainable development. Its main premise is that community-centered solutions are essential not only for improving energy resilience and living standards in rural areas but also have wider implications on both the environment and the economy.

Thesis structure

Chapter 2 is the most thorough literature review regarding rural communities and energy sustainability. It investigates previous research that focused on theories of sustainable development, the incorporation of renewable energy sources, and villages within Italy. Furthermore, it discusses construction refurbishment principles and regulations like the EPBD, as well as smart village technologies and ideas. Additionally, there is a discourse on zero-energy and self-sufficient buildings in rural settings that advocates raising the level of building envelope insulation. By making such an examination, this part provides some necessary facts about available techniques and possible directions toward energy sustainability in rural areas.

Chapter 3 offers an extensive review of related literature that focuses on important energy analysis standards and methodologies. It critically examines both ISO 52000-1 and other related standards applied in this analysis. In addition, various methods of data collection are discussed to show how they can be beneficial in obtaining relevant information. The simulation software selection process is also described, with particular attention to CitySim Pro, which was used as a tool in modeling energy systems. Moreover, it describes the techniques for data analysis used to interpret simulation outputs and extract useful insights from them. Hence, this discussion presents a comprehensive account of the relevant energy analysis standards, methodologies, and tools considering the present study case.

Chapter 4 starts by collecting technical information regarding the case study villages concerning their structure and energy systems. With these data, attention is turned towards designing renovation strategies that can solve specific problems and make good use of available opportunities. The aim of these strategies includes infrastructure upgrading, implementing energy efficiency technologies, and generally improving village sustainability. This phase also looks at how smart village concepts should be integrated for proper technology use in improving infrastructure, services, and community engagement through the exploration of innovative solutions. At the same time, an elaborate master plan is created, indicating a strategic vision as well as a development roadmap for the villages. Throughout this section, simulation analysis is crucial for comparing different options.

Chapter 5 is the conclusion and recommendations section, presenting a summary of findings while also acknowledging contributions to knowledge but with limitations on the study context. Consequently, research findings on the sustainability of rural villages are emphasized in the concluding remarks. Policy recommendations guide those who make decisions, while practical recommendations suggest ways in which they can be acted upon. Furthermore, areas for future research are identified, providing additional understanding within this area.

Work flow chapter 1

Introduction

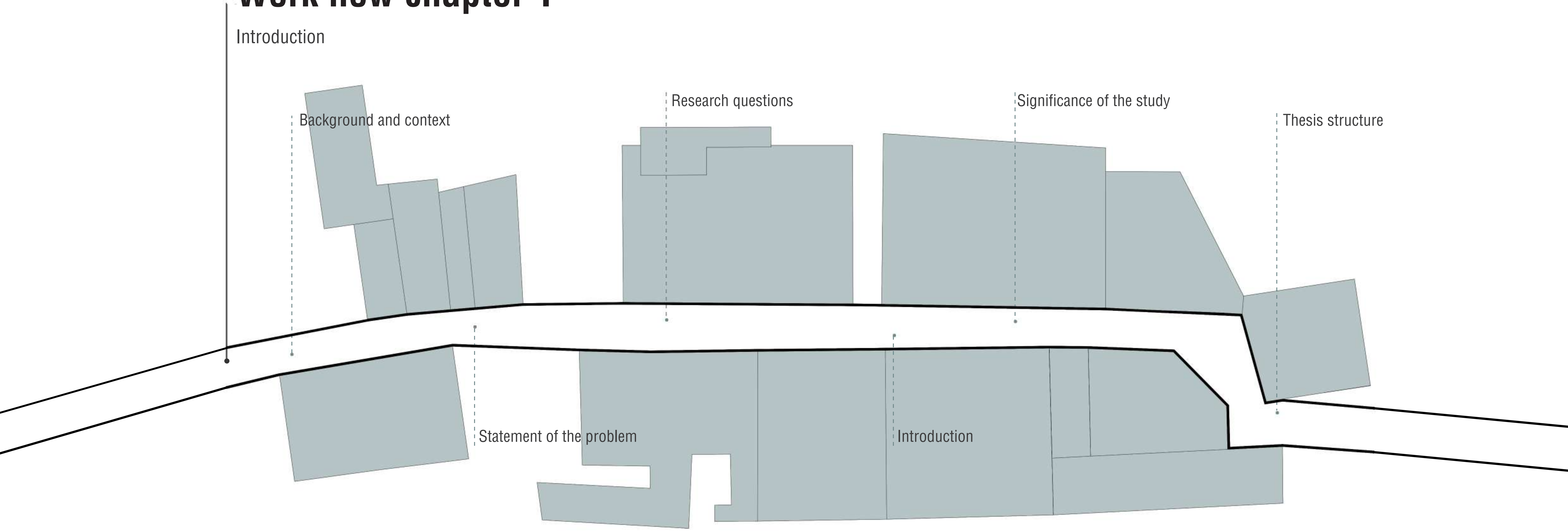

FIG. **5**- Work flow chapter1

Theoretical framework

Previous studies on italian rural villages

The term “village” (Borgo, Paese, Villaggio) in Italian describes small rural settlements typified by intimate community ties and frequently stunning natural settings. Different administrative structures may exist in these villages; they may function independently or unite to form municipal unions. Interestingly, over 70% of Italian municipalities have fewer than 5,000 citizens, which is the legal cutoff point under law n.158/2017 for being deemed “small.” This legal classification emphasizes the importance of these compact, usually historic settlements and highlights how common small municipalities are in Italy.

Furthermore, fewer than 150 residents dwell in each of the approximately 100 municipalities classified as “very small villages” (micro-comuni). These small towns, frequently found in isolated locations, represent a unique group of rural areas with specific opportunities and challenges.

The legal recognition of the management limit for small municipalities highlights the specific features of these villages and underscores the necessity for relevant plans and actions tailored to their particular requirements. Developing and implementing strategies that support the sustainability, vibrancy, and cultural richness of these quaint Italian villages requires an understanding of these needs and how to meet them.(Smart village strategy of ostana, 2020)

Energy sustainability in rural contexts

The need to address climate change and lower CO2 emissions in this dynamic environment poses constant challenges, especially when it comes to utilizing the natural energy resources found in these regions. In contrast to urban areas, which have increasing energy demands, rural areas have lower population densities and therefore have more chance for renewable energy sources. However, sustainability continues to be the essential of all efforts related to development. Following the incorporation of renewable energy in rural areas requires respecting two equally important considerations: land conservation and the preservation of cultural and natural landscapes.(Guarneri, 2021)

Renewable energy integration in rural areas

Energy access is a fundamental human right because it is necessary for many aspects of daily life, including economic activity, transportation, lighting, and heating. Since the sun, wind, and water are abundant resources, it is critical to guarantee reasonable access to the advantages they provide. Enabling everyone to use energy from renewable sources is part of this. This need is especially acute in rural areas, where an abundance of natural resources can produce substantial social and economic benefits locally, meeting urgent needs in these communities.

The wide-ranging collaboration that rural communities have had throughout Europe in setting up distribution networks and renewable energy projects since the continent’s electrification began is still largely unknown. Still, this is a movement that is spreading quickly across Europe. Leading the charge are farmers, small companies, and homeowners starting renewable energy projects, creating storage systems, and setting up district heating and cooling networks.

Europe’s community-driven energy production still has a lot of unrealized potential, despite immense progress. Across the continent, there are currently more than 3,500 cooperatives focused on renewable energy. According to projections, half of all EU residents—including those living in towns, on farms, in hospitals, and in schools—may be actively involved in generating their own renewable energy by 2050. By working together, we may be able to meet forty-five percent of the region’s electricity needs.

It has been noted that most of the existing 3,500 renewable energy cooperatives are situated in NorthwesternEurope, with numerous rural communities forming part of this population. These cooperatives have various structures designed to fit the specific circumstances of the countries and regions where they are found. Several case studies show how a small village can become independent from external sources of power by switching to energy renewable energy sources. They also illustrate how rural populations can pool their resources together to benefit from large-scale production of renewable energy, leading to reawakening forgotten places and creating new life around them again. The next section will look into five smart villages in Europe: these rural areas create their special cases and achievements. Through comparative examination, this subsection attempts to clarify strategies used by each individual village towards attaining autonomy regarding renewable sources of energy as well as promoting regional advancement. (Guarneri,2021)

Smart villages

Over time, the concept of living in a smart environment has become linked with urban development. However, smart villages are designed to support rural communities seeking practical ways to improve their local areas. These villages leverage digital technologies to connect rural and urban regions by fostering collaboration among community groups. Additionally, they establish locally-driven partnerships among various rural stakeholders from both the public and private sectors.

Context of smart villages

- **From Cork 2.0 to the Smart villages network**

It's useful to go over important meetings and documents in order to comprehend the origins of the Smart Village concept within the EU. Prefiguring the 1996 Cork Declaration, A Living Countryside, the European Commission convened the "Cork 2.0 European Conference on Rural Development" in Ireland during September 2016. More than 300 stakeholders and policymakers attended this conference, which focused on the opportunities and problems that Europe's rural and marginalized areas face. Ten policy recommendations were included in the "Cork Declaration 2.0 – A Better Life in Rural Areas," which was the result of the conference. It highlighted the disparity in access to digital resources between rural and urban areas and advocated for coordinated efforts across policy domains. It was also noted that, in order to encourage rural growth and make these places appealing to people of all ages, the problems of youth outmigration and rural depopulation must be addressed.(Guarneri,2021)

To envision the future of rural communities, the European Commission and the European Parliament launched the "EU Action for Smart Villages" initiative in April 2017. Instead of providing a one-size-fits-all solution, this strategy uses digital technologies to strengthen regional advantages. It acknowledges that every region ought to have the chance to use ICTs to improve their local economies and fundamental services. The initiative included sixteen actions pertaining to energy, transportation, research, digital policies, and rural and regional development.
New funding mechanisms, such as the European Innovation Partnership for Agriculture (EIP-AGRI), which supports forestry and food production, and the European Network for Rural Development (ENRD), were introduced in addition to already-existing funds like the Common Agricultural Policy (CAP). In addition, the initiative suggested thematic groups, conferences, workshops, and seminars to enhance comprehension of the Smart Villages methodology.
Among the significant projects are:

- **SMARTA (smart rural transport areas)**

This project looked at the problems with mobility in rural areas across Europe, found best practices, kept an eye on pilot projects, shared and discussed the findings, and planned links between rural public transportation and sustainable shared mobility.

- **Smart eco-social villages**

A pilot project that mapped Smart Village opportunities and challenges, looked at village features, and found best practices, with a focus on digital solutions and connectivity in particular.

The idea of the "smart village" has developed further and is now given priority by the EU. The outcome of the April 2018 meeting in Bled, Slovenia, was the "Bled Declaration for a Smarter Future of the Rural Areas in the EU," which expands upon earlier texts such as the Cork 2.0 Declaration. In order to support, rebuild, and strengthen rural communities throughout the Union, as well as to redesign the future of farming and food production, this declaration highlights the significance of the Smart Villages initiative. In order to facilitate the exchange of knowledge and experiences among villages and associations throughout Europe, the Smart Village Network was introduced in 2018.(Guarneri,2021)

Definition of smart villages

There doesn't appear to be a single definition for "smart villages," as the term can mean different things to different people in different contexts and with different problems that each community faces. With this knowledge, it is clear that to work together to effectively promote the Smart Villages approach, a common foundation is required at the outset. An initial definition of smart villages was decided upon in 2018 after a two-day expert workshop in Brussels and an online consultation. Additionally, a thematic group (TG) that studied Smart Villages from October 2017 to July 2020 contributed to this outcome by treating it as a sub-theme of the larger European Network for Rural Development (ENRD) work on Smart and Competitive Rural Areas.A basic definition and definitions for important terms are included in the outcome. Smart Villages are rural communities that make use of creative solutions to improve their resilience through the utilization of available opportunities and local strengths. To improve their economic, social, and environmental conditions, they use a participatory approach in the development and implementation of strategies, especially when it comes to utilizing digital technologies. These villages gain from working together and forming alliances with stakeholders in both urban and rural areas. The different of public and private funding sources may be used to support the development and implementation of Smart Village plans, which can build on current projects.
Key terms are defined as follows:

- **Rural communities**

Human settlement or settlements that can be considered rural despite existing administrative or population bounds, taking into consideration what has been said above about the eligibility of Member States to use definitions submitted by, for example, organizations like the OECD or EUROSTAT concerning rural areas or any pertinent definitions, for that matter.

- **Participatory approach**

This constitutes citizens involvement in the formulation and decision-making for the Smart village strategy. During the strategy's implementation, this approach will consider the needs for capacity building and community training.

- **Digital technologies**

Information and communication technologies, the use of big data, and developments based on the IoT. These technologies should enable Smart Villages to be more agile, optimize the use of resources, and increase the attractiveness of rural areas, along with improving the quality of life for the rural population. The use of digital technologies is not required for a village to become Smart, but, where available, high-speed broadband will certainly aid the delivery of digital solutions.

- **Smart Village strategies**

While enhancing the region's strengths and assets, strategies should be centered on its needs and challenges. Clearly state their short, medium, and long-term objectives. The roadmaps' performance indicators must be used to track progress, and they should be regularly reviewed to accommodate continued improvement. Increasing access to health, education, and transportation services; fostering more advantageous business and employment opportunities; utilizing natural resources; and adjusting to climate change are a few examples of strategies.

Protecting the environment and biodiversity; and enhancing the value of cultural heritage to attract more tourists are also important. It is important to understand that the Smart Village approach is about more than just cutting-edge technology; it is about enhancing the standard of living for people living in rural areas. The lives of individuals and their communities come first. The digital divide between rural and urban areas can be closed by using technology and digitalization to transform unattractive rural areas into more desirable locations with services, specialized employment, and a conducive entrepreneurial atmosphere. To address a variety of challenges through a bottom-up approach, the Smart Village project integrates a participatory model that can be tailored to local contexts.(Guarneri,2021)

Sustainable development theories

Smart villages prioritize the integration of digital technologies to empower rural residents in driving the transformation of their local communities. This emphasis on technology is aimed at fostering enhanced collaboration among community groups and establishing partnerships with diverse stakeholders, including both public and private sectors. As a result, smart villages serve as a conduit bridging urban and rural areas, facilitating the integration of various regions through this collaborative process.

The integration of smart villages can be categorized into two main aspects: social innovation and technical innovation. Social innovation involves enhancing community functions and fostering a sense of belonging by welcoming newcomers. Conversely, technical innovation focuses on the implementation of renewable energy solutions.

Case study

In this comparative case study, the unique dynamics and challenges faced by five distinct villages are explored: Ostana in Italy, Stanz in Austria, Tomaszyn in Poland, Torup in Denmark, and Ansó in Spain. Despite their geographical and cultural diversity, common themes emerge in their rich heritage, community values, and struggles with depopulation and economic sustainability. Through a comprehensive SWOT analysis, the study identifies the villages' strengths, weaknesses, opportunities, and threats. Furthermore, potential smart strategies and interventions are examined to foster resilience and sustainable development within these communities.

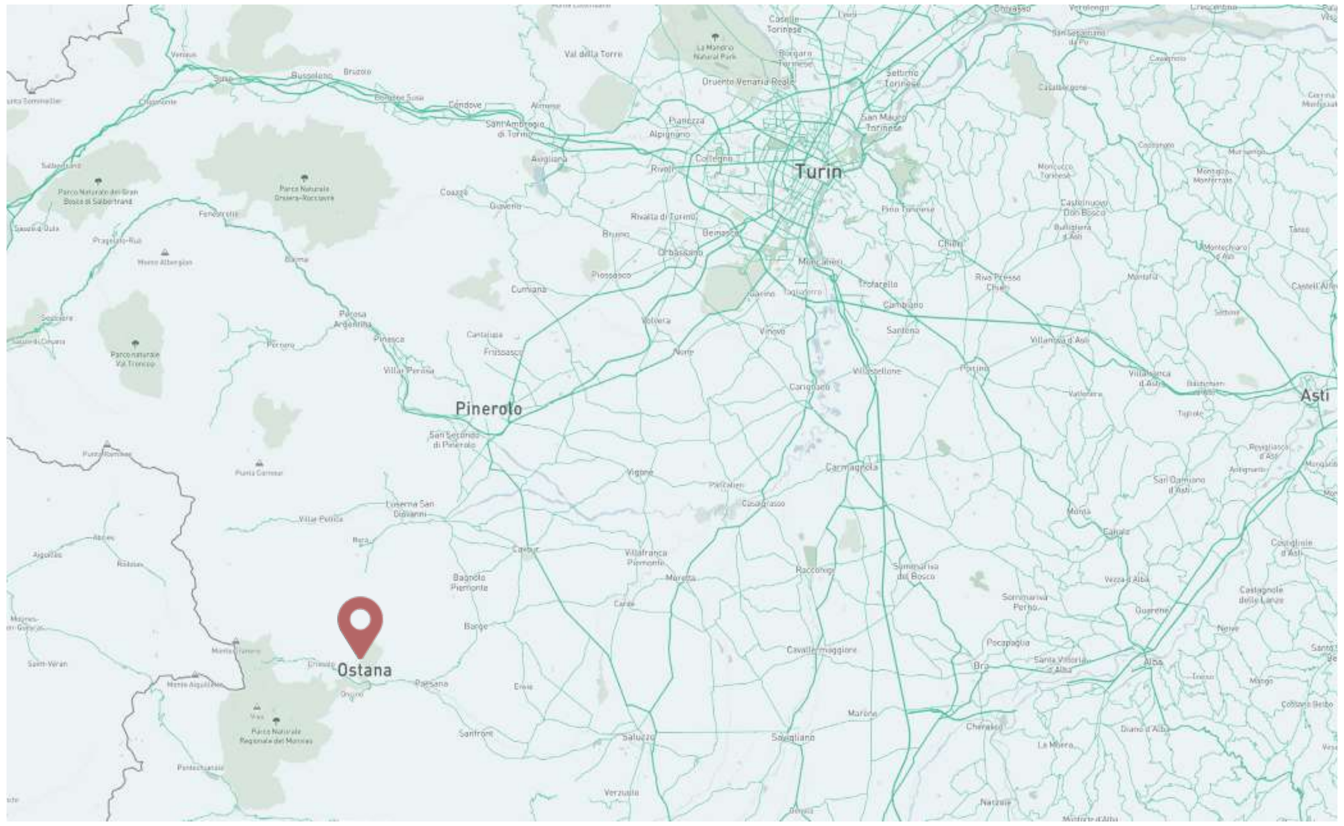

FIG. **6**-Ostana map

Ostana village case study

General overview

Location

Ostana is situated in the Piemonte region of Italy. It is an Occitan multicentric settlement located in the north-western Alps, in the Po valley, facing the Monviso mountain.

Altitude: 1000-2000 meters above sea level.

Distance to Other Parts

Ostana to Turin: 85 km

How to Reach Ostana:

By Car: Turin to Ostana - 1 hour 9 minutes

On the Train: Turin to Pinerolo, then taxi to Ostana - 1 hour 28 minutes

By Plane: The nearest airport is Turin Airport.

Population

In 1921: 1200 inhabitants

By the end of the 20th century: Only 5 residents remained in the village.

Present: 50 residents live in the village year-round. During summer and high season, the number of tourists and second-home owners increases to 500 overall.

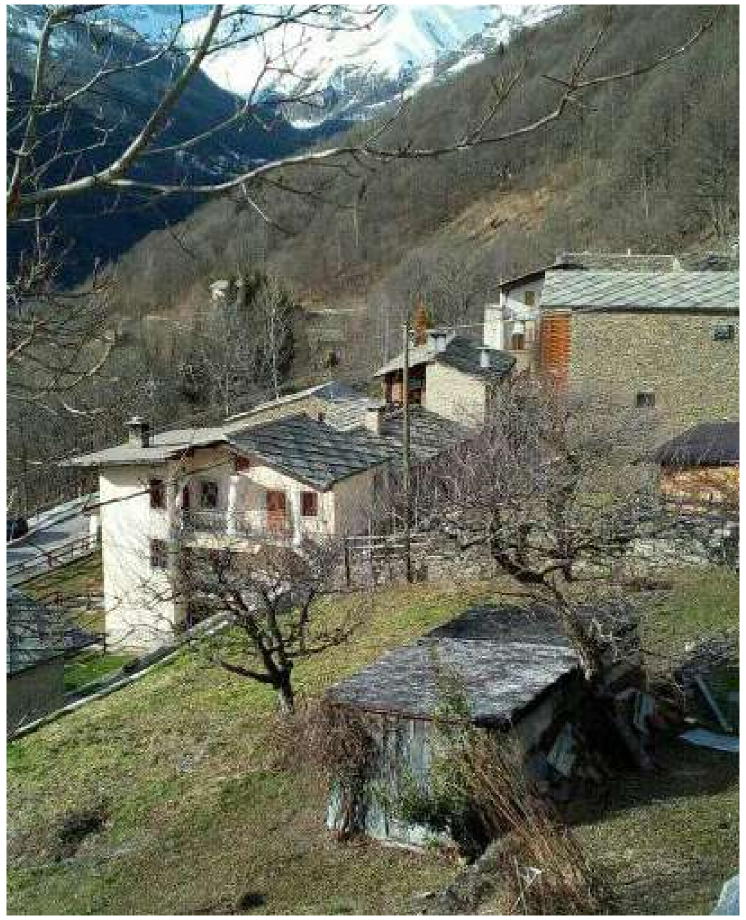

FIG. **7**-Ostana village

What are the main values of villages?

- Ostana is a collaborative project about living in the Alps in a contemporary and global way, and it has been recognized as a prominent example of alpine regeneration.
- A group of former residents initiated the village's rebirth to begin a process of successful architectural rehabilitation based on severe standards, as well as protecting and promoting the alpine environment and culture.
- Ostana is an active member of the Anci Piemonte regional branch. It participates in projects relating to small villages (Piccoli Comuni) and shared management of local services with that framework.
- Ostana is a member of the following organizations (I borghi più belli Ostana is a member of the following organizations (I borghi più belli d'Italia), which promote the most beautiful villages in Italy. The union's role in strengthening the mountain's engagement in regional and national policies is dependent on events, interchange, and communication.

Key challenges

Limited numberof residents

- The most essential issue is to increase the number of permanent inhabitants in the village to a minimum of 100 individuals. This will help to build the community and enhance the presence of services in the area.
- It is well-known that living in the Alps nowadays requires the development of new complex and integrated communities.

Seasonal (unbalanced) tourism

- The challenging issue is growing visitor numbers during the low tourism season while avoiding overcrowding in the area at peak times. This would have a significant impact on the sustainability of local businesses and the integration of new residents.

Lack of fast broadband

- The lack of infrastructure includes a lack of fast internet access. Broadband, which creates a digital gap between valley communities and metropolitan regions.
- This disadvantage inhibits the complete development of ongoing initiatives as well as the ability to offer a large number of services (smart social services such as health care and education, smart working, and e-commerce).

Lack of affordable houses

- There are a few cheap housing options for young/low-income families that might like to live and work permanently in the area.
- Based on the village's growing popularity, numerous investors came to Ostana and repaired weekend homes.
- The real estate market is now unbalanced, with high repair costs and structures that are unsuited for families that live in the town all year.

Pressure on mobility

- It is located in a small valley, approximately two hours from Turin and thirty minutes from Saluzzo, the largest town in the area with high schools, cultural infrastructure, and train/bus terminals.
- No public transport is currently available, except a school bus for students.
- In peak season, when the number of residents and tourists grows, parking spaces are scarce, and traffic has a significant influence on everyday life.(Smart village strategy of ostana ,2020)

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Biodiversity

- The territory was transformed into a complex pattern of semi-natural ecosystems (rangelands and pastures, crop fields, forests, wetlands, etc.) marked by high biodiversity, where human agricultural activities were part of the natural balance.
- This balance was destroyed as a result of out-migration and the subsequent abandonment of agriculture and farming, and such semi-natural habitats were abandoned.

Climate risks

- The Alps, due to the Alps Convention, are one of the ecosystems most threatened by the climate disaster. Water is one of the most significant challenges among the several consequences.

Energy transition to renewables

- Because wind, solar, and hydropower are not always available for geomorphological challenges, a smart power system based on a balanced mix of renewables must be developed .
- In larger buildings, heating systems are fueled by diesel or LPG, whereas homes frequently rely on conventional wood burners with no particle filters. The scarcity of locally available certified wood-based fuels with low humidity adds to the danger of direct and indirect contamination.(Smart village strategy of ostana ,2020)

SWOT ANALYSIS

Strengths

- Well established local democracy
- Very good engagement / involvement (many volunteers)
- Good cooperation with municipality (trust established)
- Human capital (diverse and resourceful)
- A culture of acceptance
- A tradition for acting on needs (not just wait)
- Sustainability is part of the Torup DNA
- Railway with trains every 30 min
- High level of local services for a village this size School,
- kindergarten, assembly hall, shared office-space, shops

Weaknesses

- A small village with few people
- Remoteness – limited access (situated on a peninsula)
- Heating (homes and community buildings) mainly based on fossil fuel
- Weak guidelines for cooperation with authorities
- Lack of fast and reliable broadband

Opportunities

- Trends of division
- Attracting / integrating (resourceful) newcomers
- Opportunity for better work/life balance
- Growing interest for sustainability
- Create further commuter-hubs/common workplaces

Threats

- Lack of integration of present and new inhabitants
- Infrastructure: railway cuts; lack of fast IT-connections
- Societal/administrative centralization
- Lack of capital/ access to house bank loans
- Danish trend is depopulation of rural areas
- Reluctance for mortgage for houses in rural areas
- Outside investors/ entrepreneurs buying the land for development

(Smart village strategy of ostana ,2020)

What are Ostana's smart strategies and interventions?

Ostana green community

A number of things have already been done, including solar and wind-powered public street lighting; solar panels on the municipality's rooftop; geothermal and solar energy for the wellness center and the Mizoun de la Villo (bakery, medical facilities); and a shuttle bus during events.

Ostana is analyzing data and assumptions to assess the change from private to public transportation. Many additional efforts try to improve the management of local natural resources (pastures, crops, and forests), integrating environmental protection with economic growth. (Smart village strategy of ostana ,2020)

Sustainable mobility

It intends to develop a new mobility model based on the increased use of electric mobility, the creation of a local carpooling system, the installation of new infrastructure for charging electric bikes, and the establishment of new interchange areas for intermodal mobility in order to reduce

Energy transition

- Sustainable Mobility, Resource aware development model
- Energy Transition, Local energy community based on a smart grid and renewables

Activities planned or taken

- Reinforcing Charging station system for e-bikes and e-cars + provide new e-bikes available for tourists and residents
- Car pooling system
- Shifting from private to public mobility
- Shuttle bus during peak season
- New interchange areas both in the valley and in the village
- Mobility app development (for coordination of car-pooling and carsharing)
- Exchanging with other national and international villages/strategies
- Setting up solar panels on public roofs

Expected results

- Energy saving (transition to sustainable energy consumption) Decreasing of circulating vehicles, decrease of polluting emissions
- Decrease of circulating private vehicles, decrease of polluting emissions,
- Road safety between the hamlets, decrease of polluting emissions
- Decrease of circulating vehicles, decrease of polluting emissions
- Improving the sustainable mobility, new users of the app
- Increasing in renewable energy use

Housing

Objective HousingThe municipality is intending to restore certain structures in la Villa village (the important one in the village), like it did in the 1990s, in order to activate a social housing program, so establishing the circumstances to attract new young working residents and preventing tourist speculation.

Social housing

- Development of experimental projects for social housing
- Renovation of housing heritage suitable for new inhabitants
- Attraction of new investments/creation of new financial tools

Activities planned or taken

- Ostana has built a strategic alliance with Politecnico di Torino, for the development of an experimental architectural project for the social housing program
- Regular meetings with stakeholders
- Checking calls for public and other fundings

Expected results

- Proceed on the basis of concrete guidelines, of recognized value, by building alliances outside the town.
- Stimulating production of projects for restoration of social housing buildings
- Building of a consistent project for long rental housing
- Getting sustainability for renovation

Culture and social innovation

Promotion of new cultural forms

- Reinforcement of cultural and community center
- Promotion of new cultural forms and community cohesion
- Reinforcement of collaboration with universities and research center, educational community

Activities planned or taken

- Public coworking and setting up 10 new workstations to carried out a residential experience
- Making BAO. Biblioteca Aperta di Ostana (Ostana Open Library), a lively entity Widespread in the hamlets, a public meeting place for the community, to study, work and consult digital contents.
- Increasing and developing the network of universities, institutes, and schools that may demands of the mountain community

Expected results

- Having a recognized attraction point for families, visitors, researchers, mountain lovers .(Smart village strategy of ostana ,2020)

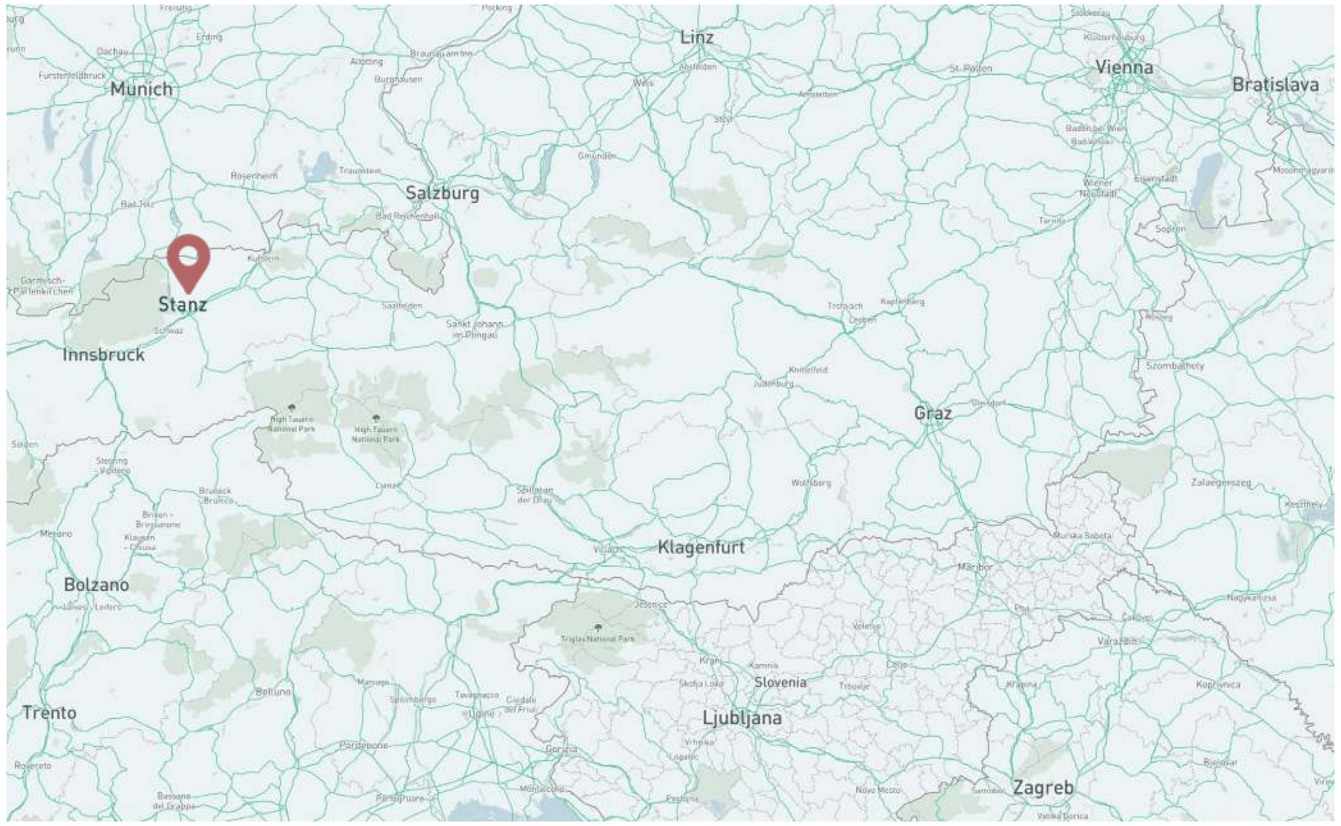


FIG. **8**-Stanz map

Stanz village case study

General overview

FIG. **9**-Stanz village

Location

Stanz im Mürztal is situated in a rural area within the province of Styria in Austria.

Distance to other parts

Stanz to Kindberg: 1 km
Stanz to Vienna: 134 km
Stanz to Graz: 76 km

How to reach stanz

By Car
Stanz to Graz: 55 minutes
Stanz to Vienna: 1 hour 29 minutes
On the Train
Stanz to Graz: 2 hours 10 minutes
Stanz to Vienna: 3 hours 11 minutes
By Plane
Nearby airports include Innsbruck Airport (30.5 km), Bolzano Airport (105.2 km), Salzburg Airport (107.7 km), and Munich Airport (110.0 km).

Population

Stanz im Mürztal has a total population of 1844 inhabitants and covers a surface area of 70 km².

what are the main values of villages?

- The region is industrial and has been affected by economic structural change in recent decades.
- Protentional wind site source in the outer eastern Alps.
- Possible dweller capable of participating in many activities and taking on responsibilities

What are key challenges?

Social interference

- Depopulation
- Local stores in the village center have closed.
- A lack of possibilities for housing
- Absence of participation in decision-making
- The economy is small-scale, as evidenced by the significant proportion of persons, who commute from the municipality.

Context interference

- One of the most significant issues is Geographically, the village is located in a side valley of the well-developed Mürztal. Because of its location, there are just a few public transportation options.
- The dependency on automotive traffic
- Loss of supply infrastructure

Energy interference

- One of the most significant current challenges and obstacles in the field of energy transition is the integration of various energy-producing sectors and networks (electricity, heat), as well as the storage of extra electricity.
- Building on creative approaches in the field of energy generation, innovative advances in this sector are being developed in the community.

SWOT ANALYSIS

Strengths

- Active civil society
- Proactive municipal policy
- Wood as a resource (>80% of the municipality area is forest)
- Water resources
- Best wind sites in the outer eastern Alps

Weaknesses

- Has limited financial and human resources for the implementation of innovative projects with increased technical and communication effort.
- Difficult accessibility to reach there
-

Opportunities

- Energy communities - new alternative ways in the highly regulated market.
- Sector coupling: smart connection of renewable energies (covering peaks, storage, ...)
- Advancing smart approach of community development.
- Financial cooperatives (acceptance by the population through participation of investors) - non-profit projects for the community

Threats

- The Stanz way should also function independently of large layers (e.g. energy supply companies) in the field of energy transition.
- Cooperation is desired without becoming dependent.
- Demolish the beauty of pure nature by adding wind power without considering people idea

(Die Stanz smart village strategy ,2021)

what are stanz's smart strategies and interventions?

Objective

- To achieve energy self-sufficiency by 2030, technical interventions will involve using wind, biomass, water, and PV panels, along with introducing a business model for the energy produced.
- To establish sustainable tourism as a new economic pillar
- To further develop civil society

Social innovation

Community members were involved in the creation of the mission in order to "live" this mission statement right immediately. Work was done on particular initiatives in six action areas: quality of life, town center, recreation and sport with Malburg pond, energy, culture, children and youth.

- Municipal e-taxi and securing public transport connection Kindberg (international rail corridor), New construction of apartments, village store, renovation of municipal office Symposium 2020.
- "Nature & Exercise," "Eating & Drinking," "Culture in Town & Country," and "Regeneration & Wellness" were identified as essential initiatives, along with entrepreneurship and self-employment, as well as the use of digitalization dynamics.
- The image of "tourism in the punch" is regarded as a counter-world to stressed everyday living. It is critical that, in addition to day tourism, stays of many days are also possible in order to provide extra value for the community. This necessitates a variety of housing alternatives.(Die Stanz smart village strategy ,2021)

FIG. **10**-local shop before intervention

FIG. **11**-local shop after intervention

Technical innovation

The goal is for the village community to be as self-sufficient as possible in terms of energy supply, and customers to become prosumers in the meaning of the European Clean Energy Act. For this reason, an FFG research project (Stanz+) is presently in progress, which will introduce Plus-energy quarters with the integration of diverse energy sources (sector coupling) to the content. New business models emerge as a result of digitization and decentralization in the sphere of energy generation.

Wind

- There are currently 13 wind turbines in the municipal area that produce 35,000 kilowatts of electricity, in operation. More wind turbines are planned.
- Wind power expansion will consequently take place only in innovative dialogues and with the participation of the community.

Water

- For more than 100 years there has been a small hydroelectric power plant with an output of around 10 KWh. This power station served to power the businesses and individual households in the town center to supply electricity.
- It is intended to leverage this potential in collaboration with private investors and at a suitable location. More compact and more powerful small hydroelectric power plants based on wind power, biomass, and photovoltaics, with much greater construction efficiency Hydropower was added to the local energy management portfolio.

PV

- PV - System (1,5 MW), roof and field assemblies.
- Proposal a new business model to exchange saved energy .

Biomass

- It has a rich potential for biomass from wood, Hydropower and potential areas for the production of energy from solar power. Here should Sectors are coupled, which digitization is used as an innovation driver and also social innovations in the field of energy transition lead to success.
- Currently also just one Biomass power plant built to generate heat. The biomass is thereby from the region based. (Die Stanz smart village strategy, 2021)

In Stanz im Muztal, researchers are looking into the possibility of combining a digital local currency with a green energy community.

Is it feasible and advisable to set up a digital local currency for the Stanz community based on the energy token issued?

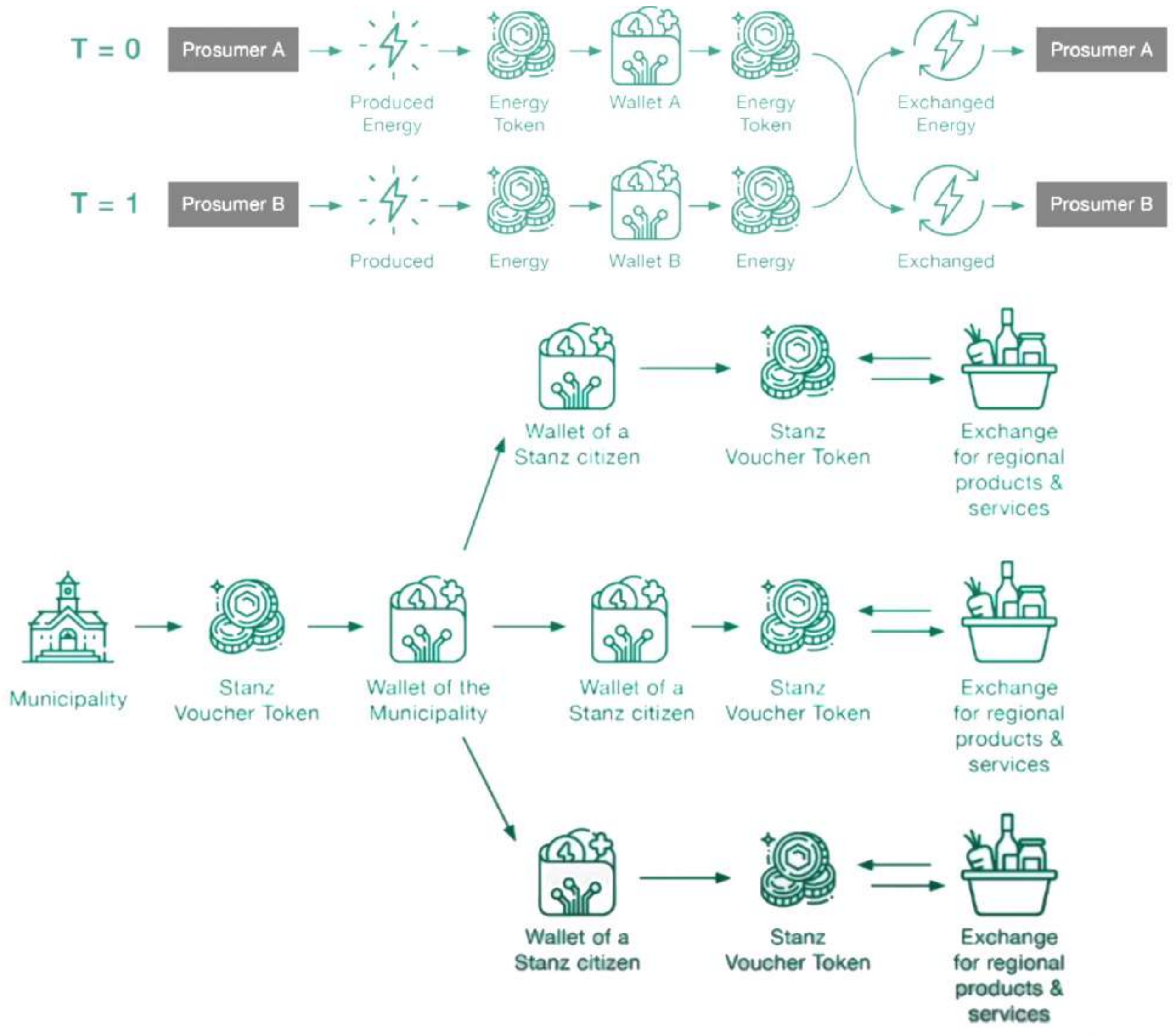


FIG. **12**-Digital local currency model(https://(www.youtube.com/@smartrural2176)

Basic principle

- Token exchange process
- Energy produced and fed into grid
- Token produced as equivalent
- Token used trade: energy based hybrid token

Token exchange process

- Stanz voucher token issued by stanz municipality
- Purpose: strengthen local economy
- Exchange fiat token
- Digitalize existing Stanz voucher

Characteristics

- Represents euro
- No decay over time
- No fees for obtaining or using it (Die Stanz smart village strategy, 2021)

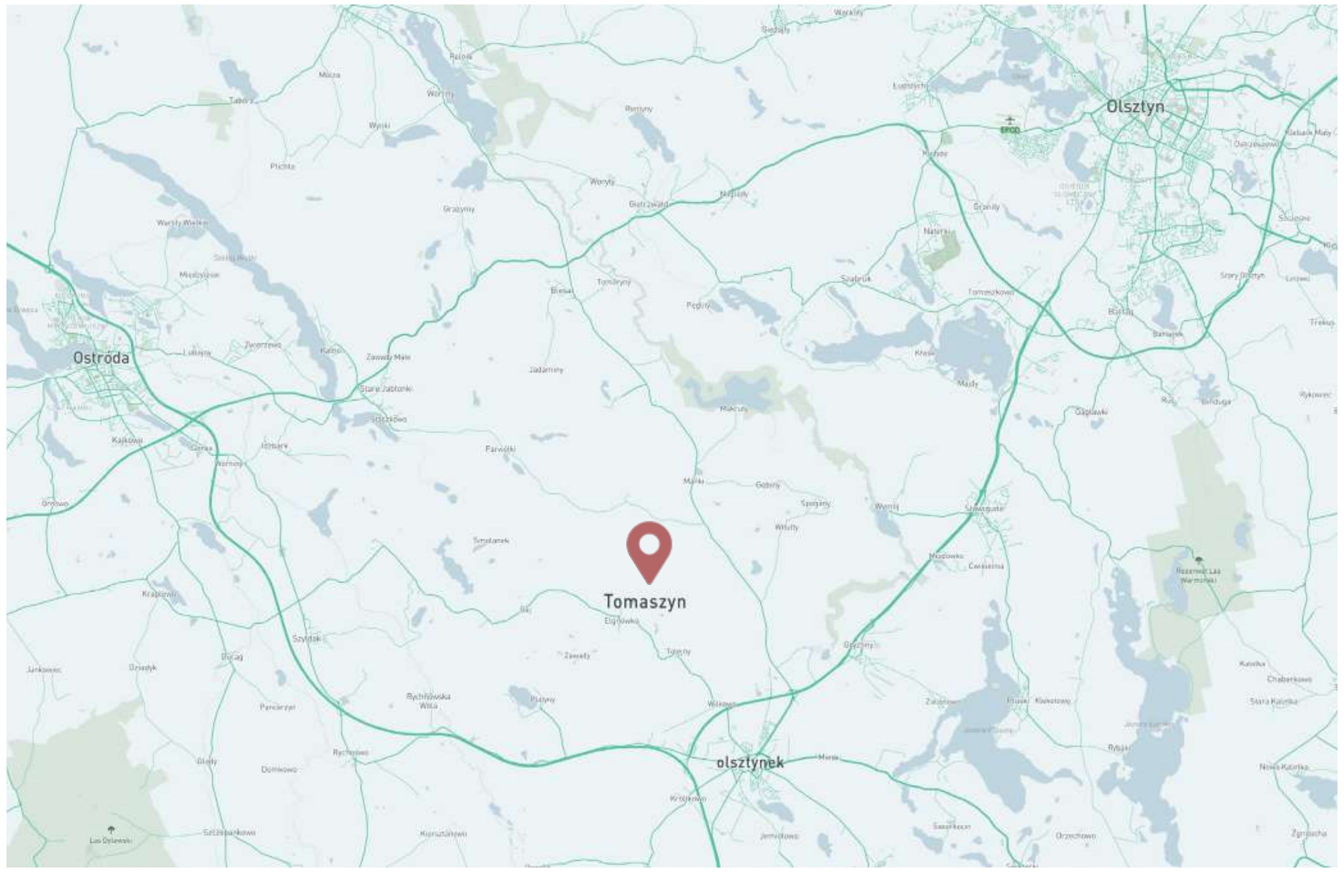


FIG. **13**-Tomaszyn map

Tomaszyn village case study

General overview

Location

Tomaszyn is located in Poland. It lies about 8 km north of Olsztynek and approximately 2 km west of Maki.

Distance to other parts

Tomaszyn to Olsztynek: 8 km

Tomaszyn to Olsztyn: 18 km

How to reach Tomaszyn

By Car:

Tomaszyn to Olsztynek: 16 minutes

Tomaszyn to Olsztyn: 33 minutes

By Plane:

Nearby Airports:

Port Lotniczy Olsztyn Mazury: 94 km

Airport Olsztyn – Dajtki: 29 km

Gryiny Airport: 12 km

Population

Currently, Tomaszyn has a population of 18 inhabitants.

FIG. **14**-Tomaszyn village

what are the main values of villages?

- Great collaboration between different part of society and association to find innovate answer to rebuild ,and of participating in many activities and taking on responsibilities.
- The demand for organic products in Poland is very limited and concentrated in large urban centers. The distribution of food from farms to the market is often local or regional. Direct sales from farmers, ecological festivals and fairs, and organic food outlets dominate. Ecological items have been presented for some time to significant retail chains in the country or budget retailers. As a result, it has the potential to be a smart town with a significant impact on organic food production and a role model for chain food.

What are key challenges?

Context

- The nearby town, Olsztynek, has a population of around 7.5 thousand people. It is the seat of the commune as well as the local service and commercial center.

Farm process

- The key difficulty is to develop a program for farms with less than 100 land areas (there are over 700,000 in Poland) that allows for the transition of production from conventional to ecological, with excellent product quality while limiting negative impacts on the natural environment.

The main challenges are

- Establishing “five farms” of Ostoja Natury
- Construction of the infrastructure
- Searching for and implementing innovative solutions and technologies
- Organization Bio Hub short chain for ecological products
- Increasing the workstation
- Automatization and mechanization of farm/field work
- Development and implementation of good agricultural practices

(Tomaszyn smart village strategy ,2021)

SWOT ANALYSIS

Strengths

- Strong leadership and engagement for territorial food management
- Cooperation with local producers
- Own independent sales channels (online store, organic local market)
- location close to a communication junction
- Innovation networked organization with collaborative relationships
- Many local producers of high-quality food products, natural cosmetics and handicrafts
- Exploiting alternative-renewable energy sources and applying of energy saving methods
- Rainwater management and water saving methods

Weaknesses

- Too few farms and too little organic food production
- Poor organization of organic farmers
- Low level of knowledge about organic farming
- Lack of innovative solutions in organic farming
- Weak position of farmers in food chains
- Lack of adequate infrastructure
- Little promotion of local and organic products in the region and the country poor service provision in local villages
- lack of cooperative between agricultural businesses with academic and research areas
- Migration of young people to cities

Opportunities

- Growing demand for organic food and high-quality products
- Promoting production with focus on local certified, high-quality products
- Attracting new residents, the opportunity to live and work still very close to the nature and nearby city
- A favorable political and policy context
- Development agricultural technology, green technology and ICT
- Incentives to cooperate universities, farmers, producer groups, food processing companies and tradesmen
- Upgrading existing road networks

Threats

- Decline in confidence in certification
- Unfavorable environment for developing and financing
- Business initiatives (pandemic state, recession)
- Risk of deterioration of the ecological areas and of the region and reducing the amount of arable land, due to the tourist pressure' in the area
- Low attractiveness of primary careers

(Tomaszyn smart village strategy, 2021)

What are tomaszyn's smart strategies and interventions?

Before the Agricultural Cooperative Ostoja Natury was created, Tomaszyn was declining and disappearing. The arrival of the cooperative gave it fresh life. Ostoja Natury's partners include all rural farmers.

The Tomaszyn - Ostoja Natury cooperative is building the agricultural environment of the future. This is a reference farm model - a smart village where we produce high-quality food and distribute it without the need for intermediaries.

Each of the five "Farms" that comprise our cooperative, by being creative while being consistent with conventional solutions and ecologically beneficial, encourages the development of a waste-free and highly effective ecosystem. When designing Ostoja Natury, it was inspired by nature's already existing solutions. The circuit is everything, just as in an ancient forest, and waste is non-existent. Our goal is to create an ecosystem that is both economically efficient and environmentally friendly.(Taskforce action plan, poland, 2022)

Healthy food farm

The main aim is continuous (all-year) organic food production that is totally free of chemical and synthetic fertilizers, pesticides, and herbicides. Soil fertilization is done organically by supplying compost and other organic matter generated from plants and animals so that the ground may naturally feed the plants.

Sustainable cultivation of plants is often known as regenerative agriculture or permaculture. It is a way of growing or obtaining food that is both environmentally and ethically responsible.

Innovation farm

The objective is to enhance the degree of profitability of production for the farmer, which will lead to lower retail pricing and so expand the availability of organic food. This production model, combined with mechanization and automation, ensures that the product meets the quality expectations of modern consumers, while also working to create a reference and self-sufficient farm environment in which both the processes, fertilizers, and machines we use meet all of the conditions for the crops born here to be fully ecological and meet the most stringent environmental conditions.

Health farm

One of the elements of Health Farm will be a rest and rehabilitation complex based on the unique healthy and environment friendly technology. Our goal is to examine and implement the anti-ageing program for seniors. environmentally harmful inputs.

The combination of access to high-quality food, a carefully selected diet, living in a clean environment and carefully profiled rehabilitation will be the basis of our activities. An important supplement to a health farm is the cultivation of a wide variety of herbs and the breeding of bees.

Culture farm

It aims to educate and provide information on topics such as the environment, modern agriculture, and innovation, as well as to promote traditional and handcrafted items that are part of Warmia's historical cultural heritage. Ostoja Natury TV is an important aspect of the cultural farm. They produce documentaries and video reports. The films tell the stories in an interesting way that makes you want to see them. Traditions and progress must coexist. So, on the one hand, the region's cultural assets and competitive advantage are dictated by the commodities and services that once gave it identity and developed a distinct character, based on many years of experience.

Green energy farm

It also focuses on RES (renewable energy sources), but the main emphasis is on the development of Bio mass energy and the construction of a small agricultural biogas plant with a cogeneration engine capable of producing electricity, heat, and cold and thus creating a 360 cycle where waste is fuel.

It intends to build a self-sufficient, waste-free project environment for rural farmers. In many circumstances, our building will be totally self-contained and will not be connected to the network. It will offer heat, energy, and water, as well as garbage disposal, without causing environmental harm.

Photovoltaic panels fitted with correct management systems and suitably scaled energy storage, wind turbines, and heating systems drawing on renewable energy sources such as sonic furnaces or air and ground source heat pumps are examples of technology used to power independent "off-grid" residences. Domestic water will be repurposed using local biological sewage treatment facilities, and rainwater will be retrieved using landscape water management (big and small retention, ponds, passive systems, rain gardens).

The goal is to produce a net zero building with zero net energy consumption, which means that the entire quantity of energy needed by the building on a yearly basis equals the amount of renewable energy generated on site (solar roof).

A one-of-a-kind ecosystem for long-term food storage

Non-toxic building material - Hempcrete is a relatively safe material, with less chemicals and herbicides used in growing. (Taskforce action plan, poland, 2022)

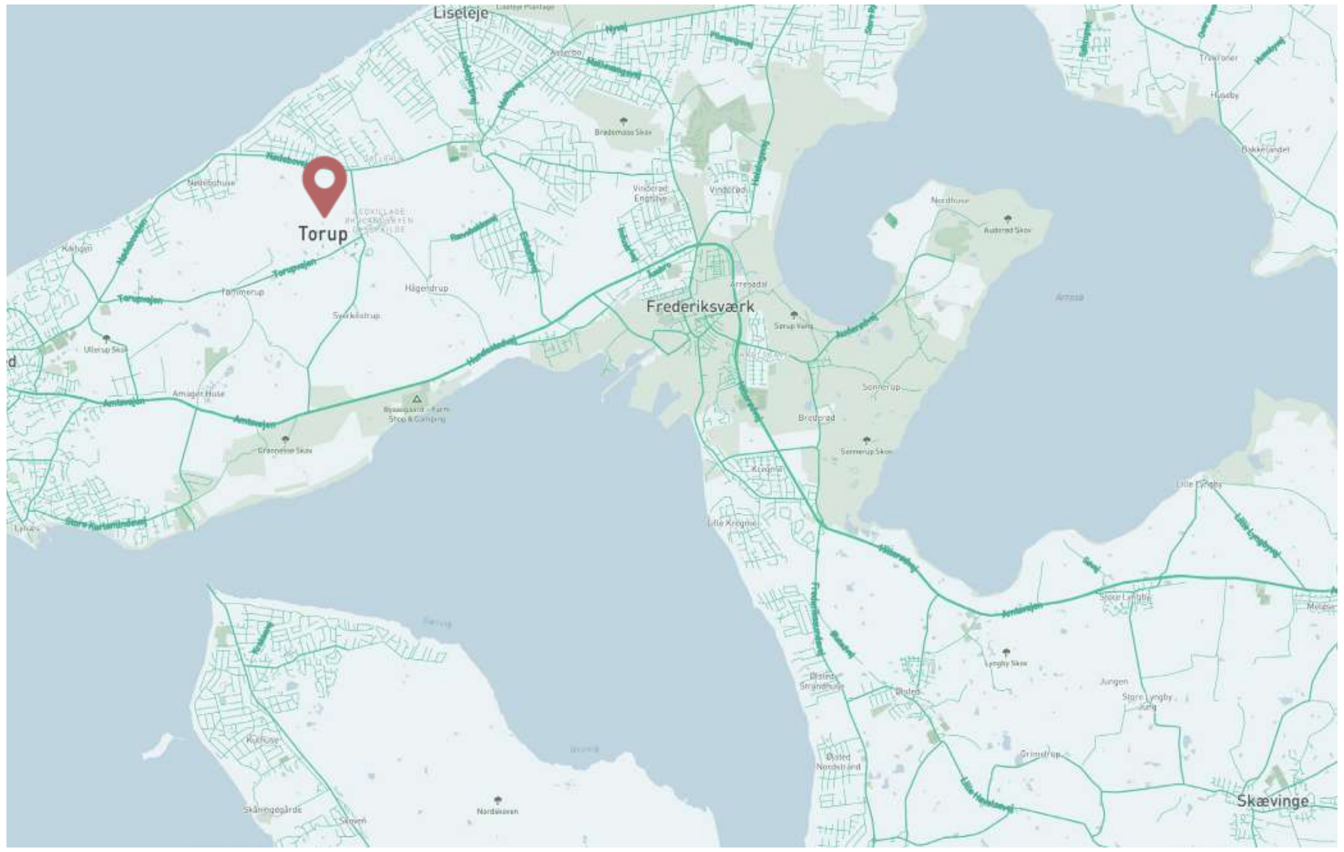


FIG. **15**- Torup map

Torup village case study

General overview

Location

Torup, Denmark

It is situated at the Northern coast of Zealand, 60 km to the north-west of Copenhagen, but somewhat isolated due to its location on a peninsula.

Distance to other parts

Torup to Frederiksværk: 7 km

Torup to Hundested: 6 km

How to reach Torup

By Car:Torup to Frederiksværk: 10 min

Torup to Hundested: 8 min

On the Train:Torup to Frederiksværk: 13 min

Torup to Hundested: 20 min

By Plane:Nearby Airports:

Alborg: 76.64 km (56 min)

Billund: 127.09 km (2h30 min)

Population

The small village Torup has a population of 356 inhabitants.

FIG. **16**-Torup village

What are the main values of villages?

- Torup is distinguished for its emphasis on sustainability. It's been called 'ecological', 'organic,' and sustainable. The group of individuals build an organic community that will now serve as a model for a substantial addition to the village 'Hvideland,' which will also be built on ecological principles.
- Torup's culture and heritage, which is hospitable, democratic, open-minded, and ambitious, separates it from other Danish villages. Furthermore, the people of Torup don't just sit around and wait for things to happen; they take action.
- Potential user capable of participating in a variety of activities and taking on duties

What are key challenges?

Fast and reliable broadband

- With a rising number of home-based workplaces and the requirement for all businesses and stores to be completely IT-connected, the demand for quick and dependable communication is expanding. Despite local demand to enhance IT-connectivity infrastructures, this has so far bypassed Torup.

Transport

- During the day, the local rail stops at Torup each half-hour. This is critical for schoolchildren and other commuters' mobility alternatives. This is a problem since IT communication and transportation are critical to rural development.(Torup smart village strategy ,2021)

SWOT ANALYSIS

Strengths

- Well established local democracy
- Very good engagement / involvement (many volunteers)
- Good cooperation with municipality
- Human capital (diverse and resourceful)
- A culture of acceptance
- A tradition for acting on needs (not just wait)
- Sustainability is part of the Torup DNA
- Railway with trains every 30 min
- High level of local services for a village this size School,
- kindergarten, assembly hall, shared office-space, shops

Weaknesses

- A small village with few people
- Remoteness – limited access (situated on a peninsula)
- Heating (homes and community buildings) mainly based on fossil fuel
- Weak guidelines for cooperation with authorities
- Lack of fast and reliable broadband

Opportunities

- Trends of division
- Attracting / integrating (resourceful) newcomers
- Opportunity for better work/life balance
- Growing interest for sustainability
- Create further commuter-hubs/common workplaces

Threats

- Lack of integration of present and new inhabitants
- Infrastructure: railway cuts; lack of fast IT-connections
- Societal/administrative centralization
- Lack of capital/ access to house bank loans
- Danish trend is depopulation of rural areas
- Reluctance for mortgage for houses in rural areas
- Outside investors/ entrepreneurs buying the land for development (Torup smart village strategy ,2021)

What are torup’s smart strategies and interventions?

Increase population

A development plan had to be developed and accepted by the municipality before the community could be expanded. The municipality was aware of the demand for building sites and had plans to expand the hamlet significantly.

- Purchase the land and farm building
- Establish alternatives to general funding practices for private homes
- Plan/ensure “welcoming and involvement” Integration

Sustain and improve local service

Local services, such as stores, schools, kindergartens, assembly halls, and restaurants, which have all been established by local initiatives throughout the years, require ongoing support and growth.

Maintain the current stores and restaurants.

- Maintain school, kindergarten, and the assembly hall.
- Ensure collective traffic;
- Ensure availability of fast broadband.
- Create a “caretaker” function to give service
- Formal agreement on a collaboration guide with the municipality

Tools and talents-support

The goal is to promote sustainability, and reuse/recirculation, and to build social interactions in the community. The IT application that will be built will enable the sharing of physical equipment and utensils for home, gardening, and maintenance purposes, as well as the sharing of

- human resources/services in many Uncover requirements and opportunities
- Create an organizational model: hiring/rent / insurance/upkeep
- App development App implementation

Sustainable common heating

To align with the overall sustainability approach and reduce the use of inefficient and individual heating systems, such as oil burners, the local semi-public company has formed a parent company with Torup with the intention of developing a new, sustainable, and integrated common heating system. Whether or whether this target will be met is dependent on ongoing talks, financial ramifications, and potential technical solutions.

(Torup smart village strategy ,2021)

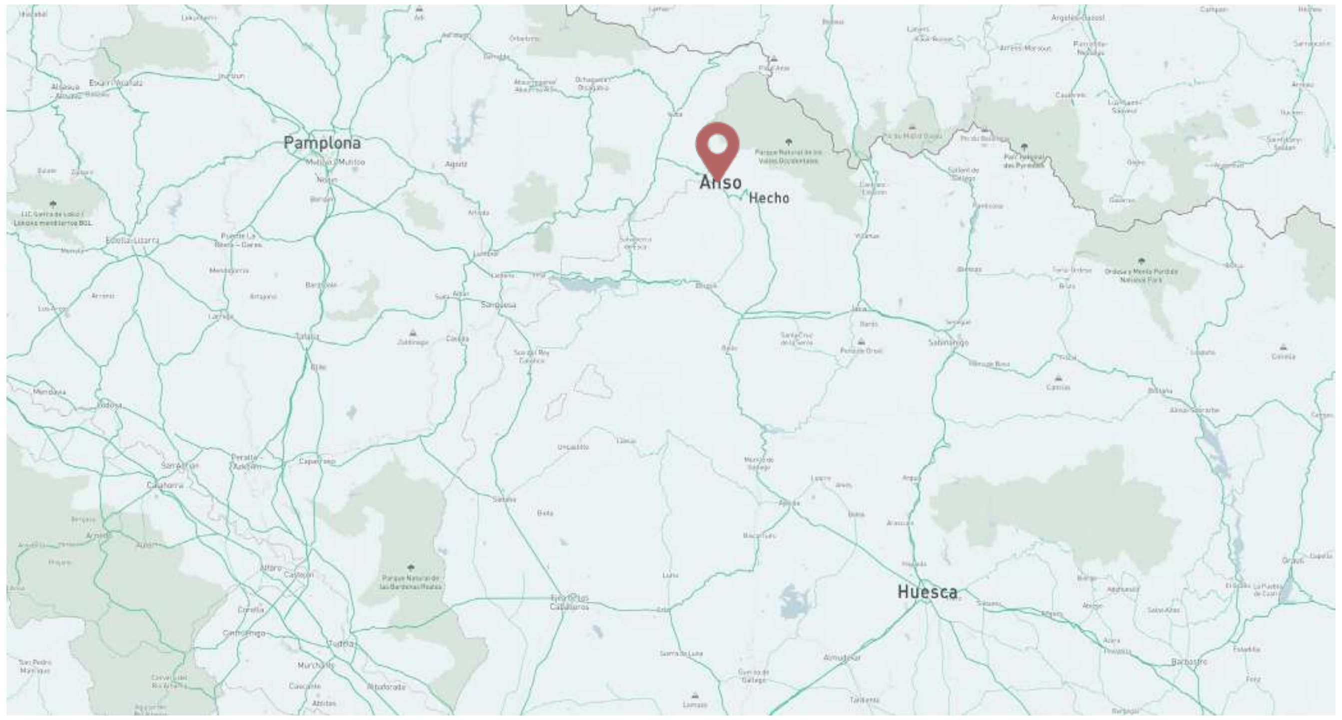


FIG. **17**-Ansó map

Ansó village case study

General overview

Location

Ansó is located in Spain, in the region of Jacetania. It is a border territory between Navarra and Aragón, and it borders France for more than 50 kilometers.

Distance to other parts

Ansó to Huesca: 102 km
Ansó to Pamplona: 101 km
Ansó to Hecho: 13 km

How to Reach Ansó

By Car: Ansó to Huesca: 1 hour 35 minutes
Ansó to Pamplona: 1 hour 22 minutes
Ansó to Hecho: 12 minutes
On the Train: Huesca to Castiello Pueblo: 1 hour 20 minutes
Castiello Pueblo to Ansó: 50 minutes
By Plane: Nearby Airports
Santa Cilia De Jaca Airport (Huesca): 103 km
Pamplona Airport: 102 km (1 hour 16 minutes)

Population

Ansó has 405 inhabitants who have access to simple but ample services, including a health clinic, banks, post office, pharmacy, grocers, butcher, bakers, and more. The state school stands out as innovative.

FIG. **18**-Ansó village

What are the main values of villages?

Nature

Natural beauty and exceptional biodiversity draw nature lovers and mountain sports enthusiasts to this area. Its broad territory comprises the Valles Occidentales Natural Park to the north and the Foces de Fago and Biniés Protected Landscape to the south, where you may participate in all high and medium mountain activities.

Cultural heritage

It is still one of Spain's richest and most diverse traditional costumes; its significance stems from the Middle Ages and Renaissance roots of some of the clothing. The outfit has exceptional anthropological importance. It is because the Ansó Outfit Museum is devoted to the outfit's growth over time.

Architectural heritage

The village's typical Pyrenean architecture has been largely conserved, and it has been designated as a Place of Cultural Value/Interest. As an architectural complex built on noble materials such as stone, wood, and tiles typical of the region, it has been designated as an Asset of Cultural Interest by the Government of Aragon.

What are key challenges?

Depopulation

They are experiencing a process of population decline (approximately 100 persons in the previous ten years), which threatens the survival of essential services.

Difficult access to housing

Expanding tourist development and ownershipThe lack of interest in selling or renting their vacant properties makes it difficult for young villagers to establish their own homes and for new people to find a place to live in the village.

Connectivity

Ansó is poorly linked in terms of infrastructure, mobility, and broadband/fiber optic capacity due to its remoteness. This impedes professional and personal growth, as well as makes it more difficult for people to stay or settle in the village.

Social-economic decline

The village's social, economic, and cultural activities have dwindled as a result of the conditions. This is most seen in the decline in the number of people willing/able to establish new businesses. (Ansó smart village strategy, 2020)

SWOT ANALYSIS

Strengths

- Care and maintenance of the natural resources that it offers the valley and the trades dedicated to it
- Access to nature and mountains: Natural Park
- Permanence of the historical and architectural heritage
- Great adaptability in terms of sustainability environmental, economic and social development
- Good access to basic services: quality health system
- The School is an innovative and unique educational attempt in the rural area.
- Good local acceptance of cultural and social initiatives

Weaknesses

- Continued population decline: aging, little birth rate and search for job opportunities in areas urban
- Difficulties with the physical connection and precariousness in the digital
- Access to housing
- Scarcity of resources to invest in rural areas

Opportunities

- Rural life is a pleasant alternative for leaving
- We can generate clean energy using our resources according to the current plans for the Transition Eco/Energy at European and national leve
- Participation in the “Smart Villages” strategy and consequent interest from institutions and private companies
- Unused buildings and spaces which can be converted for use by business start-ups and by professional projects.

Threats

- The decrease in population leads to the precariousness of the basic services
- The scarcity of resources for the care of the child population (0-3 years)
- The financial cut at the regional level due to the economic
- Lack of interest of the older population in renting or selling their houses
- High price of housing due to the tourist impact
- Many services are located in Hecho (neighboring town)

(Ansó smart village strategy ,2020)

What are ansó's smart strategies and interventions?

The key objectives of the smart village plan Overall goal: To provide perfect circumstances (technology, energy, and human) for population stabilization and recruiting new inhabitants. This would improve the overall quality of life in the community and have a positive and long-term impact.

Improve connectivity

- EMBOU installed its own fiber line that covers approximately the entire area and provides 100MB. However, we need to get funding and deploy Fiber Optics.
- Install WiFi hotspots
- Expand the mobile coverage network

Facilitate access to housing

- Give continuity to the “Program of promotion and rental assistance of the neighborhood house
- looking for more owners to join the initiative thus enabling the rental of medium and long duration vs. second home for people ,young and new residents.
- Rehabilitate municipal housing
- We want to rehabilitate the two municipal houses and readapt the spaces to expand their ability.

- Build 4 springboard houses (Ansó smart village strategy, 2020)

Promote entrepreneurship

- Prepare a municipal space to create a coworking
- Rehabilitate a municipal space to create multipurpose warehouses
- Promote entrepreneurship projects to curb depopulation and promote innovation and technology in the rural world, in Ansó special.

Positively impact the energy transition

- Positively impact the energy transition
- They want to achieve a positive impact on the environment and adapt to models energy sources that are more sustainable than the current ones to supply municipal buildings and town lighting.
- Implement renewable energy
- They seek to move towards the generation of electricity through the installation of a mini-hydraulic power plant, photovoltaic systems, and chargers for electric cars.
- Improve waste management
- They seek to improve waste management according to the principles of reuse, recycling and self-production of compost.
- Develop the Services Valuation Project environmental
- They aim to investigate the assessment of the environmental service that Ansó provides to the lowlands in terms of CO2 emissions and water quality, and then seek payment for it. It will be about a pioneering pilot initiative in Spain.

Facilitate family-social development

- Facilitate family reconciliation
- They intend to support conciliation by establishing a child care space (0-3 years) in which to develop a care network among interested families, either through the mother's and dads' own positions or through the position of a trained person.
- Strengthen community cohesion
- They seek to strengthen the cohesion of the community by reactivating the film club and facilitating social transportation.
- Contribute to educational innovation
- They aim to contribute to the promotion and development of an educational project based on active methods, which allows students to acquire substantial learning by addressing curricular subjects in a cross-disciplinary manner.
- Improve management and access to the environment
- They seek to increase access to trails near town, control the capacity of the popular spaces, and create jobs.

Multi activity center

- Using the sawmill warehouse means preserving an important piece of the town's industrial architectural heritage. The warehouse was built between 1920 and 1930 to house Ansó's wood industry's 20th-century expansion, thus using it as a container for new activities that revived the town's economic and socio-cultural fabric meant reactivating Ansó's memories.
- The early restoration concept involves preserving the structure's original look with stone gables, interior flexibility, and longitudinal character while leaving the trusses visible.(Ansó smart village strategy, 2020)

FIG. **19**-Ansó context

FIG. **20**-Ansó context

Comparative case studies of social and functional intervention

		Ostana (Italy) population 50	Stanz (Austria) population 1844	Tomaszyn (Poland) population 18	Torup (Denmark) population 356	Ansó (Spain) population 405	Toiano (Italy) population -
Stakeholder	Resident Non resident	• Active stakeholder • Welcome to the remote worker, refugee, tourist	• Active stakeholder • Welcome to tourists	• Active stakeholder • Welcome to tourists and local to back to live and remote workers	• Active stakeholder • Welcome to newcomers to stay there and tourists	• Active stakeholder • Welcome to tourist and local to back to live	! Abandoned • Welcome to local, tourist , remote worker
Collaboration	Association University	• Polytechnic University, • alpine association and research center • Great collaboration with local	• Great collaboration with local	• Great collaboration with the local community ! Lack of collaboration with other associations	• Close cooperation with Halsnæs Municipality. • Great collaboration with local	• Great collaboration with local	• Universities, art and cultural association, company (remote worker) • The rest of the neighboring villages and farm
Function	Tourist Local community	• Adding more buildings, but not enough, ! Particularly lack of housing for newcomers • Open library for a public meeting place to study, work and consult digital contents	• New apartment • Building a village store to improve “Nature & Exercise” “Eating & Drinking” “Culture in Town & Country,” and “Regeneration & Wellness	• Multi activity center • Building new houses • Give continuity to the “Program of promotion and rental assistance of the neighborhood house	• Improving local services such as kindergarten, school, shops • Buy land to build new houses	• Adding the food market for the local community ! Lack of activity for tourist	• Renovation house Adding bar and restaurant • Multifunction spaces (coworking ,festival or event) • Creating residence and shopping store
Mobility	Public services Public infrastructure	! Lack of public accessibility • Adding the shuttle bus during peak season • E-bikes and e-cars	! A few public transportation options. ! Dependence on automobile traffic	! Infrastructure and transportation are poorly related. • Adding the electric car charging point	• The local rail service stops at Torup every half-hour, but this is insufficient, ! Lack of public accessibility	! Lack of public transportation ! Nothing proposed to improve the transportation	! Lack of public accessibility • E-bikes and e-cars

FIG. **21**-Comparative case studies of social and functional interventions in six villages

Comparative case studies of technical intervention

		Ostana (Italy) population 50	Stanz (Austria) population 1844	Tomaszyn (Poland) population 18	Torup (Denmark) population 356	Ansó (Spain) population 405	Toiano (Italy) population -
Energy	Renewable energy Energy transition	• Solar panels, wind energy; geothermal solutions, renewable public lighting • Forest management(availability of timber and biomass) • Energy Transition. Local energy community based on a smart grid and renewables	• Use water, wind, PV, and biomass as sources of energy. • Set up a digital local currency for the community based on energy tokens.	• Development of biomass energy and the construction of a small agricultural biogas plant with a cogeneration engine capable of producing electricity and heat. • Use water, wind, PV, water management,..	• New heating system that support smart solutions to recycling,...	• Nature Classroom that based on learning about installing renewable energy and irrigation systems. • Waste management • Searching to provide an environmental service to the lowlands in terms of CO2 and water quality	• Use water, wind, PV, and biomass as sources of energy to create a sufficient village. • Waste and water management • Design an energy transition model according to saving energy from these sources. • Design the business model for using or sending the energy
Digital infrastructure	Wifi,…	! The lack of infrastructure includes a lack of fast internet access. Broadband, which creates a digital gap	! The lack of infrastructure	! The lack of infrastructure	• Ensure availability of fast broadband. • Establish ‘Tools and Talents’ app to support sustainability reuse/recirculation –involvement	• Install Wi-Fi hotspots • Expand the mobile coverage network • Create a community travel share app • Develop a digital marketing plan	• The lack of infrastructure • Create infrastructure, especially access to broadband internet, to encourage remote workers to settle.
Food	Organic farm	! No program for developing farm	! No program for developing farm	• Introducing the farm model – Food, especially organic food, are critical points in this area	! No program for developing farm	! No program for developing farms	• Green and technical farm design

FIG. **22**-Comparative case studies of technical intervention in six villages

Principles of renewable energy integration

Buildings must grow less dependent on fossil fuels and must move quickly to electrify and decarbonize their energy use. Solar, wind, biomass, geothermal, and hydroelectric power are examples of renewable energy sources that can be utilized in buildings. These sources are necessary to meet the nearly zero-energy building (NZEB) standard, which calls for a building's energy consumption to be mostly met by renewable sources. All new construction should be solar-ready to allow for the future, affordable installation of solar technologies. Accordingly, they ought to be tailored for solar production according to the solar irradiance of the location, enabling the installation of solar technologies without the need for pricey structural changes. Additionally, member states should ensure the deployment of appropriate solar installations on new buildings, both residential and non-residential, as well as on existing non-residential buildings. (Directive (EU) 2024/1275)

Widespread deployment of solar energy on buildings would significantly help protect consumers from the rising and volatile prices of fossil fuels, reduce the exposure of vulnerable citizens to high energy costs, and provide broader environmental, economic, and social benefits. To efficiently exploit the potential of solar installations on buildings, member states should establish criteria for implementing and possibly exempting the deployment of solar installations. These criteria should align with the assessed technical and economic potential of solar energy installations and the characteristics of the buildings involved. They should also consider the principle of technology neutrality and the combination of solar installations with other roof uses, such as green roofs or other building services.

In the effort for a greener future, solar energy presents a promising path toward environmental sustainability. However, it's essential to acknowledge the variability of solar radiation levels throughout the day, across seasons, and under the influence of atmospheric conditions. Moreover, solar energy generation completely stops at night.

All of these aspects highlight the fact that solar energy cannot be the only renewable energy source; rather, it must be combined with other forms of renewable energy to guarantee a steady supply of electricity throughout an area. Installing micro-generation technologies on building rooftops, such as solar collectors and photovoltaic panels, offers a big chance to improve building energy efficiency. However, the growing popularity of photovoltaic power plants to generate electricity could have a negative impact on rural landscapes, changing the natural and cultural heritage and jeopardizing agricultural practices.(Directive (EU) 2024/1275)

The potential displacement of agricultural activities due to the use of rural areas for solar energy production could have an impact on local development and raise issues of social equity with regard to land values and rights. On the other hand, wind energy has historically aided in the development of rural areas and has recently become a more technically and economically feasible renewable energy source. Interestingly, wind power generation emits no waste or pollutants, which makes it a useful tool for reducing greenhouse gas emissions.

Wind power varies significantly year-over-year, with winter being the season of highest production. Wind-generated electricity is implemented through wind farms, which are groups of turbines connected to an electricity substation. Nevertheless, the implementation of this technology is restricted by the area's capacity to accommodate production units and the accessibility of locations with adequate wind speed (at least 20 km/h). (Poggi, Firmino, & Amado, 2018)

EPBD objectives

By 2050, following current trends, the Final Energy Demand (FED) in Europe is projected to decrease by 20%. However, with the implementation of the Energy Performance of Buildings Directive (EPBD), an 80% reduction from the 2015 FED levels is anticipated. Approximately half of these energy savings will come from renovating buildings constructed before 1980, while one-fifth will result from more efficient new constructions. Globally, adopting the EPBD could further reduce the 2050 total FED by 10%, from 81 to 72.5 EJ. Worldwide implementation would lead to a 37 EJ reduction in final heating demand compared to 2015 levels, while cooling demand is expected to peak before declining to 2015 levels by 2050. Thus, the total FED in 2050 would be around 15 EJ, an 80% decrease from the projected level for that year.

In low and middle-income regions, most cooling demand savings will result from high rates of new construcion. For instance, China could save an additional 6.5 EJ by exclusively constructing nearly Zero Energy Buildings (nZEBs) from 2015 onwards. Globally, at least 50% of the 2050 FED savings would be attributed to implementing nZEB construction, with this figure rising to 80% in regions like India and Africa.

The 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) was held in Paris, France, in December 2015. At this conference, 197 State Parties to the UNFCCC met for the first time to establish the Paris Agreement, which aims to reduce global warming (UN, 2015). By July 2018, 195 Parties had ratified the Paris Agreement, committing to the long-term goal of keeping global average temperature rise below 2°C, with efforts to limit it to 1.5°C.

Special attention is paid to improving the energy efficiency of buildings, particularly residential ones. The European Union (EU) began an ambitious legislative journey in 2002 with the introduction of the Energy Performance of Buildings Directive (EPBD - Directive 2002/91/EC). This directive established methods for calculating building energy consumption, energy performance certificates (EPCs), and minimum energy usage requirements in buildings. Subsequently, the EPBD was revised in 2010 (Directive 2010/31/EU), mandating nearly zero-energy buildings (nZEB) as the standard for all new constructions by 2020. However, focusing solely on new construction is insufficient; the current rate of energy renovation in the existing EU building stock, around 1% per year (varying by country), must be increased .

In 2012, the EU implemented the Energy Efficiency Directive (EED - Directive 2012/27/EU), which established a legally binding framework of measures to promote energy efficiency throughout the energy supply chain. The EED requires EU Member States to conduct energy-efficient renovations on at least 3% (by floor area) of their own governmental buildings each year beginning in 2014. With the 2018 amendments to both the EPBD and the EED (Directive 2018/844/EU), EU Member States are now required to develop strategies for cost-effectively transforming their existing building stock into fully decarbonized national building portfolios by 2050. Furthermore, they must establish milestones for 2030 and 2040 to track progress, including measurable indicators for renovation rates and overall building energy efficiency. (Directive (EU) 2024/1275)

Defining the ZEB

The term ZEB can be applied to both Zero Energy Buildings and Zero Emissions Buildings, though they are often mistakenly treated as the same. In reality, their definitions are quite different. A Zero Energy Building focuses on the amount of energy it consumes during regular operations, while a Zero Emissions Building emphasizes the carbon emissions it generates. Specifically, a Zero Emissions Building ensures that it produces enough clean energy to offset the fossil fuel-based energy it uses. In addressing human-induced climate change, energy consumption implicitly affects emissions in Zero Energy Buildings, but Zero Emissions Buildings make carbon reduction an explicit goal.

Definitions of Zero Energy Buildings (ZEBs) are still developing, as the concept is relatively new. The concept was first developed in the 1970s when the Technical University of Denmark built the Zero Energy House, a groundbreaking example. Under typical Danish weather conditions, this experimental building was designed to be self-sufficient in hot water and space heating. High insulation levels, heat-recovery systems, and solar heating are examples of energy-saving features that helped it achieve this. For its electricity needs, the house was still dependent on the municipal grid. A more comprehensive conversation about ZEBs started in 2007 and attracted attention from around the world as worries about energy scarcity and climate change grew. By defining "zero carbon homes" in late 2006, the UK set a precedent. A six-tier sustainability rating system was introduced by the Code for Sustainable Homes (CSH), where a home rated at Code Level 6 is considered a "zero carbon home." This indicates that no net carbon dioxide emissions are produced by the house's energy use, which includes lighting, heating, hot water, and other energy-related expenses.

After initially appearing in the Code for Sustainable Homes (CSH), the idea of energy efficiency is now a key component of the Zero Energy Building (ZEB) definition. Depending on the boundaries and metrics chosen, ZEBs can be defined in a variety of ways. Depending on the goals of the project, the design philosophies, and the priorities of the building owner, several definitions might be required. For example, energy costs are typically the concern of building users, whereas national energy supply and source energy are the focus of government bodies. Reducing emissions from the use of fossil fuels is a common goal for environmental organizations, and building designers may prioritize site energy usage for regulatory compliance. Owing to the disparity in viewpoints, four different definitions of ZEBs have been put forth: Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Costs, and Net Zero Energy Emissions.

A building with net zero site energy produces as much energy as it uses there. Furthermore, a hierarchy of preferences for renewable energy is proposed, where energy efficiency is prioritized, highlighting the need for a strong ZEB definition to emphasize energy efficiency first.

The International Energy Agency (IEA) provides two definitions of zero net energy buildings and zero carbon buildings from a global perspective. Zero Net Energy Buildings are ones that, although they may occasionally use grid power, achieve energy neutrality over a year by producing as much energy as they consume from the grid. They do this by not relying on fossil fuels for lighting, heating, cooling, or other energy needs. On the other hand, zero-carbon buildings are those that produce enough carbon-free energy to offset any carbon-producing energy they use, making them either carbon-neutral or carbon-positive throughout the year.

The majority of definitions of Zero Energy Buildings (ZEBs) presuppose that the structure is linked to one or more utility grids, including networks for biomass and biofuels, district heating and cooling systems, gas pipelines, and electricity. Buildings can now import and export energy, doing away with the requirement for on-site energy storage. This does not, however, prevent a ZEB from existing independently of the grid. A building must meet carbon or energy neutrality as a primary requirement to be classified as a ZEB.

In the European Union, where buildings are responsible for a significant portion of total energy consumption, the definition of a ZEB remains flexible. Near zero-energy buildings were the target for 2019, though the term "near" was not made clear. There are still many EU nations without an official ZEB definition. The ZEB definition has observed a trend of relaxation in the UK. Since 2008, there have been continuous evaluations and modifications because of ambiguities and industry worries regarding the viability of the initial definition. The notion of "allowable solutions" has been presented, denoting carbon-reducing actions that developers can employ to fulfill off-site carbon reduction objectives. While the specifics of what constitutes "allowable solutions" are still being worked out, several proposals seek to establish a simple financial framework to finance off-site carbon savings via investments in renewable energy infrastructure.(Panagiotidou & Fuller, 2013)

It is possible to define ZEBs differently, and each nation may create its own according to its unique circumstances. Nonetheless, it is crucial to employ a uniform framework that covers all pertinent ZEBs. The system boundary is one of the important areas where the current definitions diverge. Previous definitions usually only addressed the energy requirements for heating and hot water, leaving out cooling because cooling technology was not widely available then. Energy requirements for appliances, lighting, and ventilation are still sometimes overlooked. Furthermore, the majority of definitions only take into consideration operational energy and ignore embodied energy, which is the energy needed for demolition, upkeep, and the production of building materials. A common cause of this omission is the absence of a reliable technique for embodied energy calculation. The energy efficiency threshold is another definitional variation. Not all definitions require energy efficiency, so a building can qualify as ZEB even if it only uses a large renewable energy system if it optimizes its energy use and encourages alterations in behavior to reduce consumption. Moreover, the definitions do not outline recommended practices for controlling and storing excess energy production. The most practical option at the moment is to connect to the utility grid because battery storage can be costly and raise the embodied energy of the building.

ZEB categories

Four types of residential Zero Energy Buildings (ZEBs) are outlined. The Autonomous ZEB and Net Zero Energy Building (Net ZEB) categories are based on definitions provided by Laustsen. In contrast, the Near Zero Energy Building (Near ZEB) definition was introduced by the EPBD.

- **Energy plus building (+ZEB)**

This ZEB produces more energy from renewable sources than it consumes from the grid over a year.

- **Autonomous zero energy building (autonomous ZEB)**

This ZEB can function independently from the grid or only needs it as a backup. It is capacity meets energy requirements, including storing energy for nighttime or winter use.

- **Net zero energy building (net ZEB)**

This ZEB is energy-neutral over a year, meaning it delivers as much energy to the grid as it takes from it. Although it may draw energy from the grid, it does not use fossil fuels for heating, cooling, lighting, or other energy uses.

- **Near zero energy building (near ZEB)**

This ZEB is highly efficient, with very low energy needs largely met by renewable sources, including energy generated on-site or nearby.

In conclusion, the energy output of each category is compared to its requirements to differentiate it. While Autonomous and Net ZEBs completely satisfy their energy needs, Near ZEBs produce less energy than needed while still heavily relying on renewable sources. +ZEBs produce more energy than they consume. A subcategory of the +ZEB category known as Life Cycle ZEB is also included; this subcategory accounts for embodied energy. For simplicity, this sub-category will be combined with +ZEBs, although embodied energy is an important factor to be discussed further. (Panagiotidou & Fuller, 2013)

General comment

Member States are required to establish criteria for applying the highest energy performance class feasible for buildings with historical or architectural significance, yet lacking official protection, while preserving their character.Buildings currently contribute significantly to the Union's final energy consumption and energy-related greenhouse gas emissions. However, a large portion of Union structures remains inefficient. The predominant use of natural gas, followed by oil and coal, for heating underscores the need for energy consumption reduction in line with the Commission's energy efficiency objectives.

Integrating green infrastructure, such as living roofs and walls, into urban planning can serve as a valuable tool for climate adaptation and mitigating urban climate challenges. Member States are encouraged to promote the use of vegetated surfaces to manage rainfall, reduce urban runoff, and mitigate the urban heat island effect.

Energy demand management is crucial for influencing the global energy market and ensuring energy supply in the short, medium, and long term.

The Union's increased climate and energy ambitions necessitate a shift towards zero-emission buildings. All new buildings are expected to be zero-emission by 2050, with existing structures gradually transitioning to zero-emission conditions. Member States should consider the energy transition timeframe and economic implications when setting target timelines.

Buildings release greenhouse gases during their whole life cycle, from the time of construction to the time of demolition. In order to tackle this issue, the Commission plans to implement a Union methodology that takes into account the emissions of buildings throughout their entire life cycle. Based on this methodology, Member States will set targets for reducing whole-life greenhouse gas emissions, initially concentrating on new construction and renovations.

Regulations and objectives targeted at lowering greenhouse gas emissions should be incorporated into Member State renovation plans for the full life cycle of buildings, not just while they are in use. Promoting the use of environmentally friendly building materials—such as those derived from bio and geo sources—as well as passive low-tech methods that improve structural integrity and insulation should receive special attention.

A special focus should be on making sure that buildings are protected from heat waves, given the growing concern over the effects on the environment.

Additionally, this Directive needs to be in line with the European Solar Rooftops program and the Commission's May 18, 2022 "EU Solar Energy Strategy" communication. Widespread adoption of solar thermal and photovoltaic technologies is necessary because they save money for homes and businesses while also benefiting the environment. With the goal of achieving payback times of less than ten years, member states are encouraged to develop strong support systems for rooftop solar installations, especially when combined with energy storage and heat pump technologies.

Given the complex relationship between water and energy consumption and the rising demand for both resources, addressing the water-energy nexus is critical. Reusing and managing water resources effectively can save a substantial amount of energy, which has positive effects on the environment as well as the economy and society.

Because they provide flexibility, balancing, and storage services, electric vehicles (EVs) have the potential to significantly reduce carbon emissions and improve energy grid efficiency. This is especially true as smart charging and aggregation technologies advance. Maximizing the potential of electric vehicles (EVs) to improve system efficiency and enable increased use of renewable electricity can be achieved by leveraging their integration with the energy grid. Strong public charging infrastructure must be created as a result, particularly in parking lots.

The energy landscape is being revolutionized by the digitalization of the energy system, which makes it easier to integrate smart buildings, smart grids, and renewable energy. In order to create connected communities and smart homes, the Union's goals for high-capacity communication networks are essential to digitalizing the building industry. By giving consumers precise information about their consumption patterns and enabling more effective grid operation by system operators, incentives should be directed towards the promotion of smart-ready systems and digital solutions in the construction industry.(Directive (EU) 2024/1275)

Subject matter

The main objective of this Directive is to reduce greenhouse gas emissions and improve building energy performance throughout the Union in order to achieve a building stock that is emission-free by 2050. It takes into account a number of variables, including local and outdoor weather patterns, the requirements for indoor environmental quality, and the contribution of buildings to demand-side flexibility enhancements that increase the dependability and efficiency of energy systems.

Important clauses in the Directive include:

Establishing an all-encompassing general framework for figuring out how energy-efficient a building or building unit is.

Putting minimum standards on new construction and building units' energy performance to make sure they adhere to predetermined guidelines.

Imposing minimum energy performance requirements on currently constructed buildings and building units in order to improve energy efficiency and lower emissions.

Definitions

Building: A structure with a roof and walls, where energy is utilized to regulate the indoor environment.

Worst-performing building: A building categorized in the lowest energy performance classes.

Passive system: A design principle or building element that enhances energy performance or indoor environmental parameters without reliance on an external energy source.

Technical building system: Equipment within a building or building unit for functions like heating, cooling, ventilation, hot water, lighting, building automation, solar shading, electrical installations, electric vehicle charging, on-site renewable energy generation, and storage.

Energy performance of a building: The calculated or metered energy required to fulfill the typical usage demands of a building, encompassing heating, cooling, ventilation, hot water, lighting, and technical systems.

Primary energy: Energy from renewable and non-renewable sources that hasn't undergone conversion or transformation.

Final energy: Energy from renewable or non-renewable sources that has undergone conversion or transformation for consumption and supply to end-users.

Energy building benchmark: A platform revealing the energy performance and yearly consumption of single and multi-unit buildings over time, compared to similar buildings or modeled simulations of a reference building built to specific standards.

Waste heat: Inevitable heat produced as a by-product in industrial or power generation installations or the tertiary sector, which would otherwise dissipate unused without access to a district heating or cooling system, where cogeneration is utilized or planned, or where it's not feasible.

National building renovation plan

Every Member State must create a national building renovation plan that targets the transformation of the country's stock of residential and non-residential buildings (both public and private) into environmentally conscious and decarbonized structures by 2050. This will include transforming existing structures into zero-emission homes, which will help in reducing greenhouse gas emissions globally, promoting environmental sustainability in the process.
(Directive (EU) 2024/1275)

The Energy Performance of Buildings Directive requires EU Member States to set national definitions and roadmaps towards nearly Zero-Energy Buildings, considering the different climates and building traditions across the continent. Since more than a quarter of the building stock projected for 2050 is still to be erected, there is especially huge potential for low-energy buildings in Europe. This means guiding and aligning common principles and quality standards that will help in the implementation of effective energy-efficient concepts. The elaboration of sustainable national definitions based on EU standards is important in achieving the expected energy savings and maximizing the socio-economic benefits. The transformation to very low-energy buildings will profoundly change the construction sector and significantly increase the market share of highly efficient technologies. It also strongly emphasizes energy efficiency in the renovation of the existing building stock. Considering that the average annual rate of new dwelling construction in EU states is about 1% and that annually only about 0.07% of existing buildings are replaced, it goes without saying that any meaningful improvement has to come through the improvement in the energy performance of buildings already erected. It is expected that, by 2050, only 25% of buildings will be newly constructed, underpinning the enormous need for energy efficiency in the remaining 75% of future building stock.

“The Energy Performance of Buildings Directive (EPBD) does not impose a standardized approach for implementing nearly Zero-Energy Buildings (NZEBs) or prescribe a uniform method for calculating energy balances. Instead, it offers guidelines for European Union member states to formulate national strategies tailored to their specific geographic, climatic, and economic conditions. Each country must define NZEBs precisely, which goes beyond simply restating the EPBD’s general definition. This definition should be formalized within national legislation or clearly outlined in national plans.
Key criteria include:

- Defining NZEBs with specificity and integrating them into national legal frameworks or national plans.
- Ensuring high energy performance, which could be indicated by achieving a high class in the Energy Performance Certificate (EPC), meeting a specific building standard like “passive house,” or demonstrating a percentage improvement over national minimum energy performance requirements.
- Specifying minimal energy consumption in terms of energy needs, final energy consumption, or primary energy consumption, typically expressed numerically (e.g., kWh/m²).
- Promoting substantial use of renewable energy, which can be defined as the percentage contribution of renewable energy or a minimum amount of renewable energy (in kWh/m² per year) needed to meet the remaining energy demands.
- Member states must integrate their national definitions of NZEBs into their legal frameworks and provide detailed information in their national plans to increase the adoption of NZEBs across the region.” (Chiaroni & Guiducci, 2017)

- NZEBs are cornerstones to achieving net-zero energy consumption in buildings. Every country brings objectives, considering climatic zones, kinds of architecture, and types of building structures while keeping in focus the principal elements enunciated by the European Commission. These are strategies of essence to enhance building energy efficiency and decrease energy use.

- **Orientation and building shape**

Buildings are oriented and shaped to maximize winter heat gain, minimize summer overheating, maximize interior natural lighting, and reduce artificial lighting.

- **Enhanced insulation**

Adequate insulation of walls, windows, and roofs avoids undue loss of heat, which constitutes the majority of energy consumption. Different building elements require more or less insulation, depending on how much of them is directly exposed to the outdoors.

- **Reduction of thermal bridges**

The areas in the building envelope that have higher heat flow are reduced with the help of insulation materials to bring down energy losses.

- **Airtightness**

The prevention of unwarranted air infiltration into the building envelope keeps at bay the resultant excessive rise in energy use. The techniques that assure airtightness, especially at the joints of windows and doors, include internal plastering and some specific materials.

- **High-performance windows**

Provide daylighting, passive solar heating, and reduced heating losses, as appropriate to design and orientation with respect to climate.

- **Thermal mass**

Used effectively—high thermal mass will store heat effectively, reducing both heating and cooling loads, and providing significant comfort from the thermal flywheel effect in certain building designs and climates.

- **Ventilation strategies**

Efficient ventilation systems provide fresh air to a building while preventing loss of energy. Mechanical ventilation with heat recovery from extracted air is more energy-efficient compared to natural ventilation.

- **Energy-efficient lighting**

Technologies such as LEDs have high efficiency and a long lifetime, making them reduce energy consumption compared to traditional lighting.

- **Automation systems**

Building automation ties together all the components related to energy use in a building, allowing them to function in a coordinated manner so that optimal energy consumption is attained while maintaining thermal comfort—a criterion of necessity in NZEB implementation.

- **Heat pumps**

Ground-source and air-to-water heat pumps transfer efficiently the heat of the ground or air for heating and hot water, thus making a large contribution towards NZEB requirements.
In view of this, each NZEB plan takes into account local conditions and climatic factors when it comes to renewable energy supply options at the country level. Key sources include solar energy in its thermal and photovoltaic form; wind energy, mainly used for electricity production; geothermal energy from heat workability in the ground; and biomass, particularly for heating. These technologies will play a very important role in achieving the objectives set by the reduction stipulated in the directive, that is, dependence on fossil fuels and primary energy use in buildings. (Directive (EU) 2024/1275)

The European Energy Efficiency Building Directive places a strong emphasis on the integration of Renewable Energy Sources (RES) to effectively reduce primary energy consumption. Each national plan for Nearly Zero-Energy Buildings (NZEBs) tailors its approach by considering a range of on-site renewable energy options that best suit local geography and climate conditions. The primary RES and technologies identified for NZEBs include:

- **Solar energy**

Solar energy technologies have wide applications in buildings, both solar thermal and PV systems. Solar thermal collectors collect solar radiation and change it into heat for use in space heating or domestic purposes. Solar thermal collectors include glazed flat, unglazed flat, and vacuum collectors, offering different efficiencies with associated costs. PV technologies achieve this through semiconductor materials. These include conventional PV cells, which have high efficiency and cost, thin-film PV technology, which is being progressively improved with lower efficiency and cost, and organic PV cells that are still in the experimental phase.

- **Wind energy**

The kinetic energy of the wind is transformed by wind turbines into electricity. While large sets of wind turbines make an extremely effective way of generating electricity to be supplied to the grid, smaller numbers of individual turbines might be used in combination with residential or public buildings to make inroads into the usage of fossil fuels. The larger challenges facing the implementation of wind turbines concern the space needed for their installation, significantly reducing their applicability for densely populated urban areas or historic sites.

- **Geothermal energy**

This kind of energy exploits the temperature difference between the earth and the air above it for heating during winter and cooling during summer. Ground-source heat pumps are crucial for both efficiently drawing out and delivering the heat from the earth into buildings. They work with very high efficiencies—producing more than they consume—and are strongly recommended throughout European NZEB plans.

- **Biomass**

It is a resource gained from organic matter through photosynthesis and is mainly used for space heating and water heating. Biomass boilers are fitted to any type of building design. Such boilers are operated by pellets, wood chips, or even firewood depending on the need at hand.

Given the intermittent nature of wind and solar energy, effective energy storage solutions are essential for optimizing NZEB performance. Battery-based systems are expected to play a pivotal role alongside thermal and hydrogen storage technologies. These solutions enable buildings to adjust to fluctuating energy demands, thereby enhancing overall energy efficiency and supporting the transition towards sustainable building practices. (Directive (EU) 2024/1275)

It is supplemented by the Renewable Energy Directive, which specifies some obligations concerning buildings. In accordance with Article 13 of the RED:

By 31 December 2014, Member States shall lay down minimum levels of renewable energy to be used in buildings in their building regulations and codes for new constructions and existing buildings that are subject to major renovation. Such requirements may refer to district heating and cooling systems using a significant share of renewable energy sources. It gives latitude to Member States to adopt measures at a national level, seeking quite significant improvements in energy efficiency and combined heat and power generation, passive, low-energy, or Zero-Energy Buildings.

Member States shall ensure that new public buildings, and existing public buildings undergoing major renovations, are used as best-practice models in complying with this Directive from 1 January 2012 onwards at national, regional, and local levels. They may allow compliance through adherence to standards for zero-energy housing or by enabling the installation of renewable energy systems on the roofs of public or mixed private-public buildings by third parties.

It shall apply from 1 January 2012, as an exemplary role at national, regional, and local levels, within the scope of this Directive. The obligation may be taken by the Member States through reaching standards for zero-energy housing, or by allowing third-party installations of renewable energy sources on the roofs of public or mixed private-public buildings, among other measures. (Directive (EU) 2024/1275)

	Pluses	Minuses	Other Issues
Site ZEB	• Easy to implement • Verifiable through on-site measurements • Conservative approach to achieving ZEB • No externalities affect performance; can track success over time • Easy for the building community to understand and communicate • Encourages energy-efficient building designs.	• Requires more renewable energy exports to offset the consumption of fossil fuel-generated energy • Does not consider all utility costs (can have a low load factor). Not able to equate fuel types • Does not account for non-energy differences between fuel types (supply availability, pollution).	
Source ZEB	• Able to equate the energy value of fuel types used at the site. • Better model for impact on the national energy system. • Easier to reach ZEB.	• Does not account for non-energy differences between fuel types (supply availability, pollution). • Source calculations are too broad (do not account for regional or daily variations in electricity generation heat rates • Source energy use accounting and fuel switching can have a larger impact than efficiency technologies. Does not consider all energy costs (can have a low load factor)	• Need to develop site-to-source conversion factors, which require significant amounts of information to define
Cost ZEB	• Easy to implement and measure • Market forces result in a good balance between fuel types • Allows for demand-responsive control • Verifiable from utility bills.	• May not reflect impact on the national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid. • Requires net-metering agreements such that exported electricity can offset energy and non-energy charges. • Highly volatile energy rates make it difficult to track over time	• Offsetting monthly service and infrastructure charges requires going beyond ZEB • Net metering is not well-established, often with capacity limits and buyback rates lower than retail rates.
Emission ZEB	• Better model for green power • Accounts for non-energy differences between fuel types (pollution, greenhouse gases).		• Need appropriate emission-factors • Easier ZEB to reach.

FIG. **23**- Consideration of the different definitions of ZEBs (Boermans et al., 2011)

Highly energy-efficient buildings in Europe lack a universally accepted definition but generally exceed the energy performance standards set by national building codes. The strategies and methods employed to achieve such efficiency vary across European countries.

Typical low-energy buildings normally have the following key components: extended insulation, low-e windows, efficient air sealing, and balanced mechanical ventilation systems with heat recovery to minimize, as far as possible, heating and cooling demands. They frequently use passive solar design principles that help capture most of the solar heat during winter and minimize it during summer. They can also implement active solar technologies, including solar thermal collectors for either water or space heating or photovoltaic panels for electricity generation. Moreover, they can avail themselves of other energy-saving technologies, such as onsite wind turbines for power generation or rainwater harvesting systems restricted to the site. (Boermans et al., 2011)

Work flow chapter 2

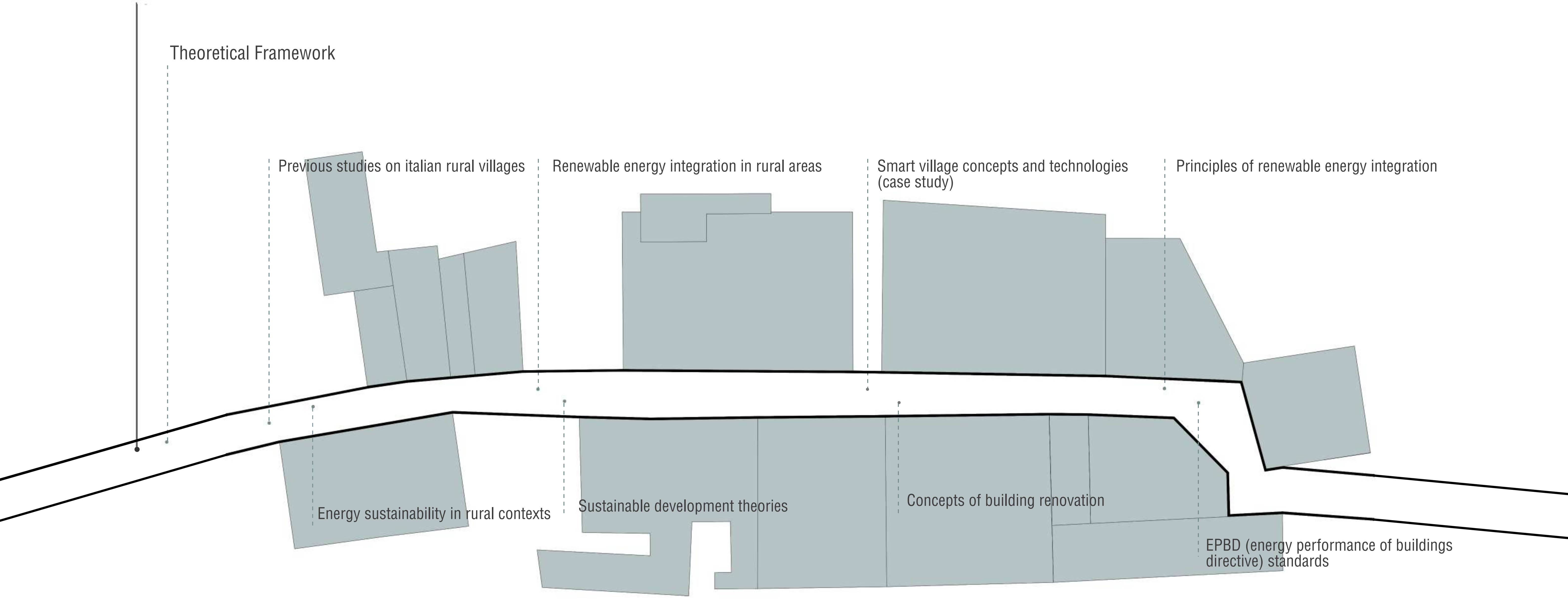


FIG. **24**-Work flow chapter2

Energy performance of buildings - Urban software simulation

EN ISO 52000-1

EN ISO 52000-1 addresses both the initial and final stages of calculating a building's energy performance and its related systems. Before actual calculations begin, spaces, thermal zones, and service areas are identified, and the process is organized to suit the building's structure. Finally, used, delivered, produced, and exported energy carriers are compiled and weighted to determine overall energy performance indicators, focusing on the final electric energy balance and the weighting of delivered and exported energy.

The process begins with analyzing the required services and energy flows within the building. Three main types of energy flows are identified: heat supply, heat extraction, and electricity use. The proportions of these flows influence the choice of generation sub-systems. These sub-systems use delivered energy carriers to provide heat, heat extraction, and possibly electricity.

The calculation procedure in ISO-EN-52000-1 covers the electricity balance and final weighting of all energy carriers, including the Renewable Energy Ratio (RER). "Weighting" supports various energy performance indicators and other types such as economic and polluting emissions. National choices can influence the crucial weighting factors.(van Dijk & Hogeling, 2019)

When there is exported energy, an additional parameter, k_{EXP} , determines whether to include exported energy in the building's energy balance. Including or excluding exported energy can affect the relationship between energy carriers and between energy import and export at different times. Another key parameter is the calculation interval. During a calculation interval, all values are averaged, so there is no strict correlation between electricity production and use. For instance, on a monthly interval, PV production during the day might seem to supply lighting at night. Any dynamics within the interval must be considered using statistical coefficients. On an hourly scale, the need for storage or compensation becomes clear.

Weighting factors can also vary over time. For example, electricity costs can have peak and off-peak tariffs. While not used for rating, this variability is necessary for accurate cost estimation and to suggest effective energy conservation measures. The day-to-day variability of electricity weighting factors may soon become significant.

An hourly model of the energy flows in a whole building can be used to test the calculation process in accordance with EN ISO 52000-1. This model can provide realistic time series of delivered and exported energy carriers by combining real EN modules (with the help of demonstration spreadsheets) with simplified calculations.

The choice of k_{EXP} is critical. Setting $k_{EXP}=1$ allows compensation between exported and imported energy at different times or by different carriers, usually resulting in better (lower) energy performance than setting $k_{EXP}=0$. Both approaches are used by EU Member States. This does not imply a "right" or "wrong" solution but shows two ways to evaluate exported energy. This is similar to economic accounting, where an item can be evaluated by its cost or potential revenue. EN ISO 52000-1 makes this choice clear and explicit through the k_{EXP} parameter.

An hourly calculation interval is most suitable. Energy carrier exchanges (delivered and exported) and their weighting factors are relatively constant over an hourly period. Using a longer interval (daily, weekly, or monthly) requires averaging and matching factors to describe variable energy flows between the building and its environment.

This module is straightforward to use with few parameters. Understanding their impact and using the correct calculation interval is crucial. This module can cover all technologies and can integrate an electricity storage (battery) into the calculation process, demonstrating its potential effect. (Socal & project team, 2021)

Energy use in a building

Building energy consumption Building energy consumption accomplishes two main goals. Its primary goal is to keep residents in comfortable surroundings so they can go about their daily lives without pain. The EU directive EPBD and the EPB standards, which place a strong emphasis on providing comfort services inside buildings, highlight this priority. Second, what's known as process use—the specific activities carried out within the building—is supported by energy consumption. Through the introduction of extra heat into the building environment, these activities can have an impact on comfort levels as well as energy consumption. Any such effects will be discussed as pertinent to the larger conversation about the energy efficiency and comfort performance of buildings.(Socal & project team, 2021)

Energ services

Code	Service name	Definition	Notes
H	Heating	Keeping indoor temperature above a minimum comfort value	Typical is 20 °C Comfort temperature depend on activity and clothing of occupants and other properties.
C	Cooling	Keeping the indoor temperature below a maximum comfort value	Typical is 26 °C.
W	Domestic hot water	Providing domestic hot water for personal hygienic needs of people within the building	Domestic hot water may be used for process purposes as well. Example: hairdresser domestic hot water should be considered process. It is not needed for people living and working in to the building
V	Ventilation	Providing a minimum flow rate of outdoor air	The need is defined by the required IAQ. Ventilation may require energy use for two reasons: • air treatment: energy required to bring outdoor air at indoor comfort conditions • air flow: the energy required to bring in outdoor air and exhaust indoor air (fans), in case of mechanical ventilation
HU/DHU	Humidification and dehumidification	Keeping indoor relative humidity within a defined range	The association of temperature (heating/cooling) and humidity (humidification / dehumidification) is called "air conditioning"
L	Lighting (*)	Providing a minimum illumination in lux on work planes	
T	People transport (**)	Transporting people around the building	This may include elevators and travelators

NOTES
(*) generally considered only for non-residential buildings
(**) not considered in the EU directive EPBD amongst the building services but already considered by some EU Member State (MS)

FIG. **25**-Comfort services considered in the EPB assessment (International organization for standardization [ISO], 2017)

Further, this touches on the variability of requirements for certain building services that principally depend on usage, building type, and climatic considerations, which should be considered when determining aspect performance. For instance, one in a colder climate would require much insulation and heating, whereas, in a warmer climate, it would not. Similarly, a residential building does not require the same level of service as a commercial or industrial building. Additionally, with numerous other factors, the demand for services like lighting, cooling, and ventilation depends on occupancy levels, building activities, and operating hours. The necessity for this demand fluctuation is indeed an important condition for performance evaluation, ensuring that the building is properly captured in its sustainable and efficient state within the confines of its context.

Energy flow in a building

Building comfort services are dependent on multiple energy types, and there are several critical steps in the physical flow of this energy. To ensure maximum comfort, these steps describe the energy's journey from initial delivery to its final use within the building. This is a thorough explanation of the procedure:

- **Energy delivery**

The building receives energy from several sources, which crosses the assessment boundary. This covers grid-supplied electricity as well. When power is produced locally, there may also be a flow of extra power that is exported back to the grid. While the concept underlying this procedure is addressed in EN ISO 52000-1, exporting heat is a rare occurrence and is not specifically covered in detail by the standard.

- **Energy conversion**

Once energy carriers, such as electricity, reach the building, they are then converted into subsystems that can be appropriately named "generation" subsystems. The more accurate way of naming them would be "transformation" subsystems because their role in this stage is to transform the energy carriers into usable forms of energy: heat, heat extraction (cooling), and electricity. The conversion is necessary to suitably adapt the energy into forms that can be effectively used within the building.

- **Energy distribution and utilization**

After conversion, the produced heat, cooling, and electricity are distributed in the building for use to achieve the different comfort requirements. It implies delivering energy to the various zones and systems in the building, ensuring that each zone has enough energy to attain and maintain comfort levels.

Technical systems within the building play a significant role in utilizing these energy forms to generate specific services. For example, mechanical ventilation systems and lighting systems depend on heat, cooling, and electricity. A key example is the Air Handling Unit (AHU), which uses electricity to power its fans and heat to condition the air that is supplied to the building. Advanced technical systems can include features like heat recovery, heat exchange, and active heat transfer (used when both heating and cooling are required simultaneously) to boost overall efficiency. These features make the energy flow in modern, high-tech buildings more complex due to their integrated nature and higher efficiency.
When calculating energy performance, the process works in reverse—from determining the needs to the amount of energy delivered—following these fundamental steps:

- **Defining requirements**

Initially, the required comfort levels and profiles are established. These requirements are primarily based on the building's intended use and occupancy patterns.

- **Calculating needs**

These comfort requirements are used to calculate the specific energy needs. This entails taking into account certain technical systems as well as the characteristics of the building envelope, which serves as a physical partition between the interior and exterior. It is noteworthy that not every need is directly associated with energy. For example, fresh outdoor air is necessary in certain amounts for ventilation. Then, energy is needed to condition the air (by adjusting its temperature and humidity with heating and cooling) and move it (by powering fans).

- **Determining required energy**

The following stage entails figuring out how much electricity, heat, and cooling the building will require for comfort, omitting the generation systems.

- **Calculating energy carriers**

Following that, the available generation subsystems and their operational priorities are taken into account when calculating the required energy carriers. This stage makes sure that the energy requirements of the building are satisfied effectively, accounting for the hierarchy and effectiveness of various energy sources and systems.

- **Expressing energy as weighted energy**

Finally, the weighted energies of the energy carriers required are expressed. This is the conversion of raw energy data into a standardized form, which could be used to provide global energy performance indicators—incipient factors that would matter in evaluating the general energy efficiency of a building.

It is a detailed method to understand the full energy performance of buildings and their improvement. It provides calculations and optimizations at each step—from the delivery of energy carriers to the final provision of comfort services—so that efficiency and effectiveness are taken care of. (Socal & project team, 2021)

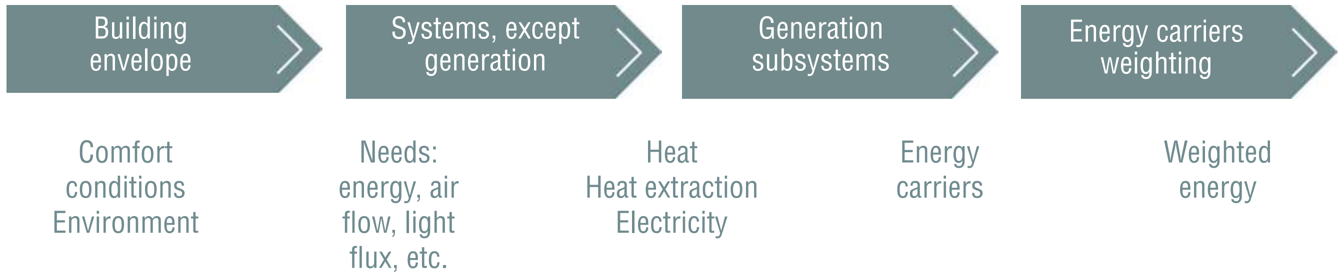


FIG. **26**-Block diagram for the calculation of energy flow in a building (Socal & project team, 2021)

The previous scheme details the calculation process and highlights the stages where energy amounts are: calculated, and/or measured,and/or used to create indicators,and/or subject to legal regulations.

The role of EN ISO 52000-1

There are many variants for how to configure the building and its technical systems. In order to manage all this variety, EPB standards offer a set of modules that need to be combined in such a way as to suit the individual layout and components of the building.
EN ISO 52000-1 serves a dual role:
Initial Role: Before any calculations commence, EN ISO 52000-1 must be considered as it establishes the overall framework for the building's energy balance organization. This includes:

- Defining which services need to be accounted for
- Establishing the methodology for zoning
- Setting the overall options for calculation
- Determining the sequence for conducting the calculations
- Addressing other pertinent topics
- Final Role: Upon completing the calculations, EN ISO 52000-1 is revisited to address:
- The comprehensive electric energy balance, potentially incorporating aspects of electricity storage
- Weighing the amounts of energy delivered to and exported from the building
- Calculating partial energy performance indicators specific to each service or zone

To effectively test and evaluate EN ISO 52000-1, it is essential to simulate the building to generate realistic hourly energy flow patterns. The simulations employ detailed hourly profiles encompassing various building requirements such as heating, cooling, and domestic hot water, computed using EPB modules. Additionally, they incorporate region-specific climatic data.
Following this, the impact of technical systems is simulated using straightforward models and calculations that encompass:

- Assessing non-generation losses attributable to technical systems.
- Evaluating the auxiliary energy consumed by these systems.
- Studying how storage systems affect the heat required for domestic hot water preparation.
- Analyzing fundamental characteristics of generators, including boiler efficiency, heat pump COP, and the peak power output of PV panels.
- Examining the influence of operational conditions such as flow temperature and varying climatic conditions on the performance of boilers and heat pumps.
- Developing prioritization strategies among generators based on their available power capacities.(International organization for standardization [ISO], 2017)

The relation between EN ISO 52000-1 and building technical systems

The energy efficiency of a building is the result of the complicated interaction among several factors: the desired indoor comfort conditions, the prevailing outdoor environmental conditions, the quality of the building envelope, and lastly, all the technical systems at work.
EN ISO 52000-1 serves to form vital decisions related to heat generation, heat extraction, and electricity production systems. Such choices are bound to bring about a direct impact on the type and quantity of energy carriers supplied to or exported from the building and thus on the general energy balance and efficiency.
Building energy demands and operational competencies of technical systems in the building—not including the generation of energy—are fundamental factors that establish the needs for heat supply, heat extraction, and electricity.
These are needs intrinsic to various building functions—such as heating and cooling distribution, lighting systems, and the operation of air handling units—all of which are specifically designed according to building type and climatic conditions.

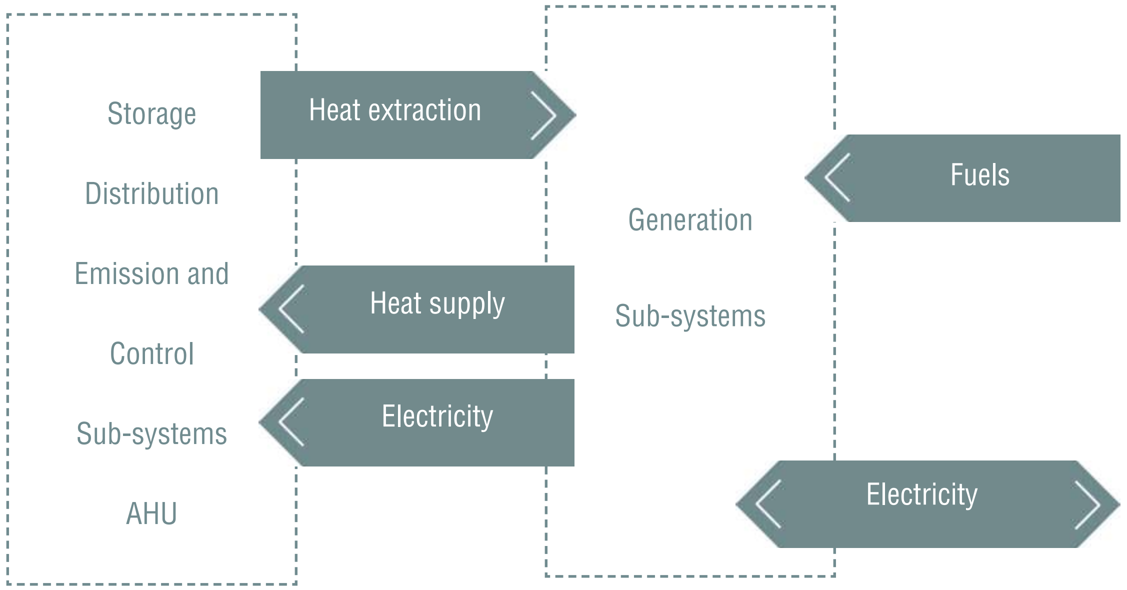


FIG. **27**-Simplified energy flow (Socal & project team, 2021)

Furthermore, the selection of generators for heat, heat extraction, and potentially on-site electricity production significantly influences the final demand for fuels and electricity, thereby shaping the building's overall energy consumption and efficiency profile.

Coverage of performance indicators

EN ISO 52000-1 addresses a range of criteria outlined in the EU's EPBD directive, encompassing non-renewable primary energy, renewable primary energy, total primary energy, CO2 emissions, and costs. It also allows for flexibility to incorporate additional criteria as necessary. The accompanying spreadsheet has been enhanced to simultaneously calculate primary energy consumption, CO2 emissions, and costs.

The standard evaluates both energy delivered to and exported from buildings. It offers two main options for handling exported energy:
Option A (k_exp = 0): Excludes exported energy from the building's energy performance assessment.
Option B (k_exp = 1): Includes exported energy directly in the building's energy performance assessment.
These options, also known as "step A" and "step B," involve a sequential calculation process where energy performance is initially computed with k_exp = 0 and subsequently with k_exp = 1 to gauge the impact of exported energy inclusion.The choice between Option A and Option B depends on the intended interpretation of the energy performance indicator, with specific applications guiding the preferred selection.

EN ISO 52000-1 also provides the ability to calculate the Renewable Energy Ratio, which is even open to flexibility concerning the choice of which renewable sources are considered within that index.
It is also scalable since it might be applied down to the level of local energy grids, which are called energy communities, and Option A would be recommended. This option, tracing the contribution a building provides to the local grid, both in terms of electricity quantity and weight, is feasible. These data can be aggregated by local grid administrators to establish suitable weighting factors and total import/export values for the grid.
Besides, EN ISO 52000-1 allows the allocation of weighted energy for individual building services and zones, supporting the calculation of partial performance indicators. This allocation is predefined in dedicated spreadsheets, which could automate this assessment without the need for the user to provide configuration options.(International organization for standardization [ISO], 2017)

Coverage of calculation intervals

EN ISO 52000-1 accommodates various calculation intervals (seasonal, monthly, weekly, etc.) despite specifically mentioning only hourly and monthly intervals in the text.
If there is a two-way exchange of energy with the grid or if weighting factors fluctuate over time, it's crucial to use a calculation interval that matches the frequency of these changes. Otherwise, correction factors will be needed to adjust for these dynamic effects. Hourly intervals are well-suited for evaluating electric energy balances because they assume that energy demands remain fairly consistent within each hour. Moreover, hourly tariffs and weighting factors are typically designed to align with these hourly time frames.
In cases involving exported electric energy, a matching factor is necessary to approximate dynamic grid interactions in the monthly calculation method. Using a monthly interval without this matching factor could significantly distort results.
To analyze the impact of calculation time intervals:
Hourly profiles of variable inputs will accurately capture any timing discrepancies between on-site energy production and consumption.
Monthly calculations will aggregate hourly data to illustrate how results differ when starting from the same input data.(International organization for standardization [ISO], 2017)

Building categories

EN ISO 52000-1 provides a robust framework for classifying buildings into distinct types, applicable to both new constructions and existing structures. This classification system encompasses a wide spectrum of residential and non-residential buildings, each designed to fulfill specific functional needs and operational contexts.

For residential buildings, there are further subtypes according to EN ISO 52000-1: single-family houses of different architectural styles, designed to accommodate one household with personal requirements; apartment buildings for urban living with compact dwellings and shared facilities; dwellings for older people or those with disabilities where accessibility and supportive facilities are stressed; residential units for communal ways of living, where the community is very important. Mobile homes provide flexible living solutions with movable designs, thus accommodating the diversity in lifestyles. Vacation homes are designed for seasonal or recreational use and offer users getaways from the routines of daily life by locating them in calm environments. Each residential category thus reflects different patterns of energy use and associated challenges to efficiency, which mirror varied lifestyles and behavior in use.

Within the area of non-residential buildings, EN ISO 52000-1 includes a very wide range of buildings related to many different kinds of functions in society. In this respect, office buildings provide an administrative function by housing business activities and professional services. Educational buildings, such as schools and universities, provide study environments for students and teachers. Hospitals represent, in their own way, a core element in healthcare, enabling medical treatments and patient care. Hotels and restaurants can satisfy hospitality requirements through accommodation and dining facilities provided to travelers and guests. Sports centers promote physical activities and recreation for community health and well-being. Wholesale and retail trade buildings accommodate shops and distribution centers where trade is facilitated. Industrial sites are reserved for manufacturing processes associated with economic production and development. Special workshops offer an enabling environment for skilled trades and artisanal activities. Non-residential agricultural buildings support farming and connected agricultural activities, thus guaranteeing food production and rural sustainability.

EN ISO 52000-1 allows detailed case studies and energy performance assessments, which can be carried out by grouping buildings according to their intended use and operation. It provides a basis for sector- and application-specific strategies on low-energy building concepts and efficient energy management in this way.(International organization for standardization [ISO], 2017)

Buildings account for 40% of global energy production, so it is imperative to enhance existing buildings' energy efficiency and integrate on-site sustainable power generation technologies. By modernizing energy systems and improving the thermal characteristics of building envelopes, buildings can achieve higher levels of energy efficiency. To further enhance a building's energy autonomy and partially meet its energy demands, on-site power generation techniques such as wind turbines and building-integrated photovoltaics (BIPV) can be employed. Distributed energy hubs can link dispatchable energy sources, energy storage, and building-level renewable energy technologies at the neighborhood level. These tactics promote greater energy independence within neighborhoods and make it easier to incorporate more renewable energy technologies. While on-site energy generation and building renovations both lower operating costs and carbon footprints, they fall under different domains of expertise, which frequently leads to a communication gap.

Building energy efficiency is a topic covered in great detail in recent literature, which highlights important developments at the component and system levels. Improved wall insulation and modern window glazing are two examples of specific improvements, along with advancements in HVAC and Building Management Systems (BMS). But the needs of distributed energy systems—virtual power plants and multi-energy hubs, for example—need to be addressed at the neighborhood scale rather than building by building.

To meet neighborhood-scale demands, it is imperative to integrate renewable energy technologies, upgrade distributed energy systems, and increase building energy efficiency. These processes are interrelated. To provide decision-makers the best answer, building renovation and energy system design cannot be reduced to a single optimization problem. To create the best plan of action, each process—renovating buildings, incorporating renewable energy into buildings, and enhancing energy systems—must be assessed independently before being combined.

In order to tackle this research problem, we present a computational platform that focuses on energy hub optimization and makes use of multiple software tools that are currently available. Afterwards, an extensive evaluation of the building stock and energy systems is carried out in order to assess the impact of building modifications and the integration of renewable energy sources at the building and neighborhood levels.(Robinson, 2011)

Building energy modeling

Building Energy Modeling (BEM) is the process of conducting a thorough analysis of a building's energy use and energy-using systems using computer-based simulation software. In order to provide an approximative representation of the building, the simulation software enacts a mathematical model. To create the building model, an energy modeler will input data such as weather, building orientation, geometry, constructions, occupant schedules, and energy-using equipment. Calculations with roots in building science and thermodynamics are resolved by a calculation engine. Depending on the complexity and level of detail of the analysis, a single whole-building simulation can take anywhere from a few seconds to several hours to complete. Annual performance results are usually provided, along with information on daylighting effects, equipment energy consumption, resource consumption, energy costs, and other performance-related factors.

Efficiency improvements can be gained by incorporating recommended items garnered from prescriptive lists into design elements. BEM, on the other hand, provides a different strategy that promotes integrated, customized design solutions that yield higher savings. Making design decisions before construction begins is facilitated by using BEM to compare energy-efficiency options. In order to optimize operation or investigate retrofit opportunities, it also provides guidance for ongoing building projects. In BEM, specific concerns like moisture transfer through building materials, daylighting, indoor air quality, natural ventilation, and occupant comfort are addressed through both detailed component analysis and whole-building simulation using specialized software instruments.

BEM offers several advantages to projects involving both new construction and retrofitting. BEM, for instance, facilitates the integrated design process (IDP). Project stakeholders establish and approve outcome-based goals through IDP. The team receives the information from BEM to strategically and economically weigh the costs of the project up front against the yearly energy expenditures of the building. The cost of modeling services is typically a marginal incremental cost for the project, but it has the potential to significantly lower yearly energy costs. An owner's return on investment for integrated systems, renewable energy components, and building efficiency can be maximized by quantifying performance tradeoffs.Existing buildings can also benefit from the use of BEM to monitor and inform operations.BEM can also be used to existing buildings to monitor and provide operational information. Owners can find performance gaps in their buildings by comparing the output of building energy modeling with the actual performance of the building. To make sure everything works as it should, BEM serves as a standard against which to compare actual performance at the building, system, or equipment level. Finding the causes of differences between BEM and real performance can help identify areas for improvement and deviations from ideal operation.

Building energy modeling is essential for estimating and improving building energy performance.The prediction of energy consumption, thermal comfort, and global performance under many varying conditions is handled by simulations. It is a means through which designers, engineers, and policymakers can simulate the impact that various design decisions, retrofitting options, and operational practices have on buildings. BEM can provide detailed insight into possible savings in energy and efficiency improvement through modeling building geometry, material properties, occupancy patterns, and climate conditions. Such simulations are important in the development of sustainable buildings and energy-efficient buildings that have reduced operational costs and impacts on the environment.

Urban building energy modeling

Urban modeling simulates a large diversity of subjects that can be tackled at various levels of detail. At its core, it is dynamic, comprising the analysis of flows of goods, energy, waste, and people in urban environments. The types of analysis can be numerous: for example, building scale, road traffic, renewable energy sources, and energy networks. However, within the concept of urban modeling, three areas have been distinguished. Urban building energy modeling involves building energy modeling at the urban level. This category is therefore very general and may cover all kinds of tools and methodologies that have different scopes: some oriented to specific points, such as building daylighting or the impact of new green areas in cities, while others target life cycle assessment at the urban scale or simplify methods for evaluating energy savings from building renovations. In cases where several aspects need to be accounted for simultaneously, more complex tools and methodologies are required. Within UBEM, there are two major approaches to modeling in use: top-down and bottom-up. (Ballarini, Corrado, & Piro, 2021)

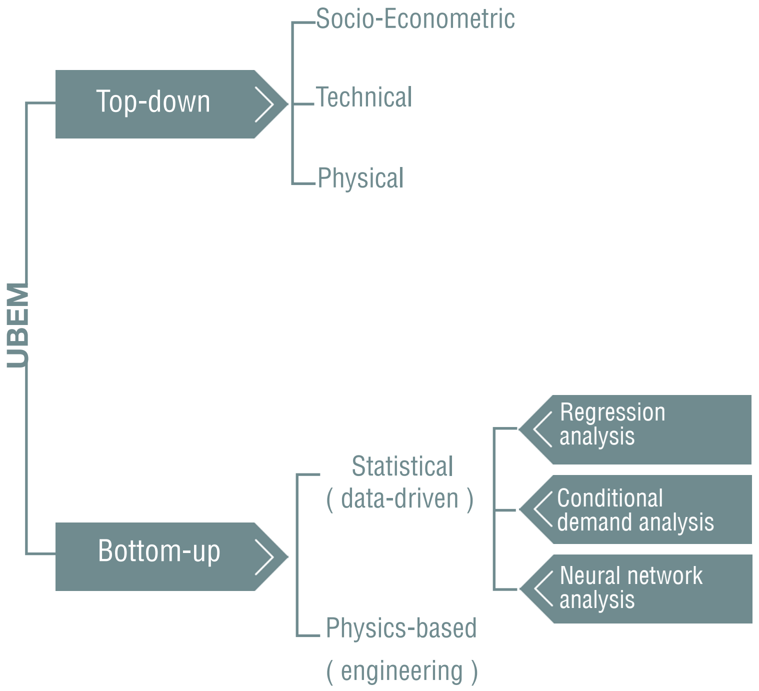


FIG. **28**-Schematic of the UBEM approaches (Ferrando, Causone, Hong, & Chen, 2020)

Top-down modelling methods

Top-down models use large amounts of aggregated data to estimate building energy consumption. They identify long-term correlations between an urban area's energy consumption and various influencing variables. These factors can be divided into three categories: socio-economic, technical, and physical models. The most common type of model is socio-econometric, which is based on social, economic, and market factors . Technical models provide a more detailed analysis by using building technical characteristics as drivers (Huo et al., 2019). Physical models identify environmental characteristics, such as weather, as the primary influencing factors. These top-down models require only a few input data points, which are typically easily accessible aggregated data. They can also build in long-term socioeconomic factors into the model. However, this approach has limitations because it forecasts future energy consumption using historical relationships between the energy and economic sectors. Another disadvantage is a lack of technical detail in the analysis. (Ballarini, Corrado, & Piro, 2021)

Bottom-up modelling methods

Bottom-up models calculate energy consumption at the individual building level and then aggregate the results across multiple scales within an integrated framework. To function properly, these models require a large amount of data, which can be difficult to obtain due to privacy concerns and other factors. Models in this category can be further classified as statistical or physics-based, depending on how they calculate energy demand. Statistical (or data-driven) models estimate building energy demand through data mining and machine learning techniques. Common methods include regression analysis, conditional demand analysis, and neural network analysis. Regression methods relate a building's energy demand to combinations of various parameters that are expected to directly affect energy consumption. Conditional demand analysis uses survey data, consumption records, and weather data to estimate energy consumption.

Neural network techniques are also used to estimate building energy demand. Google's Environmental Insights Explorer (2018) is one example of a well-developed tool that combines these methods. It uses advanced data analytics to assist policymakers in understanding carbon emissions, solar potential, and the overall feasibility of a greener future for cities. Physics-based (or engineering) models use detailed modeling and simulation techniques derived from BEM. This category, which the paper intends to investigate in depth, includes tools that can better evaluate scenarios for managing and designing current and future urban environments. While physics-based models have advanced rapidly in recent years, they are typically time-consuming (requiring detailed building descriptions) and computationally intensive. (Ballarini, Corrado, & Piro, 2021)

BEM vs. UBEM features

The main difference between BEM (Building Energy Modeling) and UBEM is based on the scale and, of course, specific objectives set out by energy performance assessment. BEM looks at individual buildings, while UBEM focuses on urban scales such as districts, cities, provinces, or regions. As the magnitude of energy analysis increases, the accuracy of the energy model tends to decrease, though with reduced computational costs.

The digital transition from BEM to UBEM means the creation of an energy model moving from individual buildings to the urban scale. This uses the basis laid down by BIM, the Building Information Model, as a stepping stone into something more geographical in scope. UBEM acts as a very useful tool for public administrations, urban planners, designers, and clients aiming to estimate the energy use and environmental impact of parts of an area. It helps to identify the energy-greedy building structures in the local vicinity, facilitating more sustainable and efficient urban transformation through targeted interventions.

Input data that can be regarded as key to developing a building-system energy model will include geometric and dimensional features that define the architectural configuration; climatic historic data for the area of interest; thermo-physical properties of building components; expected comfort conditions; and the regime of calculations selected. Lastly, the identification of thermal zones and service areas takes into account the complexity of the property and variations in usage and systems. (Piro, Ballarini, & Corrado, 2023)

An overview of urban building energy modelling (UBEM) tools source

CitySim was developed in 2009, utilizing the SUNtool—Sustainable Urban Neighborhood Simulation Tool. CitySim is used for simulating the use of energy by buildings at a scale that varies from some isolated buildings to tens of thousands. The program is written in Java and C++, with its thermal model based on an equivalent electrical circuit approach. This model allows for considering various subspaces within buildings, and it connects them through the conductance of separating walls. CitySim thus presents itself as a very powerful tool for urban energy modeling due to its flexibility in handling various scales; it can run detailed simulations at the building level while considering complex interaction processes between different building parts and the urban environment.

SimStadt is an open, urban energy simulation platform developed to enable planning for the energy transition at the urban scale. It further enables the creation of evaluation scenarios, such as with variables like refurbishment rates, time horizons, or priority indexes. SimStadt is written in JavaScript and currently supports the city model format CityGML and its extension Energy ADE, which provides detailed descriptions of building fabrics and technical components. This integration allows for in-depth simulations of very high relevance concerning effective urban energy planning, such as the assessment of different retrofit scenarios or the possible impact of various energy policies, within SimStadt.

The same year, UMI, the Urban Modeling Interface, was created to focus on estimating energy use at the neighborhood and city scales. Many sustainability topics are addressed: choices in sustainable transportation, daylighting, outdoor comfort, and food production. UMI uses Rhinoceros as its CAD modeling platform, with its strengths in detailed architectural modeling. It is also integrated with the Urban Weather Generator to account for urban weather effects on energy use and with Daysim for estimating daylight availability. Such integrations enable UMI to provide a holistic analysis of urban energy performance, encompassing a number of environmental and sustainability features beyond traditional energy modeling tools.

There were significant developments related to bottom-up physics-based tools in 2015 and 2016. In 2015, CityBES was released as a web-based platform for simulating building energy performance at the city scale. It can be applied to various use cases such as energy benchmarking, urban energy planning for the optimization of energy systems, energy retrofit analysis in assessing various retrofit scenarios, building operational management toward better operations of urban building stocks, evaluation of solar photovoltaic potential, and urban microclimate visualization. The detailed characterization of the building stock and performance made possible on this platform by CityBES generates valuable insight for energy planners and policymakers.

Also in 2015, another open-source framework was developed on the basis of Modelica: OpenIDEAS - Open Integrated District Energy Assessment by Simulation. The OpenIDEAS tool provides an opportunity to evaluate building load profiles for the study of optimal neighborhood energy networks. By doing this, buildings can be simulated in an energy network at a district level using low-voltage grids, statistical methods, and detailed simulation. It can contribute vitally to district-scale understanding of interactions among various buildings and energy systems for the design of more efficient and resilient energy networks.

Another tool, CEA, is a Python-based tool with a user-friendly GUI, which went live in 2016. Large datasets can be handled easily, and energy simulations allow for apples-to-apples comparisons between many different scenarios. This tool is used to support urban energy planning, giving insights into energy demand patterns and saving potential from several interventions. Now, CEA is able to give urban planners and energy analysts insight into the consumption patterns and a measure of the potential savings from many different types of interventions.

In 2017, URBANopt was already developed as an application to simulate the energy performance of low-energy districts. URBANopt comprises options for local heating and cooling systems; it is therefore appropriate to assess the performance of integrated energy systems at the district level. It is based on detailed energy simulation at the building level on the OpenStudio platform, powered by the EnergyPlus simulation engine. It uses NREL's COFFEE to generate baseline energy models of buildings, providing the basis for detailed energy analysis. The TEASER—Tool for Energy Analysis and Simulation for Efficient Retrofit—was only launched in 2018. This tool is Python-based and provides detailed urban energy system characterization that includes the distribution networks. It allows for the rapid assessment of energy efficiency potentials by combining multiple datasets and running dynamic simulations on building energy use. It enables a better understanding of urban energy dynamics, therefore enhancing the planning and realization of energy efficiency. (Ferrando, Causone, Hong, & Chen, 2020)

Input

One of the greatest configuration points of departure from traditional BEM tools is the building geometry. Building models can be single, where internal sub-divisions and even rooms may be detailed. However, for computation speed reasons when evaluating several buildings at once, UBEM requires that geometries be simplified. Most UBEM tools integrate well with GIS file formats such as CityGML, GeoJSON, Shapefile, and OpenStreetMap. These formats are widely adopted by municipalities for storing building information and allow for a detailed description of any urban environment with regard to terrain features, water bodies, vegetation, transport networks, and urban infrastructure.

Currently, Umi does not support integration with these GIS formats, but a forthcoming version is in development to address this limitation. In UBEM tools, buildings are generally represented as simple extrusions of their footprints to the building height, corresponding to the first level of detail (LOD) in CityGML files. Level of detail 2, encompassing more detailed geometric information like loggias and saddle roofs, is supported by tools like SimStadt, CityBES, or even TEASER. LOD 3—introducing detailed modeling of windows and other openings—is currently under development.

If not available for an urban area, and much more so for new developments, these latter may be replaced by manually created GIS files, which can then usefully act as input for building geometries.

This would be followed by the next critical step of assigning the thermophysical properties to building geometries. Where BEM tools do a detailed characterization of buildings individually, UBEM tools most often simplify this task using archetypes. Archetypes may be considered as buildings prototypical, representing a stock of buildings. They have already been pre-defined, based on typical characteristics of buildings, such as construction year and use type, like residential, office, and commercial, and the typology of buildings, like towers and detached houses. These archetypes usually form part of the UBEM tools that will speed up the process, as they will have derived representative buildings through large data sets.

Interoperable tools like SimStadt and CityBES, along with Energy ADE, an extension to CityGML files including thermophysical characteristics of building components, enhance the accuracy of energy simulations.Occupant behavior modeling is the other aspect of building characterization: the presence and activities of occupants in buildings, such as opening and closing windows/blinds, using appliances, etc. Whereas most of the existing tools in UBEM almost exclusively make use of deterministic schedules for modeling occupant behavior, research is underway with probabilistic models, which could provide an enhanced ability to deal with the stochastic nature of occupants' activities and their circulation across various thermal zones that exist in urban models. For instance, OpenIDEAS' StROBE module includes stochastic residential occupancy behavior modeling, while similar functionality is being researched for implementation into other UBEM tools. Some other input parameters may be required by some UBEM tools to run the said analyses. For instance, SimStadt, CityBES, and CEA can define input about energy-saving measures to be evaluated or optimized and set targets regarding energy to achieve the desired outcome.(Ferrando, Causone, Hong, & Chen, 2020)

Assessing and comparing inputs from urban simulation tools

		Input	CitySim	SimStadt	umi	CityBES	OpenIDEAS	CEA	URBANopt	TEASER
Input Formats and Integration Capabilities		Geographic Information System (.shp,.gdb, etc.)		X	S			X		
		CityGML	X	X		X		X		X
		GeoJSON				X			X	
		Open Street Map (.osm)							X	
		Intermediate data Format (.idf)			X	X			X	
		Modelica (.mo)					X			X
		Python (.py)					X			X
Building characterization		EnergyADE integration	`	X		S				x (as output)
	Archetypes based on	Intended use	x		x	x	x	x	x	x
		Construction Year				x		x		x
		Volume								x
		Building typology	x			x		x	x	
		Default characteristics included		x	x	x	x	x	x	x
	Characterization includes:	Envelope	x	x	x	x	x	x	x	x
		Systems	x	x	x	x	x	x	x	x
		Energy use	x	x		x			x	
	Occupants descriptio	Deterministic	x	x	x	x		x	x	x
		Stochastic	S		S	S	X (residential)	p		p
Other		Energy conservation Measures				X				
		Target		X		X				

X = feature or capability currently available, P = feature or capability partially implemented, S = feature or capability under study

FIG. **29**-Summary of the inputs required by the tools (Ferrando, Causone, Hong, & Chen, 2020)

Output

The outputs from running a typical simulation with each tool vary, as different developers use unique terminologies that complicate comparisons. Therefore, general terms like heating/cooling thermal energy are used, since distinguishing between energy needs and uses according to ISO 52000-1 isn't always practical.

These outputs can be divided into four main categories:

- building-related
- resource potential
- urban energy systems
- large-scale general evaluations

The most developed outputs are related to building energy use, including heating and cooling thermal energy, domestic hot water demand, electric use, and sometimes daylight. Many tools also assess resource potential, such as the solar potential on roofs and facades, as well as ambient heat potential (e.g., geothermal, lake water, and waste heat). These findings can help calculate the electric and thermal potential of photovoltaic and solar thermal installations. Tools like SimStadt, which uses PVGIS, employ sub-tools for similar assessments.

The third category involves urban energy systems and the integration of methodologies used in urban system energy models (USEM). Several tools use equation-based, object-oriented district system analysis solutions.

For example, UrbanOPT uses OpenStudio, while OpenIDEAS and TEASER are based on Modelica. CEA generates district system geometry from OpenStreetMap, runs simulations using a simplified network-based approach, and considers constant heat loss for pipes and coefficients for nodes. It optimizes thermal networks and plans thermal and electrical grids, considering building connections, geometry, pipe dimensions, and cost analysis. It also optimizes energy supply systems to minimize annual capital costs, greenhouse gas emissions, or primary energy consumption.

CityBES is integrated with EnergyPlus for running district heating and cooling system simulations. It imports the district heating and cooling load profile and visualizes it. This choice varies between different district energy systems, whose characteristics are defined by the user. Subsequently, EnergyPlus models are generated, simulated, and the energy use and related costs are calculated. Results allow performance comparisons among systems. District energy system types that are supported by CityBES include water-cooled chillers and boilers, water-cooled chillers with ice storage and boilers, heat-recovery chillers and heat pumps, and geothermal heat pumps; network heat loss was simplified to be a load correction factor. Many tools also provide the functionality for comparing Energy Conservation Measure scenarios and evaluating resulting GHG emissions directly. Special types of analysis can be performed by some tools: for instance, CityBES offers 75 pre-developed ECMs to test; CEA provides cost-benefit analyses of strategies, and the recent release includes electro-mobility analysis. CitySim can interface with the Multi-Agent Transport Simulation toolkit, MATSim-T, when it comes to transport analysis. Umi provides district efficiency evaluation related to walkability, bike-ability, and food production.

The type of output is crucial and can influence the preference for one tool over another. Comparisons are made based on time resolution, spatial resolution, and available display implementations. All tools provide yearly results for building stock energy consumption, with some offering detailed models down to the minute (e.g., CityBES, OpenIDEAS) or hourly (e.g., CitySim, CEA, URBANopt, TEASER). Detailed resolution data is often aggregated into coarser visual results. The time resolution of the results can differ from the simulation resolution; for example, umi runs minute-by-minute simulations but presents results as yearly aggregates. Spatial resolution also varies, with data derived from individual buildings that can be aggregated. For daylight analysis, umi directly shows results for a single story in each building. All tools provide outputs as spreadsheet files (typically CSV), and all, except OpenIDEAS and TEASER, also offer graphical visualization. Some tools display outputs on 3D geometry with color scales, while others use graphs, charts, or GIS shapefiles for further post-processing and visualization.(Ferrando, Causone, Hong, & Chen, 2020)

Assessing and comparing outputs from urban simulation tools

		Output	CitySim	SimStadt	umi	CityBES	OpenIDEAS	CEA	URBANopt	TEASER
Building-related		Daylight	x		x				x	
		Heating/Cooling thermal energy	x	x	x	x	x	x	x	x
		Domestic hot water demand	x	x	x	x	x	x	x	x
		Electric use	x	x	x	x	x	x	x	x
Resource potential	Solar	Roofs		x	x	x		x	x	
		Walls			x			x		
		Other						s	x	
Urban Energy Systems		District Heating/Cooling	p			x	x	x	x	x
		Electric Grid	p				x	x	x	x
		Energy Storages	p			s	x	s	x	x
Large scale general evaluations		Scenarios	x	x		x		x	x	
		Benchmarking				x		x		
		Cost-Benefit analysis				x		x		
		Transport/Mobility	x(MATsim-T)		x			x		
		Life-Cycle analysis	x	x	x			x		
		Food			x					
Large scale general evaluations		Minute				x	x			
		Hour	x			x	x	x	x	x
		Day	x			x	x	x	x	x
		Month	x			x	x	x	x	x
		Year	x	x	x	x	x	x	x	x
Spatial resolution		Single building floor			p (only dailylight)					
		Single building	x	x	x	x	x	x		x
		Group of buildings	x		x	x	x	x	x	x
Display		Spreadsheet	x	x	x	x	x	x	x	x
		Graphic visualization	x	x	x	x		x	x	

X = feature or capability currently available, P = feature or capability partially implemented, S = feature or capability under study

FIG. **30**-Summary of the outputs provided by the tools (Ferrando, Causone, Hong, & Chen, 2020)

Tool	CitySim	SimStadt	umi	CityBES	OpenIDEAS	CEA	URBANopt	TEASER
Year	2009	2013	2013	2015	2015	2016	2016	2018
Developer	EPFL	University of Stuttgart	MIT	LBNL	KU Leuven	ETH Zürich and Singapore	NREL	RWTH Aachen University
URL	https://citysim.epfl.ch/	http://www.simstadt.eu/de/index.jsp	http://web.mit.edu/sustainabledesignlab/projects/umi/	https://citybes.lbl.gov/	https://github.com/open-ideas	https://cityenergyanalyst.com/	https://www.nrel.gov/buildings/urbanopt.htm	https://github.com/RWTH-EBC/TEASER
Status	Actively maintained	Active, under development	Active, under development	Active, under development	Actively maintained	Active, under development	Active, under development	Active, under development
Availability	Free	Not publicly released	Free, but needs Rhinoceros 6 License	Free, via developers' support	Free	Free	Not publicly released	Free
Modeling approach	Reduced-order RC Model (CitySim solver)	Reduced-order RC Model (ISO 13790)	Heat-Balanced Physics Model (EnergyPlus)	Heat-Balanced Physics Model (EnergyPlus + OpenStudio)	Reduced-order RC Model (FastBuildings)	Reduced-order RC Model (ISO 13790 adapted)	Heat-Balanced Physics Model (EnergyPlus)	Reduced-order RC Model
Computing platform	Personal Computer	Personal Computer	Personal Computer	Web-based	Personal Computer	Personal Compute	High-Performance Computer	Personal Computer
Usage examples	EPFL University campus La Jonction district (Geneva)	Grünbühl (Ludwigsburg), Rintheim (Karlsruhe), Bospolder (Rotterdam)	Boston ,Kuwaiti city neighborhood MIT University campus	Different districts of San Francisco	Belgian city block, Belgian residential zero-energy neighborhood	One central area in Zurich City block in Zug	National Western Center and Sun Valley district	Research campus in Germany, Bad Godesberg
Main Structure	Four core models: thermal model, radiation model, behavioral model, plant and equipment model + possible integration with Multi-Agent Transport Simulation toolkit	Energy analysis run exploiting ISO 13790 and estimation of solar potential through online database PVGIS or weather data files Meteonorm	Six modules: daylight module, energy module, lifecycle module, mobility site module, harvest module for food production.	Three main sections (District Building, Modeling and Analysis and Urban Climate). The Modeling and Analysis section includes five sub-tools (benchmarking, retrofit scenarios, renewables, Life Cycle GHG and simulation)	Three components: systems (Modelica IDEAS library), stochastic residential occupancy behavior (Python StROBe), building modeling (Modelica FastBuildings library + reyBox)	Seven databases (weather, urban environment, energy services, conversion, distribution, systems, and targets) and six modules (demand, resource potential, system technology, supply system, decision, analysis)	Three main components: 3D building energy models from map imagery and billing data, COFFEE as simulation platform and Building Component Library (BCL) for energy conservation measures and retrofit analysis	Three main packages: the data package (that allows the input of data and the reading of outputs), the logic package (that helps in the manipulation of data), and the GUI package

FIG. **31**-Main characteristics of the selected tools (Ferrando, Causone, Hong, & Chen, 2020)

Work flow chapter 3

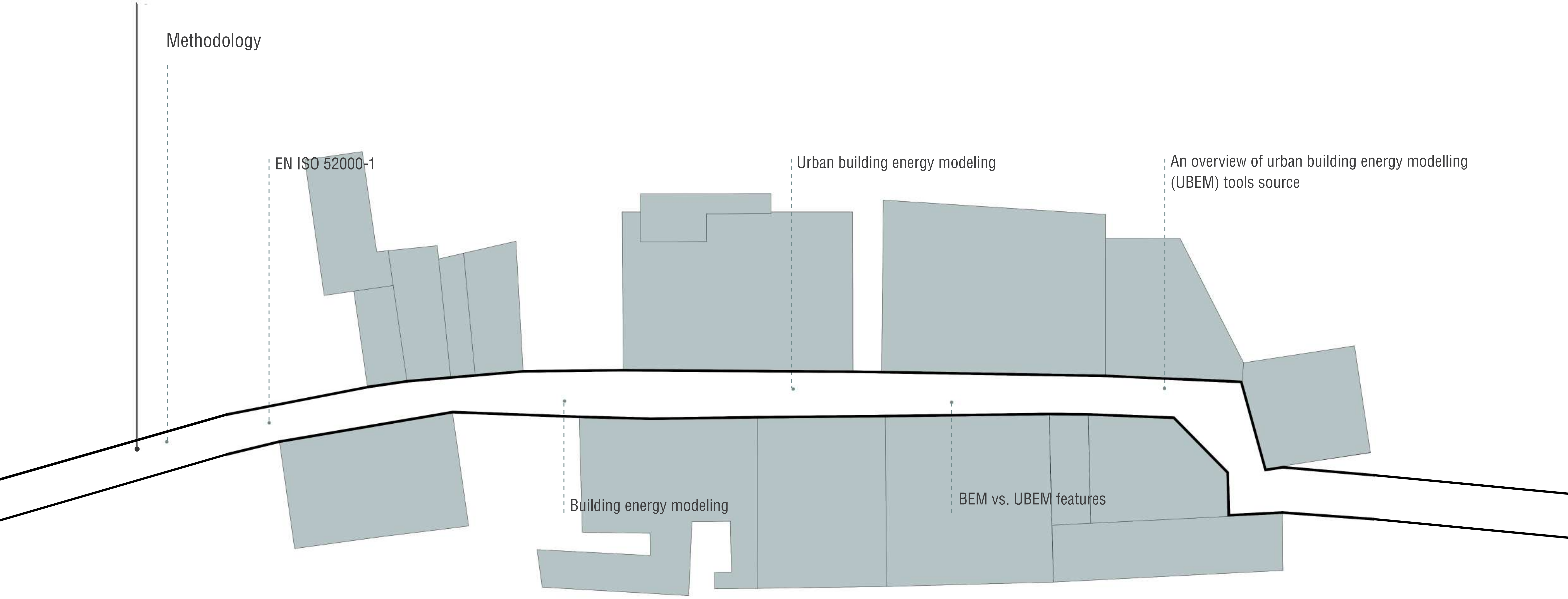


FIG. **32**-Work flow chapter 3

Planning-Simulation

Selection of case study Toiano villages

Right in the heart of Tuscany lies the tiny, abandoned village of Toiano. It fits into the gently rolling landscape; Toiano features 11 buildings, including a quaint church. It's all centered on the 50-meter-long Via del Castello, a very thin road curving up the hilltop, with stunning views of the surrounding countryside. The passing of time, however, has not been kind to Toiano. Most of its historical buildings have collapsed or are seriously damaged, with only a few small restorations done many years ago. With an average elevation of 217 meters, a latitude of 43.58728°, and a longitude of 10.81102°, Toiano is a very small abandoned village in the middle of Tuscany.

The village can be split into two very distinct parts. One has a farm for agriculture, a church, and a cemetery, along with the bridge and entrance to the village. Most of the area in this section is open land with only one destroyed building and the rest of fields and green space. The second part of the village is far more densely built up, with 11 buildings along a long, thin path mainly used by pedestrians. Most of these buildings line at several points along this pathway, thus making the layout of the second part more compact and structured in comparison with the first part, which is expansive and open.

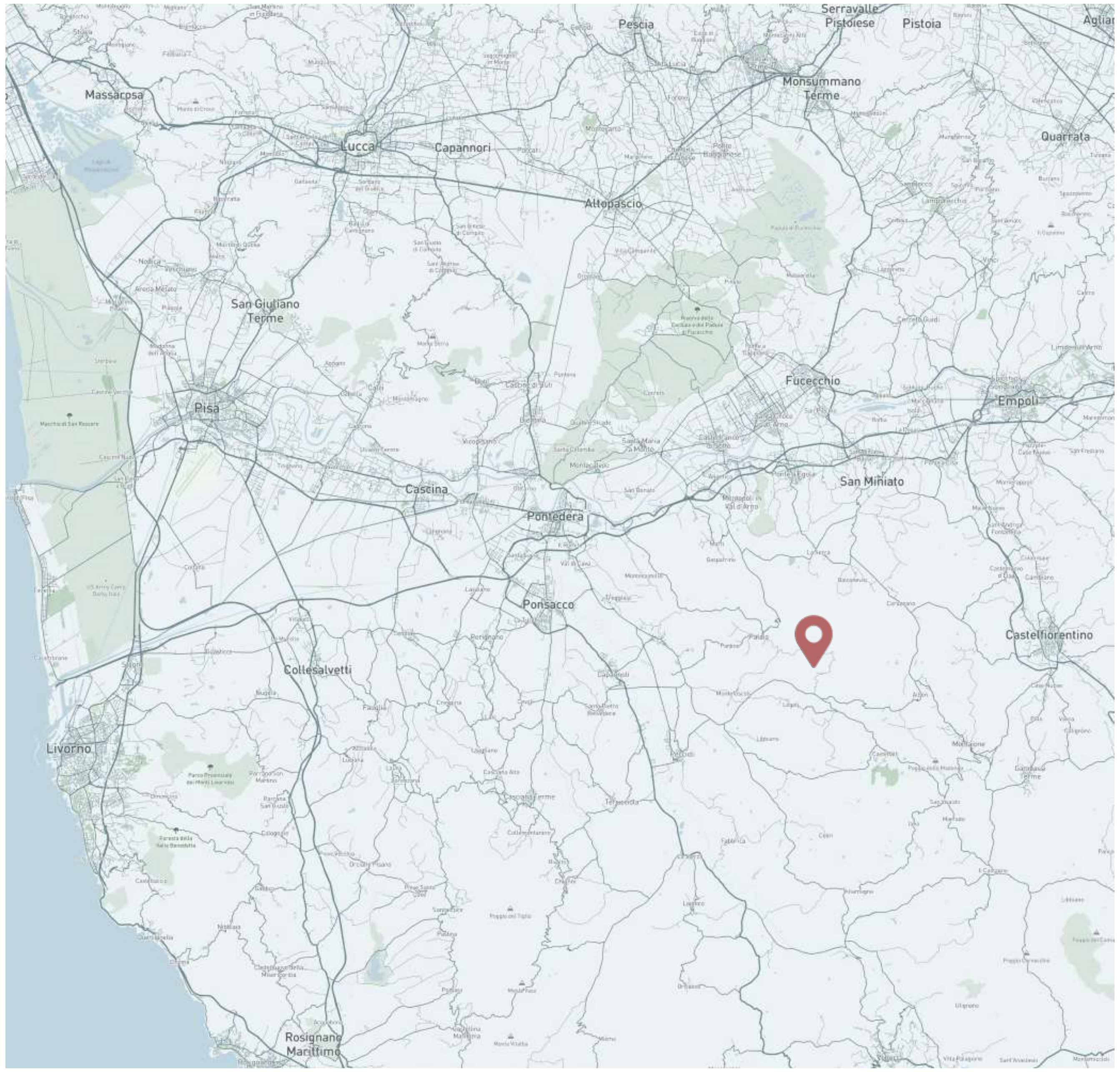


FIG. **33**-Location of toiano

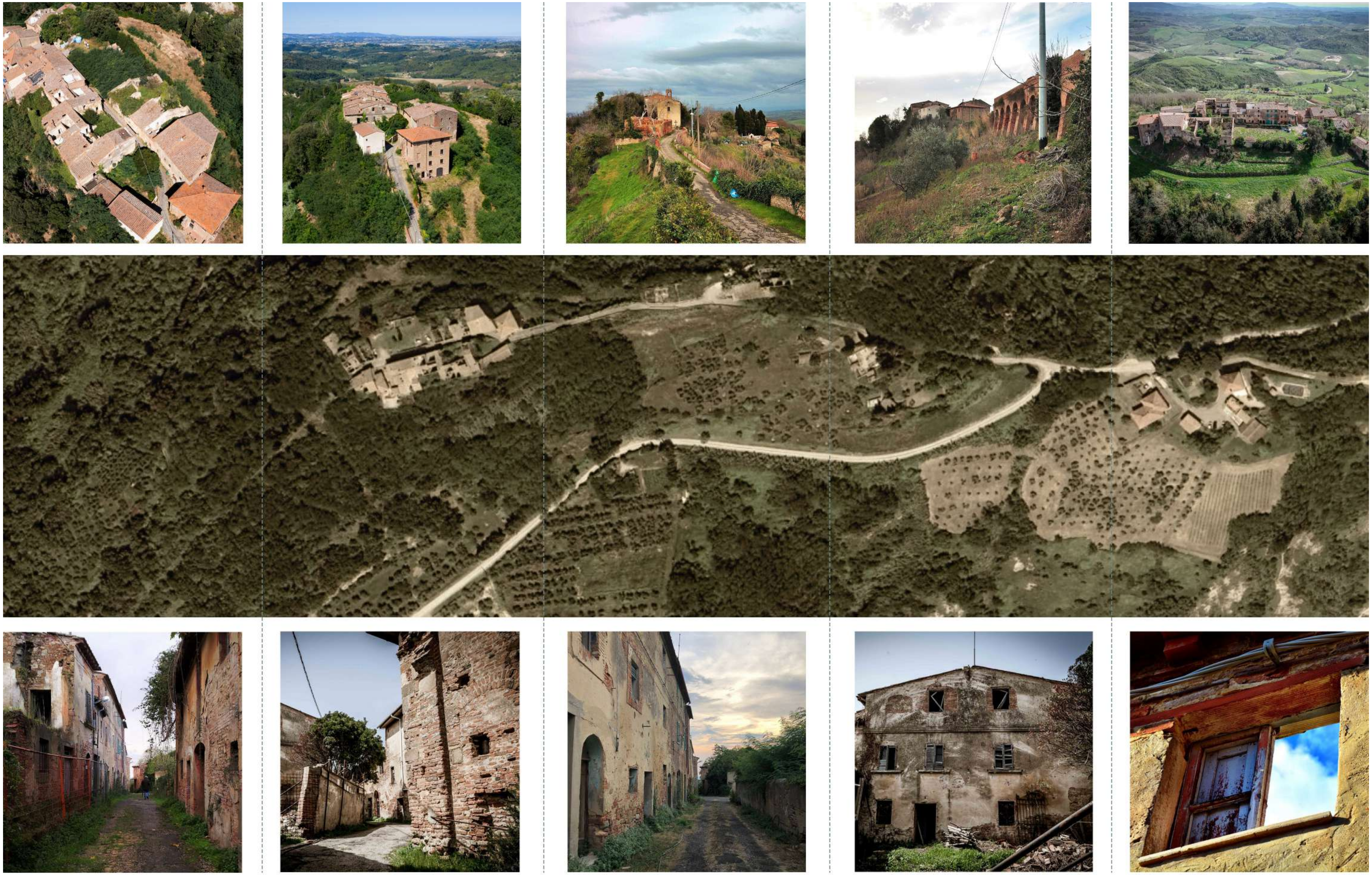


FIG. **34**-Toiano village (https://www.spiritoinvolo.it/urbex-toiano.html)

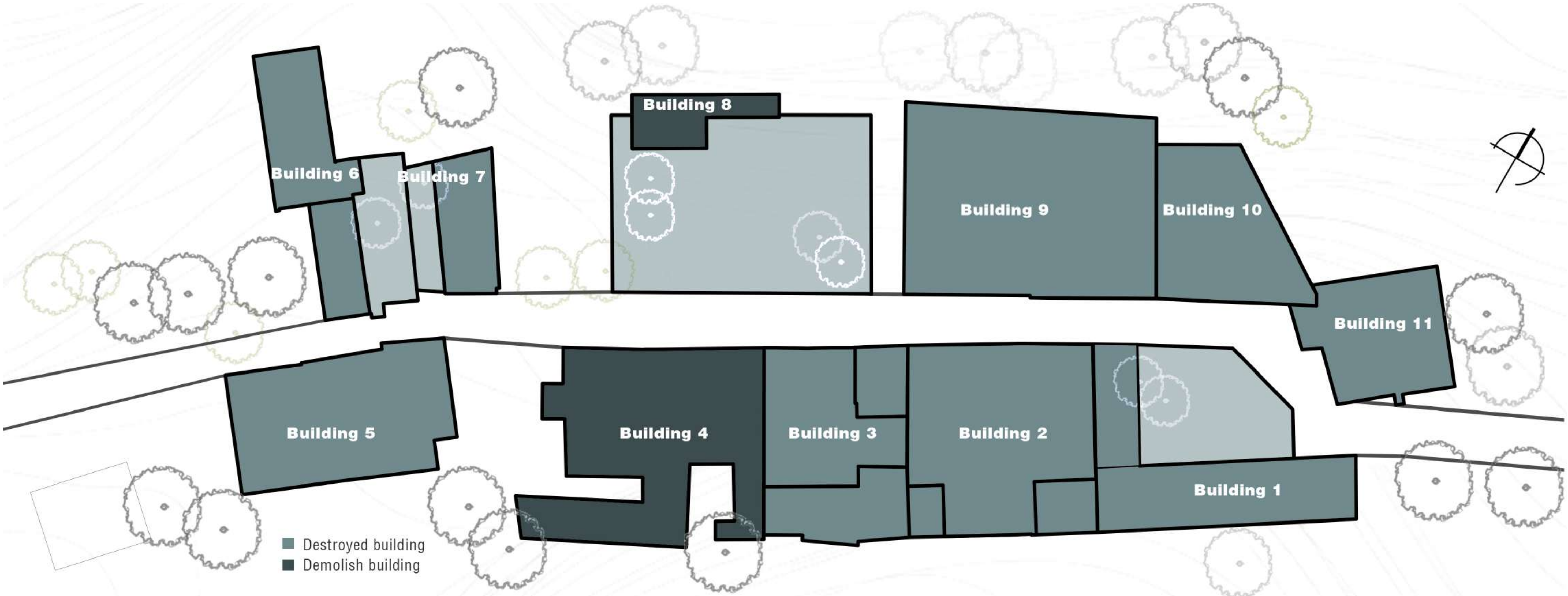


FIG. **35**-Map of toiano
scale 1/400

	Building1	Building2	Building3	Building4	Building5	Building6	Building7	Building8	Building9	Building10	Building11
Year of construction	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950	1900-1950
Floor number	3	3	3	1	2	1	1	2	2	2	2
Area	280 m^2	351 m^2	262 m^2	347 m^2	259 m^2	155 m^2	76 m^2	54 m^2	449 m^2	183 m^2	154 m^2
Height	12 m	11 m	11 m	5 m	8 m	5 m	5 m	8 m	8 m	8 m	8 m

FIG. **36**-General information on buildings

Overview of citysim pro software

Citysim Pro: advanced urban planning and management software

Citysim Pro is the most state-of-the-art offering in urban simulation software. It is designed to provide an all-encompassing, flexible framework for urban planners and managers. Armed with this powerful tool, users can simulate, analyze, and visualize urban dynamics and infrastructure. Equipped with all the necessary tools, Citysim Pro can model the urban environment in detail to express the behavior of every individual in terms of traffic patterns, use of public transit systems, environmental impacts, and how one would respond in the event of an emergency. Moreover, it improves decision-making and strategic planning for urban sustainable development by utilizing advanced algorithms and an intuitive user interface (Kämpf, 2009).

Future urbanization and energy consumption

Projections by the UN and IEA postulate a heavy population increase in urban areas, with higher energy consumption in these areas from fossil fuel energy. This calls for proper planning, design, and renovation of buildings to limit non-renewable energy use in urban areas. To meet this challenge, the Swiss Federal Institute of Technology Lausanne developed CitySim—a dynamic building energy simulation tool. The different features of CitySim include simulations of multiple building interactions such as shadowing, light reflections, and infrared exchanges. Balancing computation time, output accuracy, and input data requirements through reduced-order modeling assumptions enables CitySim to quickly deliver plausible results despite likely overestimations and underestimations.(Emmanuel & Kämpf, 2015)

Programming languages and frameworks

Python: Because of its rich libraries and frameworks in Machine Learning, Data Analysis, and ease of integration with technologies.

C++: Applied to parts of the product that are vital to high performance, in order to achieve great processing times and perfect memory handling. The Qt Framework is used as the cross-platform application framework for providing responsiveness and a user-friendly experience on Windows, macOS, and Linux. It is used in the development of the Graphical User Interface.

Real-time data integration and processing

Citysim Pro improves predictive modeling through the fusion of real-time data from sensors and IoT devices by using machine learning algorithms. This capacity has to be built in order to model future trends and simulate present times; in the special case of emergency management and disaster preparedness, this is necessary.

Interoperability and APIs

The software can pride itself on the myriad of supported Application Programming Interfaces (APIs) to ensure seamless integration with Geographic Information Systems (GIS), traffic management platforms, environmental monitoring tools, and other technologies related to urban planning. This interoperability improves analysis capabilities and allows for extensive sharing of data.

Database administration

Citysim Pro has SQL databases that facilitate efficient data storage and retrieval. Such SQL databases can handle vast amounts of data needed during urban simulation.

Modeling and visualization

OpenGL helps in rendering high-quality 3D graphics for the realistic and detailed 3D modeling of the urban environment. This assists stakeholders in visualizing complex data and scenarios that help in decision-making.

Advanced visualization tools

Such tools should include interactive dashboards, 3D modeling, and other graphical tools that allow the user to acquire a better discovery and presentation of data.

Scripting and automation

It has a Lua scripting engine that enables task automation and the creation of custom scenarios, hence providing flexibility and efficiency in project management.

Modular architecture

Citysim Pro uses a modular architecture, which provides flexibility and easy ways for scaling and customization. Users can easily extend it with plugins and add-ins to suit the actual needs of the project at hand, which makes it

Urban planning applications

Citysim Pro's technological robustness and versatility enable diverse applications in urban planning. It is frequently used to simulate traffic congestion, aiding in the planning of efficient public transportation and road networks. Environmental planners use the software to assess the impact of new developments on green spaces and air quality, supporting sustainable urban growth. Additionally, city officials can simulate emergency scenarios, such as natural disasters or major public events, to develop robust contingency plans and enhance urban resilience.

Citysim pro for energy efficiency

CitySim pro aims to support decision-making for stakeholders and urban energy planners to reduce the use of non-renewable energy sources and corresponding greenhouse gas emissions. The development and testing of this software achieved several challenging goals:

- **3D geometrical modeling**

Enables efficient attribution of thermo-physical properties to hundreds of buildings in an urban district by describing their 3D geometrical forms using an XML file format designed for this purpose.

Energy Demand Simulation: Involves simulating energy demands of buildings, accounting for various HVAC systems and the stochastic nature of occupant presence and behavior.

- **Energy supply determination**

Involves calculating energy supply from renewable sources, including radiation exchange generated by buildings and various energy conversion systems in the urban environment.

Data Export: Allows users to export standard text files (TSV) to support the analysis of energy performance data, helping identify opportunities for building performance improvement using preferred graphical tools.

Citysim Pro stands out as a comprehensive solution for modern urban planning challenges, integrating real-time data, supporting a wide range of APIs, and offering advanced modeling and visualization capabilities. Its high level of technological sophistication enables architects, engineers, and urban planners to accurately simulate, analyze, and visualize urban environments, enhancing decision-making and strategic planning for resilient and sustainable cities.(Kämpf, 2009)

Modeling the case study with citysim pro

CitySim, developed at the Swiss Federal Institute of Technology Lausanne (EPFL), specializes in dynamic building energy simulations within urban environments. To initiate a case study using CitySim, several key steps and types of information are essential:

- **Climate Data**

These climatic zones of Italy naturally follow its geographical diversity, spreading from the Alps in the north to the Mediterranean Sea in the south. The northern regions include areas like the Alps and the Po Valley, with a temperate climate—cold winters, hot summers, and heavy rainfall throughout the year. The central regions comprise Tuscany and Umbria, representing the Mediterranean climate with hot and dry summers and mild, wet winters. The general description of the climate would be a warm Mediterranean climate, with a long, hot, and dry summer and a short, mild winter for Southern Italy and the two islands: Sicily and Sardinia. Because of the influence of the sea, the temperatures are somewhat moderated along the coast, whereas they become more extreme inland, especially in the mountains.

Hourly climate data from the Pisa weather station, the closest station to the village of Toiano, has been sourced to ensure that the climatic readings highly represent Toiano's actual weather patterns. The data from Pisa has been meticulously matched and correlated with specific local observations from Toiano, ensuring that the resultant dataset accurately reflects the microclimatic conditions of the area. After correcting the climate data of Pisa, which will be explained later, these parameters have been selected and subsequently imported into the CLI file.

In addition to the climatic file, citysim pro requires the import of a file with a HOR extension, which contains the horizontal surface data and can be generated using Meteonorm.

	Name	Units
d	day	
m	month	
h	hour	
G_Dh	Diffuse horizontal irradiance	W/m^2
G_Bn	Beam normal irradiance	W/m^2
Ta	Air temperature	°C
Ts	Soil Temperature	°C
FF	Wind speed	m/s
DD	Wind Direction	°
RH	Relative Humidity	%
RR	Precipitation	mm
N	Nebulosity	octa
G_Dh	Diffuse horizontal irradiance	W/m^2
G_h	Global horizontal irradiance	W/m^2

FIG. **37**-The meteorological data(https://github.com/kaemco/CitySim-Solver)

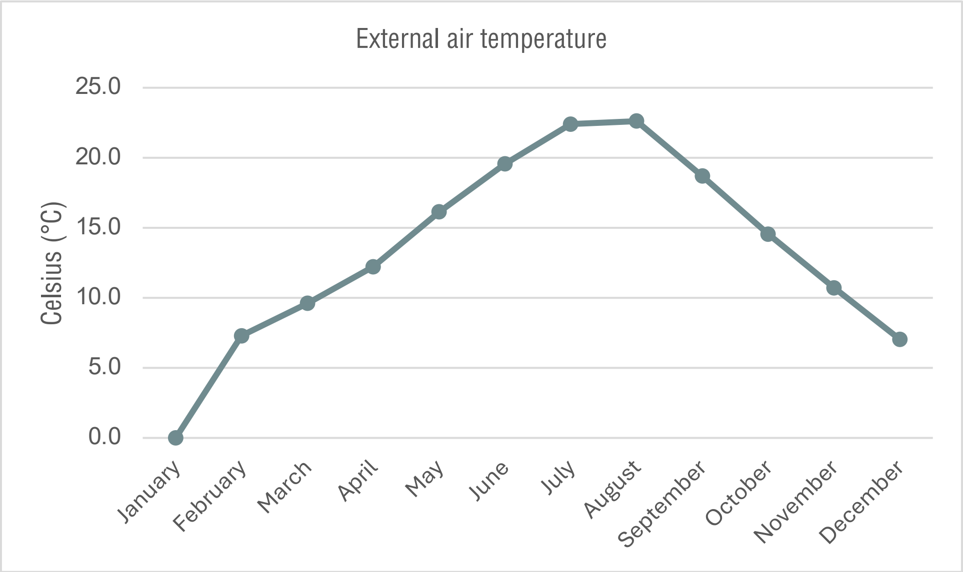


FIG. **38**-External air temperature data

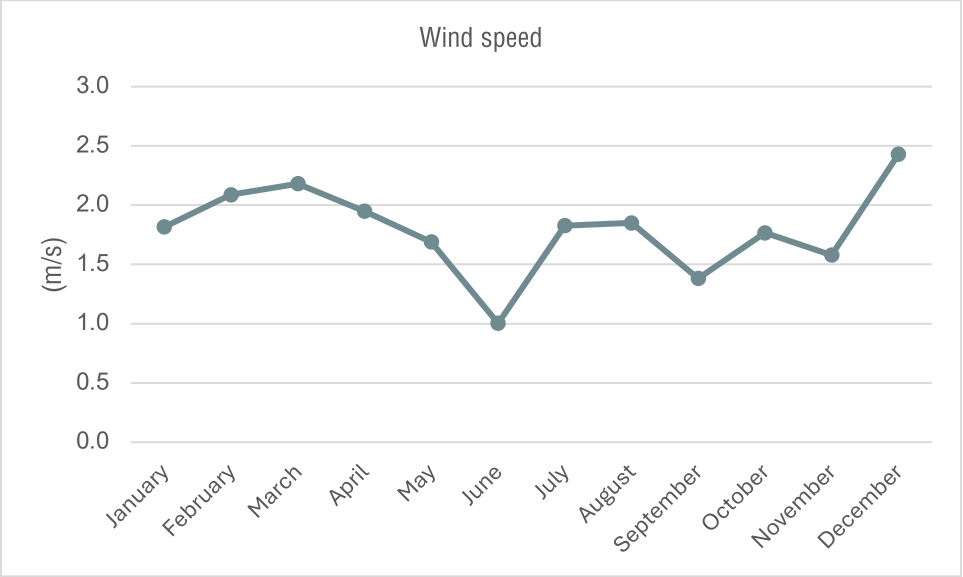


FIG. **39**-Wind speed data

- **Correction of climatic data**

To correct climate data for the nearest location to Pisa, it is essential to calculate both wind speed and external air temperature. For wind speed correction, the following formula is applied:

$$V = v_{\text{ref}} \cdot c$$

- v The corrected wind speed at a specific location or condition.
- v_{ref} The reference wind speed, which is the wind speed measured or observed at a reference location or under specific conditions.
- c A correction factor that adjusts the reference wind speed based on the differences in location, altitude, or other relevant factors.

	Coastal strip	Band subcoastal	Hinterland>20km altitude(m)						
Wind region	≤20 km	≤40 km	300	500	800	1200	1500	2000	>2000
A	3	2	1	1	2	2	3	3	4
B	2		1	2	2	3	3	4	4
C	3		2	2	3	3	3	4	4
D	3		3	3	3	4	4	4	4
E	4		3	3	3	4	4	4	4

*with the exception of region A for which the hinterland is >40 km.

Wind zone of the reference location	Wind zone			
	1	2	3	4
1	1.000	1.780	2.780	4.000
2	0.562	1.000	1.560	2.250
3	0.360	0.640	1.000	1.440
4	0.250	0.455	0.694	1.000

FIG. **40**- Reference wind load and zone data (UNI10349-1)

And for external air temperature, the following formula is applied:

$$t_e = t_{\text{e,ref}} - (h - h_{\text{ref}}) \cdot d$$

The formula provided is used to correct the external air temperature (t_e)at a different altitude (h)based on a reference altitude (h_{ref}) and a reference temperature ($t_{e,ref}$).
In this formula:

- t_e represents the external air temperature at the altitude .
- $t_{e,ref}$denotes the reference external air temperature at the reference altitude.
- h refers to the altitude where the corrected external air temperature is being calculated.
- h_{ref} is the reference altitude at which the reference temperature is provided.
- d stands for the temperature lapse rate, which indicates the rate at which the temperature changes with altitude, typically expressed in degrees Celsius per meter (°C/m) or degrees Celsius per kilometer (°C/km).

and in this case study h=270 , h_{ref}=4 and d=1/200

- **External air temperature -solar irradiance**

Solar irradiation brings seasonal and geographical variations in solar irradiation. The days are the longest during summer with large angles of incidence, which correspond to a high level of solar radiation. On the other hand, winter has the shortest days and smallest angles of incidence with low solar radiation. These variations in solar radiation can therefore have a huge impact on both the efficiency of solar energy systems and the energy use in buildings.

The external air temperature also significantly impacts everyday activities, environmental systems, and public health and safety. An increase in temperature raises the potential for general increases in illnesses associated with heat. On the other hand, very low temperatures can cause hypothermia and frostbite. As such, a proper weather forecast is critical in allowing for early warnings and preparation by the public. It is, therefore, important to understand and monitor external air temperatures for the suitable planning of emergencies, public health management, and adapting to the challenges brought about by climate change.
Given that it affects both our personal comfort and more extensive ecological systems, the outside air temperature is a crucial component of both life and the environment. It establishes our daily outfits, activities, and energy expenditure. For instance, during heat waves, people frequently rely on air conditioning to stay cool, which raises energy consumption and could put stress on the power systems. On the other hand, low temperatures necessitate the use of heating systems to maintain comfort and safety indoors, which has an impact on fuel consumption and related expenses. Such outdoor air temperature conditions affect ecosystem health and agricultural productivity in addition to human comfort and the economy. Strong heatwaves have the potential to upset natural behavioral patterns, reduce crop yields, and ultimately have an impact on animal behavior and ecosystem balance.

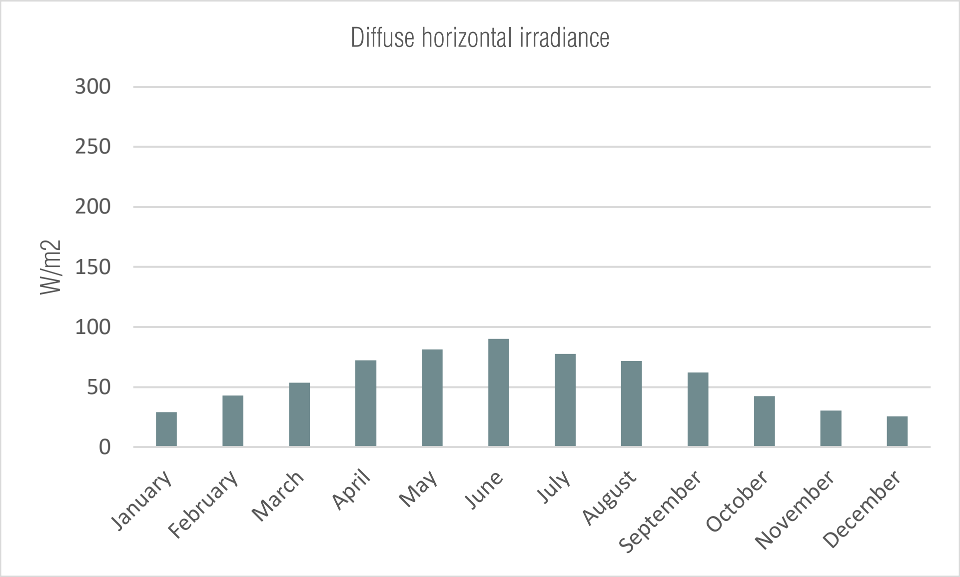


FIG. **41**-Diffuse horizontal irradiance

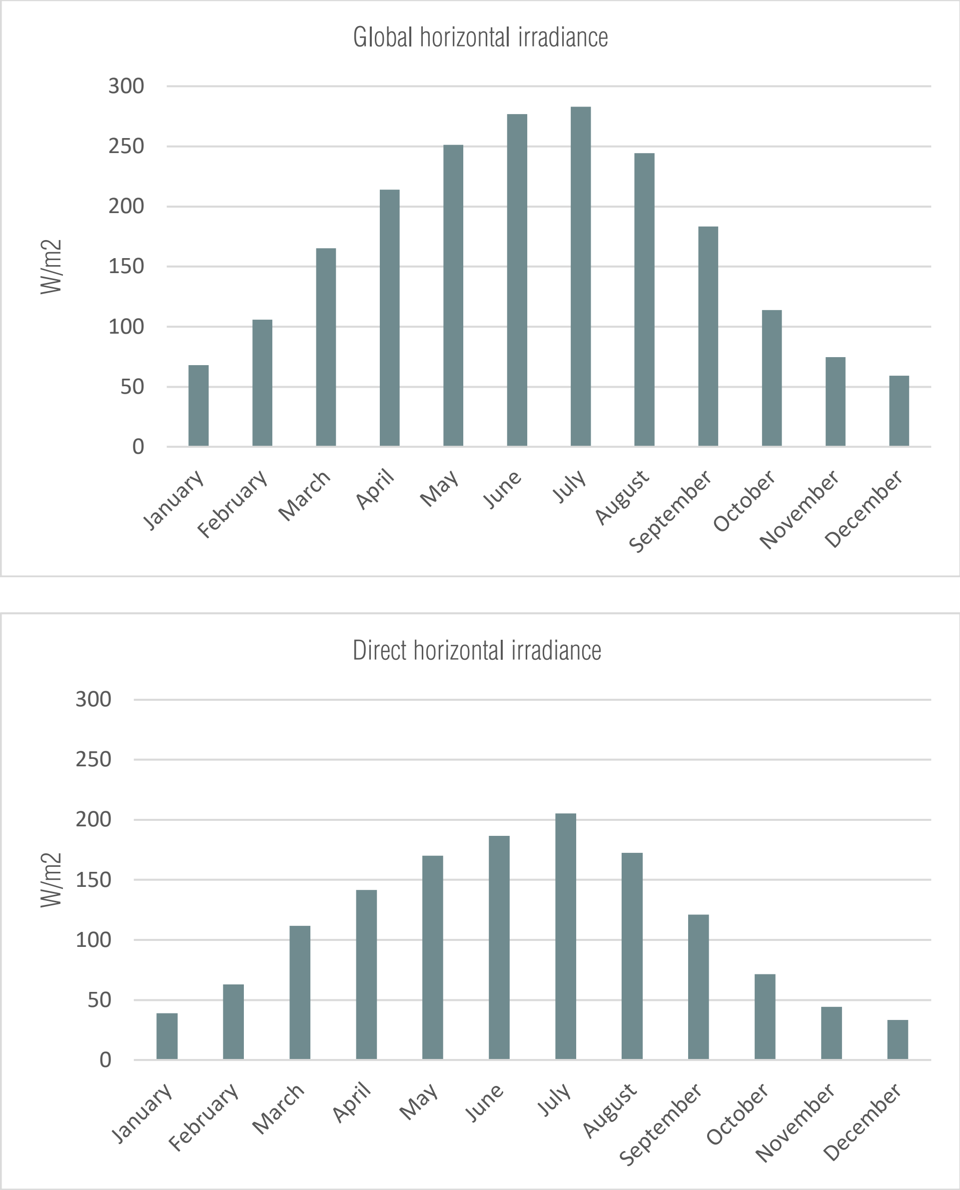


FIG. **42**-Global horizontal irradiance and direct horizontal irradiance

- **Modeling building properties**

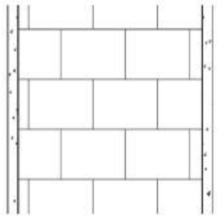
2D documents provided by the municipality and property owners, along with information extrapolated from Google Maps, were used to understand the village's layout. A detailed 3D model of the village was meticulously created using SketchUp and exported into DXF format for importing into CitySim Pro, aiding in visualizing the village's structure and identifying potential redevelopment opportunities.

- **Building slection and characteristics**

In this case study, due to insufficient technical details about the building, the thermophysical parameters for both opaque and transparent parts of the envelope were determined using the UNI/TR 11552 standard from 2014. This standard provides a catalog of typical stratigraphies for opaque envelopes, categorized by construction period and regional characteristics in Tuscany. It details specific properties of each layer within the envelope components, such as thickness, thermal conductivity, volumetric mass, and specific heat. Additionally, the standard allows for the direct calculation of thermal transmittance based on the total thickness of the component.

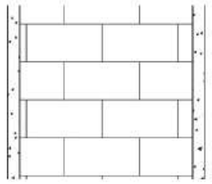
Using this standard and the information it provides, it was possible to define the envelope components in detail, which will be presented in the table.

Vertical components

Code	Description	Thickness	Thermal transmittance	Representation
2001	Brick wall 1	50cm	1.288 W/m^{2}K	

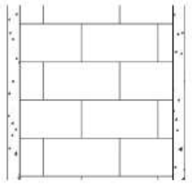
Layer(int.-ext.)	Thickness	Density	Specific heat	Thermal conductivity
Plaster	2 cm	1400 kg/m^3	1000 (J/kg K)	0.70 (W/m K)
Brick& stone	50 cm	2000 kg/m^3	1000 (J/kg K)	0.90 (W/m K)
Plaster	2 cm	1800 kg/m^3	1000 (J/kg K)	0.90 (W/m K)

FIG. **43**- Specifications 2001 component

Code	Description	Thickness	Thermal transmittance	Representation
2002	Brick wall 2	40cm	1.503 W/m^{2}K	

Layer(int.-ext.)	Thickness	Density	Specific heat	Thermal conductivity
Plaster	2 cm	1400 kg/m^3	1000 (J/kg K)	0.70 (W/m K)
Brick& stone	40 cm	2000 kg/m^3	1000 (J/kg K)	0.90 (W/m K)
Plaster	2 cm	1800 kg/m^3	1000 (J/kg K)	0.90 (W/m K)

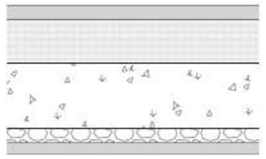
FIG. **44**-Specifications 2002 component

Code	Description	Thickness	Thermal transmittance	Representation
2003	Brick wall 3	35cm	1.640 W/m^2·K	

Layer(int.-ext.)	Thickness	Density	Specific heat	Thermal conductivity
Plaster	2 cm	1400 kg/m^3	1000 (J/kg K)	0.70 (W/m K)
Brick& stone	35 cm	2000 kg/m^3	1000 (J/kg K)	0.90 (W/m K)
Plaster	2 cm	1800 kg/m^3	1000 (J/kg K)	0.90 (W/m K)

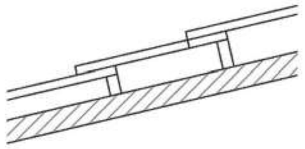
FIG. **45**-Specifications 2003 component

Horizontal Components

Code	Description	Thickness	Thermal transmittance	Representation
2005	Floor1	21.5cm	1.457 W/m^{2}K	

Layer(int.-ext.)	Thickness	Density	Specific heat	Thermal conductivity
Plaster	2 cm	1800 kg/m^3	910 (J/kg K)	0.90 (W/m K)
Cement mortar	6 cm	600 kg/m^3	1000 (J/kg K)	0.10 (W/m K)
Light weight concrete	9 cm	400 kg/m^3	1000 (J/kg K)	0.15 (W/m K)
Brick & block	2 cm	2000 kg/m^3	670 (J/kg K)	1.40 (W/m K)
Plaster	1.5 cm	1700 kg/m^3	710 (J/kg K)	1.47 (W/m K)

FIG. **46**-Specifications 2005 component

Code	Description	Thickness	Thermal transmittance	Representation
2006	Roof 1	7cm	2.601 W/m^{2}K	

Layer(int.-ext.)	Thickness	Density	Specific heat	Thermal conductivity
Plaster	4 cm	1800 kg/m^3	910 (J/kg K)	0.90 (W/m K)
Wooden plank	3 cm	550 kg/m^3	1600 (J/kg K)	0.15 (W/m K)

FIG. **47**-Specifications 2006 component

Transparent component

In the case study for the current situation, the original windows are characterized as single wood frame units, reflecting the building's age. The dimensions of the windows exhibit only minor variations, and thus, all windows are regarded as being of the same type and size. This uniformity simplifies any analysis or renovation efforts, as the consistency in window design and dimensions eliminates the need for customized solutions for different windows.

	Glass surface N	Glass surface S	Glass surface E	Glass surface W
Building 1	18.5%	22%	25%	0%
Building 2	23.5%	18.5%	0%	0%
Building 3	15.3%	20.5%	0%	0%
Building 4	20%	20%	0%	0%
Building 5	13%	10%	0%	8%
Building 6	12%	18%	18%	17.5%
Building 7	0%	15%	0%	18%
Building 8	0%	10%	0%	0%
Building 9	20%	20%	0%	10%
Building 10	10%	30%	0%	0%
Building 11	14%	10%	10%	0%

*G value considered as 0.85

*U value considered as 1.80 (W/m²·K)

FIG. **48**-Percentage of glazing for each building in relation to facade exposure

Identification of thermal zones

Internal heat loads are thermal inputs that affect comfort conditions within the building's thermal zone. In winter, they are free gains; in summer, they are excess heat to be removed. They can be convective or radiative. While the convective component directly becomes a heat load, the radiative component must first be absorbed by the environmental surfaces before it is transferred to the system. Accumulation and subsequent release of this energy because of the thermal inertia of space elements delay and dampen the radiative component.

They, however, can be grouped based on their source: occupants, lighting systems, and electrical appliances. The available literature indicates that the loads can be estimated either by stochastic means or by deterministic methods depending on the space or individual. In the stochastic approach, a parametric value can be assigned based on the type of space or usage to use class-specific values. In contrast, deterministic methods assess occupants' behavior individually and their interaction with the environment in terms of thermal sources. The incomplete definition of occupant profiles may result in rather big deviations of simulated values from actual ones.

One simple way to represent the occupants in a model would be to use deterministic tables defining the likelihood that spaces will be used at any time of day or throughout the year, based on the various space usages of the building. Stochastic occupancy models—such as Bernoulli processes, survival analysis, and discrete-time Markov chains—are all based on calculations of the probability of occupants moving from one state to another where the future state is dependent only on the current state. However, they are more complicated and need many input parameters, so they can't be applied at an urban scale. Thus, in this context, it is considered that values used are of a deterministic type according to the kind of space, which is more practical than managing the acts of the users within an urban environment.

Within CitySim Pro, data related to endogenous thermal loads produced by electrical devices and lighting systems can be entered by filling in the XML file, as already done for the other data sets. In detail, this is accomplished using the Tags DeviceType and ActivityType. Using the Tag DeviceType, it is possible to enter the average power output, the shares of convective and radiative heat contributions, and the daily hourly usage profile.

An algorithm could be designed to produce for each hourly value a stochastic number, which should represent the probability of use of the device. Provided that this number turns out less than or equal to that corresponding to the i-th hour, the consumption derived from the considered DeviceType would be accounted for.

This can be done through the use of the ActivityType tag, where electrical devices of every building can be associated. In this way, through the algorithm, consideration will be taken into account for the usage of an individual's referenced devices or their combined usage or non-usage.

This algorithm generates a stochastic value for each hour under conditions where there are several electrical devices, and every device has an hourly usage profile with power outputs and compares them with the values for that same hour of every device to predict the usage by devices present in the environment.(Ruggiero, 2021)

Time profile

To assess endogenous heat sources, hour profiles shall be provided with estimates of the intensity of thermal inputs from occupants, lighting, and electric appliances. In the next section, methods of data collection are described that may be applied to generate the hourly time profiles valid for a reference year and consistent with the respective time steps of the two programs.

The required data were sourced from the EN 16798-1:2019 standard, which refers to residential use. A summary sheet was developed showing all input parameters that shall be used by the software programs, and daily load profiles for weekdays, Saturdays, Sundays, and holidays. In this analysis, attention is focused on a residential single-family house. For weekdays, Saturdays, Sundays, and holidays, time profiles were created, each featuring hourly variations according to the annual profile. In other words, the time profiles that are created will be relevant for representing in an integral way thermal loads and energy demands throughout the year.

It is impossible to define a thermal zone independently of the definition of the thermal loads. In a residential building, there are several types of occupants: elderly, families, or students, which provide occupancy-specific profiles. Hence, although the intensity of the thermal loads might be correctly estimated by the summation of individual apartment behaviors, it would be less accurate to model presence/absence or usage profiles.

In CitySim, a time profile is an extensive way of presenting changes in certain parameters, for example, thermal loads, energy use, or occupation patterns, over time for a building or thermal zone. This profile forms a basis for variable building performance simulation and analysis in different periods: hourly, daily, monthly, or yearly.

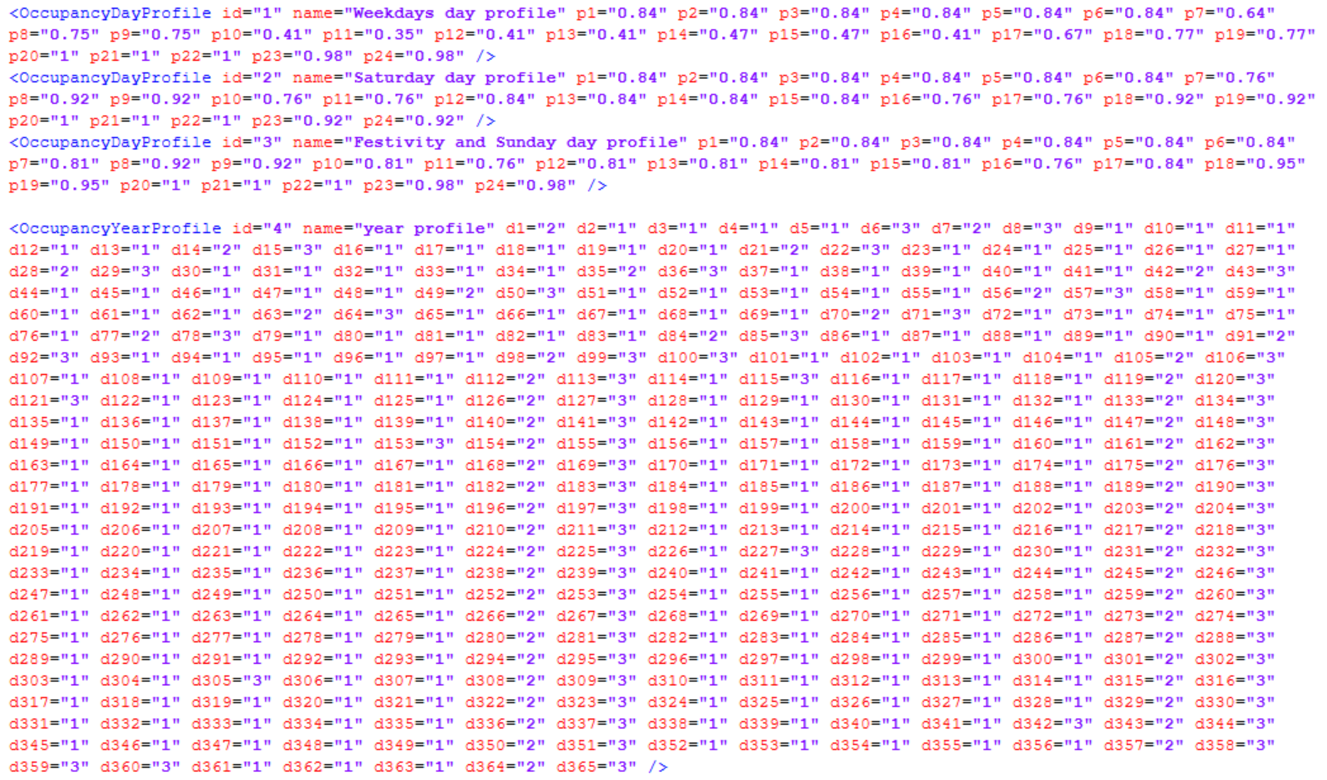
	Weekdays			Saturday			Sunday/Festivity		
H	Occ.	App.	Light	Occ.	App.	Light	Occ.	App.	Light
1	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
2	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
3	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
4	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
5	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
6	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
7	0.50	0.50	0.15	0.80	0.50	0.15	0.80	0.50	0.15
8	0.50	0.70	0.15	0.80	0.70	0.15	0.80	0.70	0.15
9	0.50	0.70	0.15	0.80	0.70	0.15	0.80	0.70	0.15
10	0.10	0.50	0.15	0.80	0.50	0.15	0.80	0.50	0.15
11	0.10	0.50	0.05	0.80	0.50	0.05	0.80	0.50	0.05
12	0.10	0.60	0.05	0.80	0.60	0.05	0.80	0.60	0.05
13	0.10	0.60	0.05	0.80	0.60	0.05	0.80	0.60	0.05
14	0.20	0.60	0.05	0.80	0.60	0.05	0.80	0.60	0.05
15	0.20	0.60	0.05	0.80	0.60	0.05	0.80	0.60	0.05
16	0.20	0.50	0.05	0.80	0.50	0.05	0.80	0.50	0.05
17	0.50	0.50	0.20	0.80	0.50	0.20	0.80	0.50	0.20
18	0.50	0.70	0.20	0.80	0.70	0.20	0.80	0.70	0.20
19	0.50	0.70	0.20	0.80	0.70	0.20	0.80	0.70	0.20
20	0.80	0.80	0.20	0.80	0.80	0.20	0.80	0.80	0.20
21	0.80	0.80	0.20	0.80	0.80	0.20	0.80	0.80	0.20
22	0.80	0.80	0.20	0.80	0.80	0.20	0.80	0.80	0.20
23	1.00	0.60	0.15	1.00	0.60	0.15	1.00	0.60	0.15
24	1.00	0.60	0.15	1.00	0.60	0.15	1.00	0.60	0.15
AV	0.60	0.60	0.10	0.87	0.60	0.10	0.87	0.60	0.10

FIG. **49**-Graphical representation of occupancy and equipment usage hourly profiles

The values in the table probably show how different energy-consuming entities (lighting, appliances, and occupants) are used throughout the day, taking into account holidays and celebrations. The European standard EN 16798-1:2019 for the energy performance of buildings serves as the foundation for this table. The standard offers techniques for energy calculations as well as requirements for indoor environmental parameters. In order to guarantee effective building performance and adherence to energy regulations, it also contains comprehensive information about the energy usage of residents, appliances, and lighting.

The values are from 0 to 1, where 0 denotes 0% and 1 represents 100%. These figures represent the amount or percentage of energy used for activity, occupancy, or use.

Building occupants, appliances, and lighting are the various energy-consuming entities that fall under these categories. The presence or activity level of these entities at particular times of the day is indicated by the values under these columns.



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p8="0.75" p9="0.75" p10="0.41" p11="0.35" p12="0.41" p13="0.41" p14="0.47" p15="0.47" p16="0.41" p17="0.67" p18="0.77" p19="0.77"
p20="1" p21="1" p22="1" p23="0.98" p24="0.98" />
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p20="1" p21="1" p22="1" p23="0.92" p24="0.92" />
<OccupancyDayProfile id="3" name="Festivity and Sunday day profile" p1="0.84" p2="0.84" p3="0.84" p4="0.84" p5="0.84" p6="0.84"
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p19="0.95" p20="1" p21="1" p22="1" p23="0.98" p24="0.98" />

<OccupancyYearProfile id="4" name="year profile" d1="2" d2="1" d3="1" d4="1" d5="1" d6="3" d7="2" d8="3" d9="1" d10="1" d11="1"
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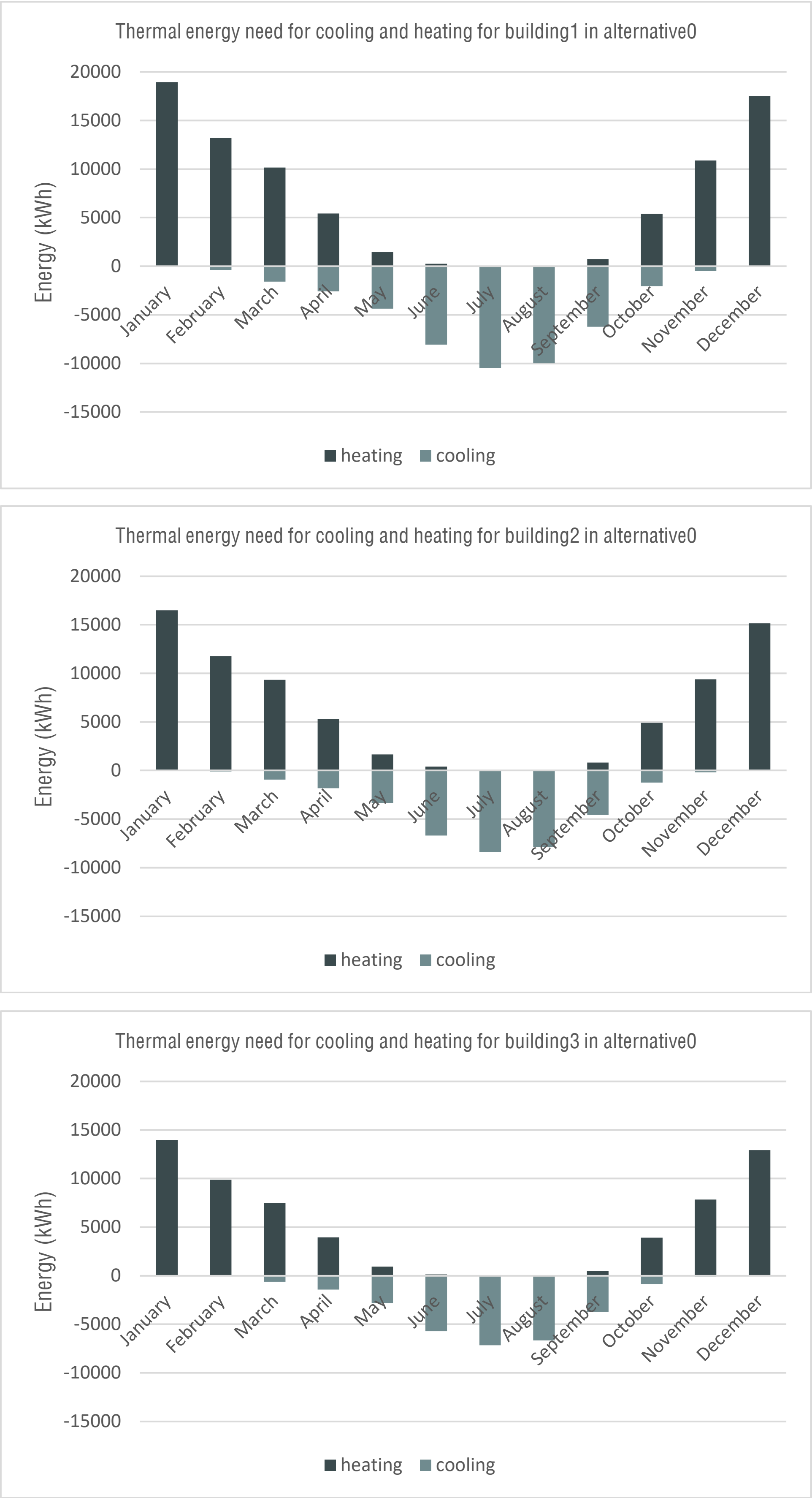
FIG. **50**-CitySim representation of occupancy and equipment usage hourly profiles

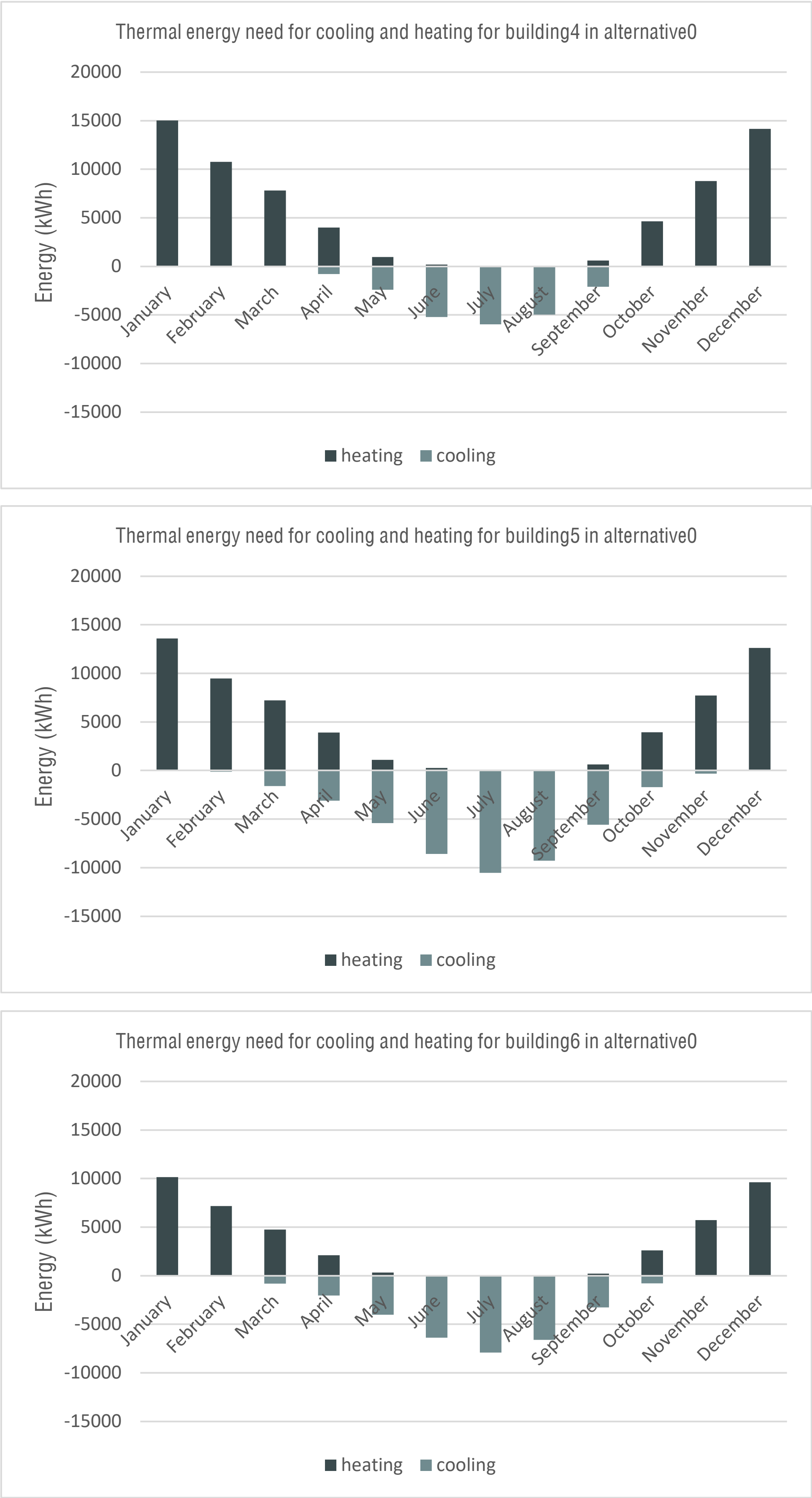
Simulation results of thermal energy needs for space heating and cooling in alternative 0 buildings



Thermal energy need for cooling and heating for building1 in alternative0

Thermal energy need for cooling and heating for building2 in alternative0

Thermal energy need for cooling and heating for building3 in alternative0

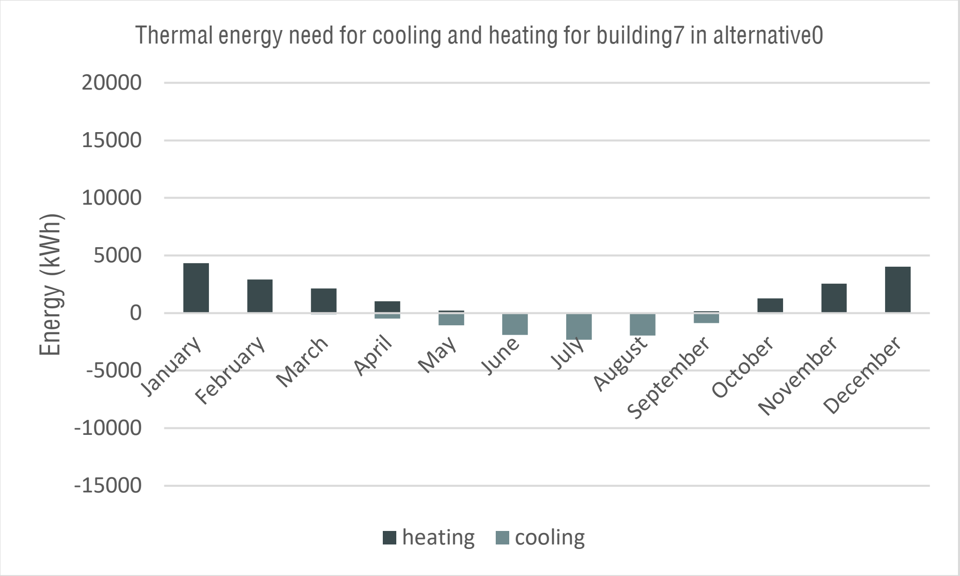


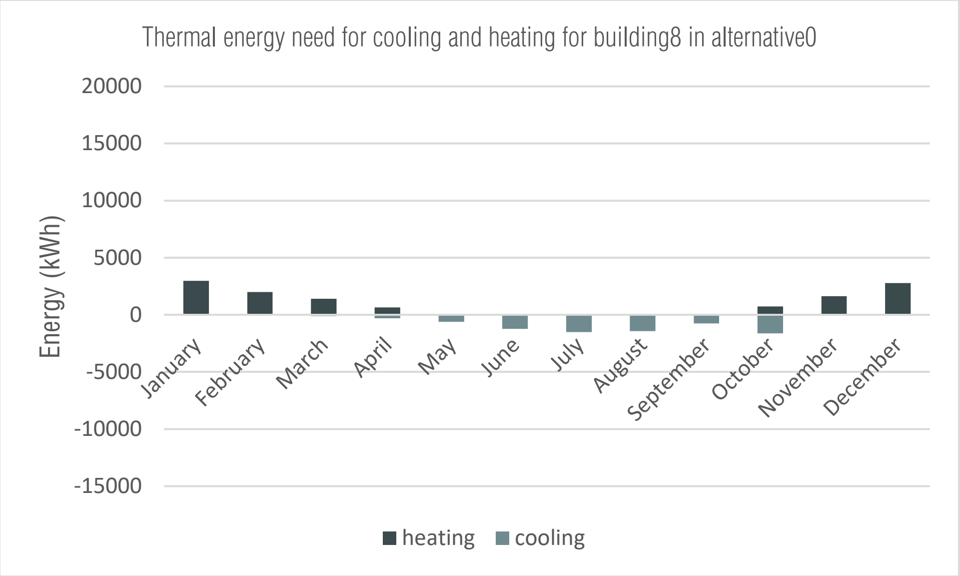
Thermal energy need for cooling and heating for building4 in alternative0

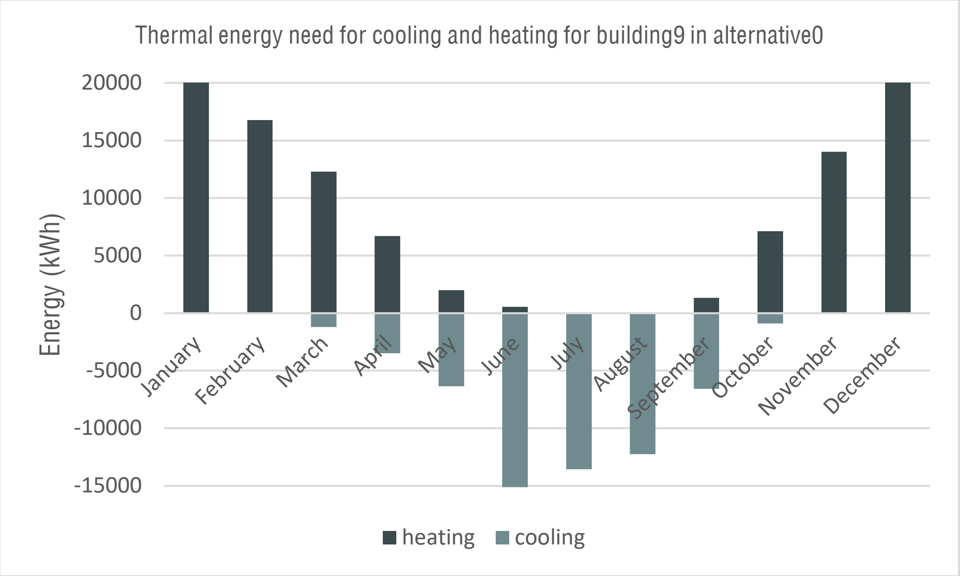
Thermal energy need for cooling and heating for building5 in alternative0

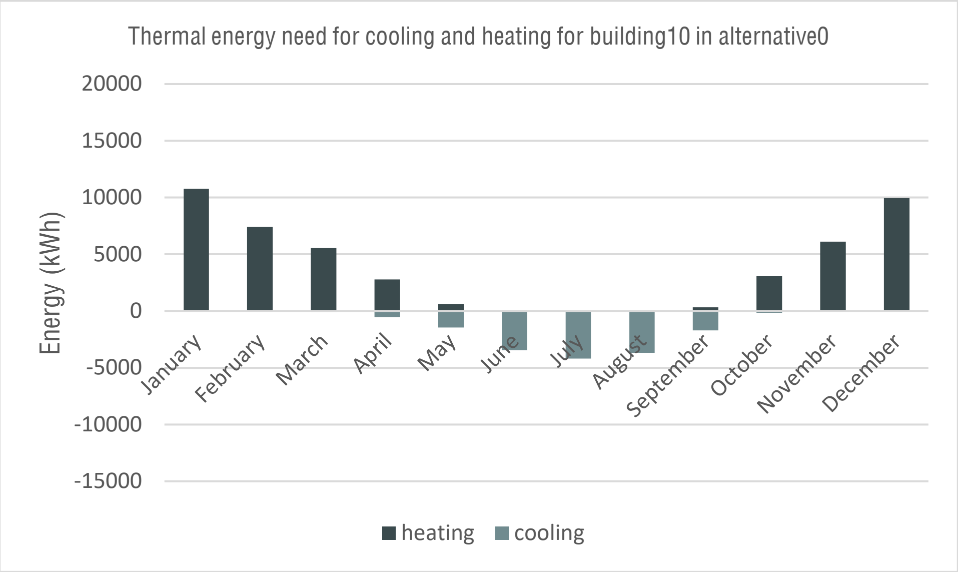
Thermal energy need for cooling and heating for building6 in alternative0

FIG. **51**-Results of thermal energy need for cooling and heating for buildings1-6 in alternative 0









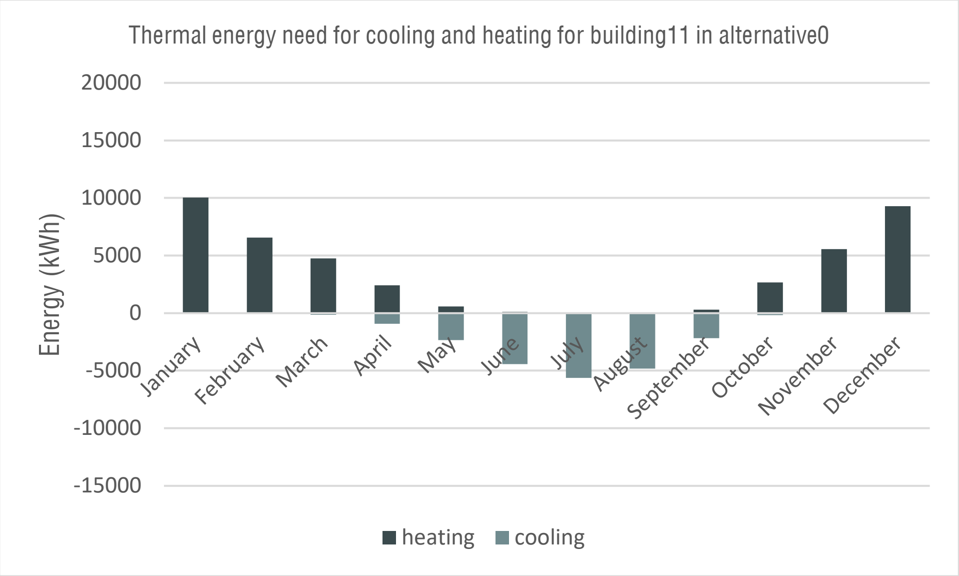


FIG. **52**-Results of thermal energy need for cooling and heating for buildings 7-11 in alternative 0

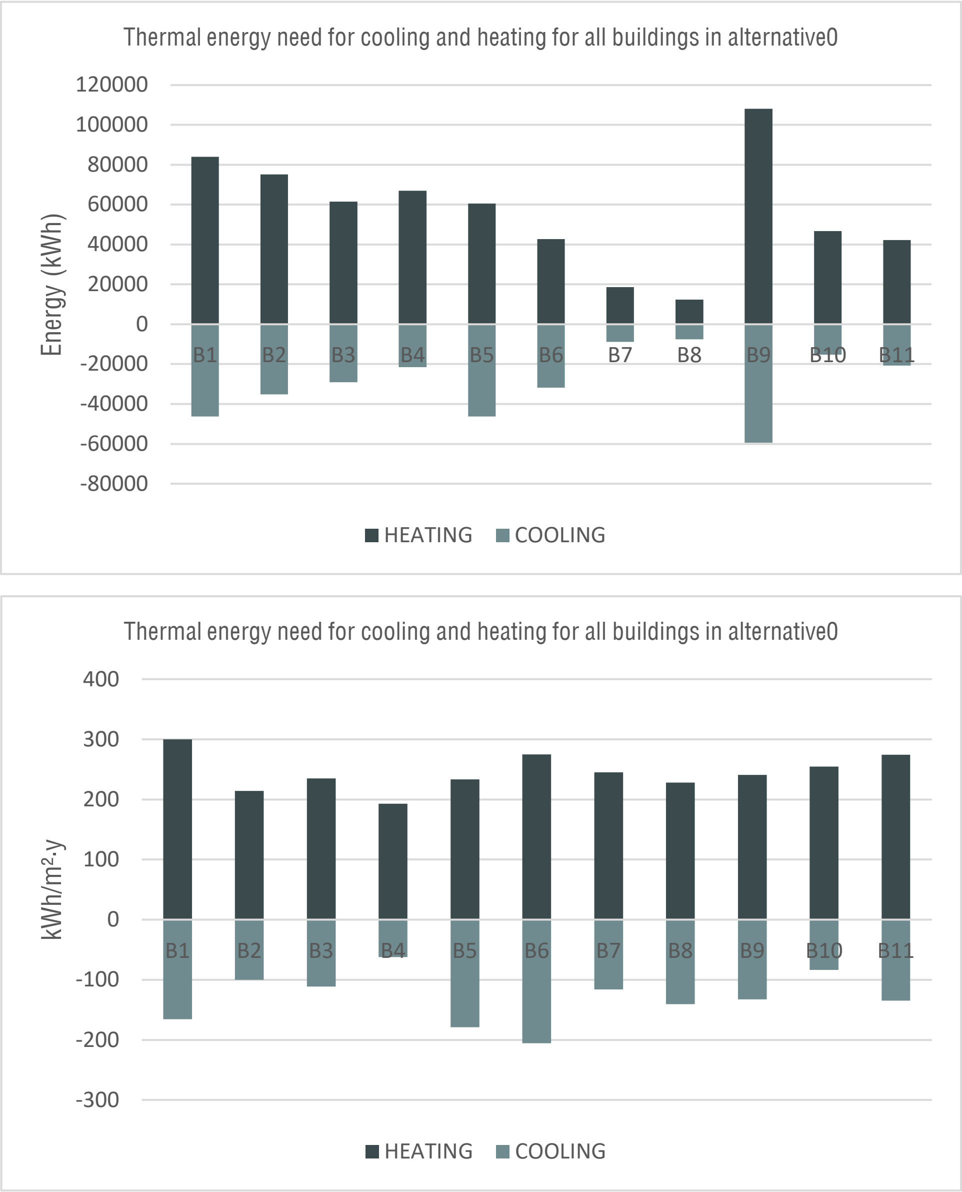


FIG.**53**-Comparison of thermal energy need for cooling and heatingfor all buildings in alternative 0

The main energy consumption of each building was simulated in alternative 0, which depicts the current state of affairs where all buildings are regarded as residential. A thorough comparison of the energy use of each building was part of the analysis. A thorough understanding of each building's energy usage performance under the current residential scenario is made possible by this comparison.

Smart village integration

According to the European case study research, interventions to transform Toiano into a NZEB village can be categorized into two main parts: social and technical interventions. In the context of Toiano and its potential, both aspects are taken into consideration.

Social intervention

The main goal of social intervention is to set up appropriate activities that draw a wide range of users—both Italians and foreigners—to participate in different activities in the village. These could be day trips or longer stays that include sports, workshops, or even work from home opportunities. Bringing in these kinds of events and friendly locals will help to rejuvenate the village and bring back the feeling of community life.

Investing in Toiano as a tourism destination makes more and more sense financially. There's room for substantial economic growth if the activities offered are expanded and the village is made more enticing to tourists. This expansion may result from higher tourism-related income as well as chances for local companies to thrive by offering goods and services that meet the needs of both locals and visitors.

In the end, Toiano has the ability to regain its vitality and develop into a bustling center of activity, which would be advantageous to both locals and tourists, through deliberate social interventions meant to improve the village's attractiveness and functionality.

Technical intervention

The basic concept of nearly zero-energy buildings comes from the Energy Performance of Buildings Directive, providing general targets to be used by each European country in setting their own specific objectives. Because there are 28 countries in Europe, all with different climatic conditions, economic contexts, and building types, the directive does not specify a single way of implementing NZEBs. It only provides recommendations to member states for their national plans and regulations that would be suitable for the conditions in each country. In trying to attain these targets, countries should also consider their climatic conditions in choosing standards for NZEB, taking into account temperature differences, humidity, solar radiation, and all other environmental factors that have an impact on the energy performance of buildings. Economic differences between countries are also huge, and each country has to tune its NZEB definitions and measures to its economic environment in terms of financial viability and accessibility. Another dimension is added by the great variety of building types: residential, commercial, public, and industrial, all of which require special approaches whereby each country has to develop NZEB criteria specific to the particular energy requirements and uses of the different building categories. Member states shall develop their national plans accordingly, defining NZEB, outlining measures for reaching NZEB, and detailing methods for calculating a building's energy balance. While all member states are required to implement the EPBD, there is leeway within the approach for the country-specific adaptation of strategies to local conditions, thus making NZEB standards only realistically achievable and relevant to the needs and capacities of each country. Setting the framework for NZEBs, the EPBD provides general targets and guidelines, leaving each European country to make a detailed national plan, taking into account specific climatic conditions, the economic situation, and the building types of every country. This, therefore, ensures that it will be tailored to specific needs and an effective approach toward Nearly Zero-Energy Buildings.

According to the national report on NZEB buildings, one of its key focuses has been to establish current heating and cooling limits derived from cost-optimal analysis. These set targets vary by the geographical region in Italy where the building is located and the surface area to volume ratio, S/V. The country of Italy has been divided into six different climate zones, each having its limits.

This case study applies target data that are compatible with specifications and requirements for zone D, considering that it is located in climate zone D. From the information and standards set concerning this climate zone, relevant analysis has been done as shown below. (Ruggiero, 2021)

The strategy for ensuring compliance with the Italian legislation on Nearly Zero-Energy Buildings is usually divided into three phases.

Generate Renewable Energy,technologies such as solar photovoltaic panels, wind turbines, or geothermal systems should be integrated into the building to provide on-site clean energy. The building's energy needs shall thus be supplied by these renewable resources, reducing reliance on non-renewable energy sources and consequently the environmental impact of the building. At least 60% of used energy should be produced from renewable sources.

Another important aspect shall be the enhanced thermal envelope. Improved insulation in walls, roofs, and floors shall reduce heat loss during winter and limit heat gain during summer. Installation of high-performance windows and doors greatly improves the thermal insulation and minimizes air leakage. The enhanced thermal envelope shall, to a great extent, consider reducing the energy consumption of a building for heating and cooling. Technical systems should also be adopted that incorporate advanced technologies and energy-efficient systems. These will include high-efficiency heating, ventilation, air conditioning, etc., That ensures reduced energy use without sacrificing comfort.

Smart controls and automation systems shall also be used to optimize energy use depending on occupancy and weather conditions. The lighting and appliances used are also energy-efficient and help reduce energy consumption further. These technological measures, like building envelope and renewable energies, are complemented by improvements to ensure the optimal operational efficiency of the building. Italian legislation seeks to ensure that NZEBs achieve better energy performance, aligning these steps with the target data mentioned for each zone, which causes minimized energy demands and coverage of a significant portion of their energy needs through renewable sources. Only then can this integral approach enhance the building's sustainability and support broader goals of reducing greenhouse gas emissions and advancing energy efficiency that ensures reduced energy use without sacrificing comfort. (Ministry for ecological transition, 2021)

Designing master plan

In designing the master plan for the revitalization of Toiano Village, I have considered various crucial aspects to ensure a holistic and sustainable development. These considerations encompass the village's potential to attract visitors, the essential needs of the community, adherence to municipal regulations, economic feasibility, and compliance with Italian standards. By addressing these diverse elements, the master plan aims to transform Toiano into a vibrant, multi-functional community that harmoniously blends modern amenities with its unique charm and heritage.

The potential of Toiano

Toiano, cleaned up and in a very strategic position, holds great potential for both local and international visitors for either long or short stays. This tranquil setting would offer a haven to remote workers, tourists, and athletes who want to retreat for some peace. A renovation of Toiano would give it a new identity—from a village to an actively living one, which attracts various target groups without losing the characteristic touch.

For the renewal and development of Toiano, the refurbishment should be able to cater to basic requirements and activities with the help of both existing and new buildings. The following are the new activities that would be incorporated into the master plan:

Residential Spaces: Single rooms, double rooms, suites, 2- and 3-bedroom apartments.

Reception and Waiting Area: A well-appointed reception area would serve as an exquisite space for check-in and orienting guests with information.

Bar and Restaurant: A shared dining area for local cuisine, along with hosting space for locals and visitors to socialize.

Coworking Spaces: Modern coworking facilities that would appeal to remote workers and digital nomads.

Multi-function Spaces: Versatile spaces for events, meetings, and community activities.

Childcare Spaces: Safe and engaging spaces for children, accommodating families visiting or living in the village.

Store: A convenience store selling basic supplies, linked with local products.

Municipality rules

Adhering to municipal regulations is crucial for the successful implementation of the master plan. According to the municipality, the maximum allowable volumetric integration is 25%. This restriction presents a challenge in adding new volumes in a way that harmonizes with existing buildings and does not disrupt the village's aesthetic and functional coherence.

Economic challenge

A modern amenities with its historical charm, and securing a sustainable and prosperous future for the village.

A key aspect of the project is determining the optimal number of occupants that the village can accommodate while ensuring a sustainable economic model. The balance between the investment required for renovation and the projected revenue from occupancy must be carefully calculated to attract investors and ensure the project's viability.

By considering The Potential of Toiano, Municipality Rules, Economic Challenges, two proposals, and the master plan prepared for this thesis and municipal presentation, two scenarios are evaluated: one without adding volume and the other with a 25% increase in volume. In both case studies, the goal is to renovate the village into a Nearly Zero Energy Building (NZEB) village.

Concept village

Both technical and social interventions are being considered for the renovation of this village.

Concept bridge

As previously mentioned, the village is connected to the main street by a bridge that offers a breathtaking view of the unspoiled countryside and the Tuscan hills from both sides. It is advised to use the bridge's functions as a pedestrian path to enter the village and as a time exhibition space. On either side of the bridge, there will be urban furniture that serves as a place to sit and take in the view as well as an exhibition that highlights the history of Toiano. These urban furniture pieces, which are covered in photovoltaic panels to symbolize technology, force visitors to interact with both new and traditional trains. the power generated by these parts used for lighting of bridge.

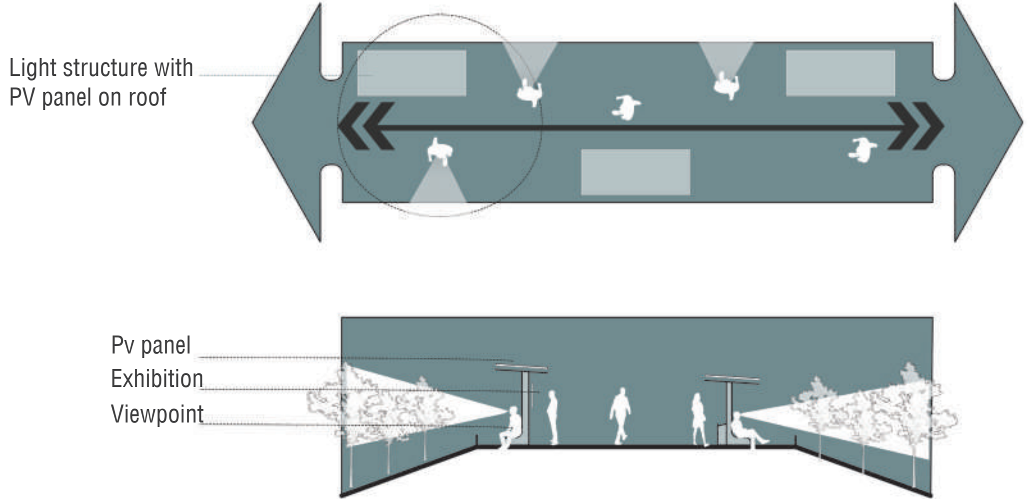


FIG.**54**-Conceptual diagram of the future-past bridge

Concept parking lot

Due to the narrow dimensions of the main pathway and entrance of the village, a spot at the beginning of the village has been designated as a parking lot, also accommodating bicycles. This area can be integrated with future public infrastructure. The main idea of the parking space is to cover it with a shelter equipped with PV panels, which will not only provide shelter but also generate renewable energy.

Concept agrivoltaic farm

It is an undeniable fact that in rural areas, there is a great opportunity to combine farming with energy production. In this context, there are plenty of agricultural lands and farms that can be used to produce energy as well. Considering the perspective and view from the village, an agrivoltaic farm is suggested along the border. By installing PV panels, the amount of energy produced can be used for urban street lighting and to meet the energy needs of the village. If the amount of energy produced is insufficient, the surplus can be stored or sold for use at night or during winter.

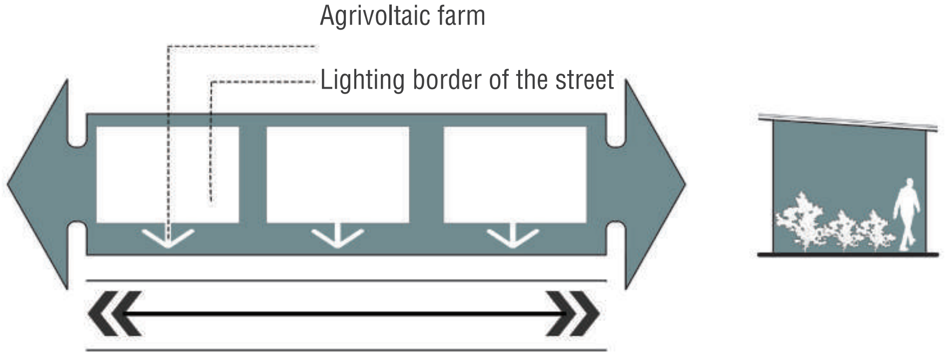


FIG.**55**-Conceptual diagram of the future-past

Alternative 1
Design and integration without volume expansion

In Scenario 1, which is considered without adding any volume, the village is mainly residential, catering to both short-term and long-term stays, as well as one-day trips. Considering the nature and potential of the surrounding area of Toiano for mountain climbing, Toiano can appeal to athletes and people who want to take a short vacation or work remotely away from the city. All these potentials and needs have been considered in designing the master plan of Scenario 1.

- There is a reception at the entrance of the village that serves all the residents and also includes small spaces for those who work in Toiano.
- The geometry of the village features buildings on two sides with an unlimited view and perspective of nature. This potential is utilized for the residential part. Each building includes coworking or shared spaces that can be used for smart working. These spaces can collaborate together and function like small units. Therefore, the ground floor is mostly a combination of residential and shared spaces, while the first and second floors are entirely residential. The types of residential spaces, due to the scale of the project and the effort to minimize interventions such as demolishing walls, are considered single-family houses with 1, 2, or 3 bedrooms, as well as small rooms and suites.
- Other potential features include multifunctional spaces that can accommodate various events such as temporary exhibitions, workshops, and art galleries. These spaces can be used differently depending on the season.
- There is also a restaurant and bar with a garden that offers both indoor and outdoor seating, capable of welcoming groups of tourists.
- Additional functions of the spaces include a store that can sell farm products and organic products from the Tuscany region, and a small childcare space that can be necessary for families who want to enjoy nature and work remotely.

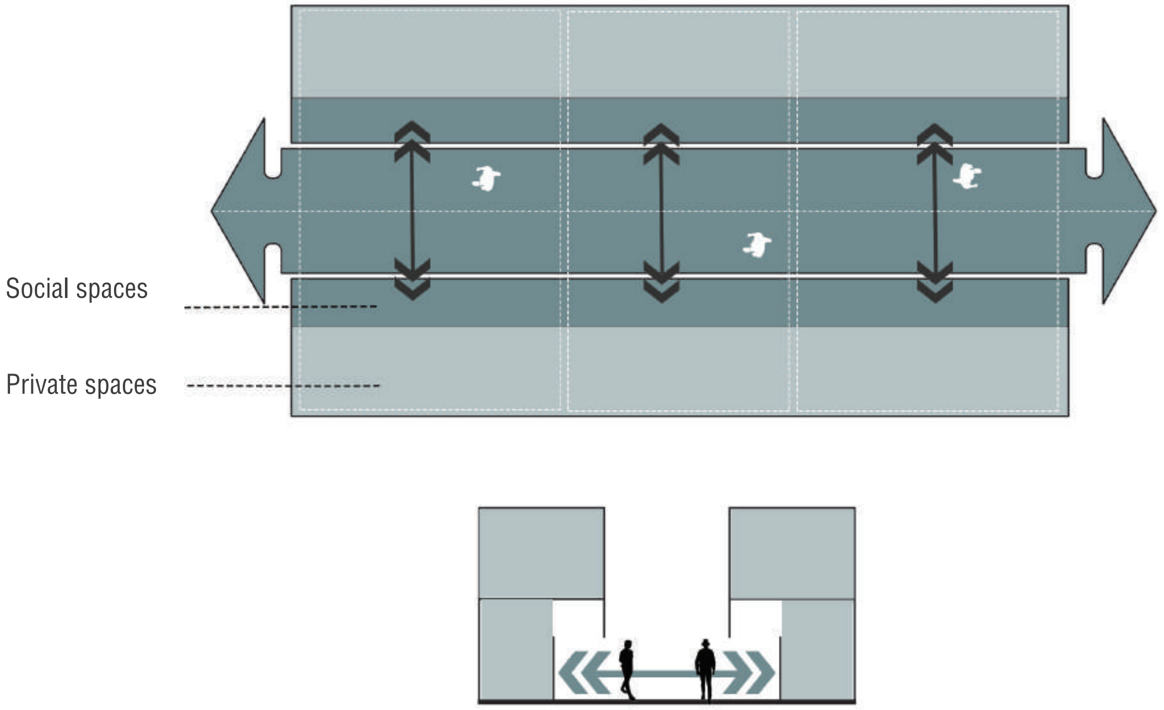


FIG.**56**-Conceptual diagram of the future-past bridge-Conceptual diagram of dividing and designing

Architectural document for alternative 1
Design and integration without volume expansion

social intervention

🟧 **Residential**

⬜ **Social space**

▨ **Restaurant- Bar**

🟨 **Muli function space**

🟫 **Store**

🟦 **Child care space**

▨ **Reception**

FIG.**57**-Axonometric functional analysis

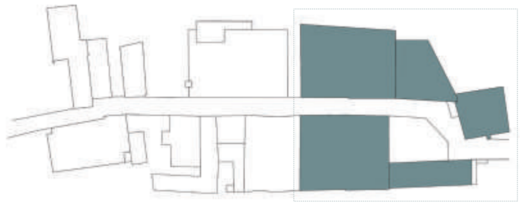
Alternative1

Ground floor plan **scale 1/350**

FIG.**58**-Ground floor plan alternative1

FIG.**59**-Ground floor furniture plan alternative1

Key plan



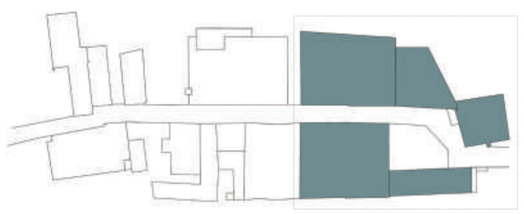
Legend

1 - Resturant
2 -Residential
3 -Reception
4 -Social spaces

Alternative1 **scale 1/200**
Ground floor furniture plan

FIG.60-First floor furniture plan alternative1

Key plan



Legend

1 - Resturant
2 -Residential
3 -Reception
4 -Social spaces

Alternative1 **scale 1/200**
First floor furniture plan

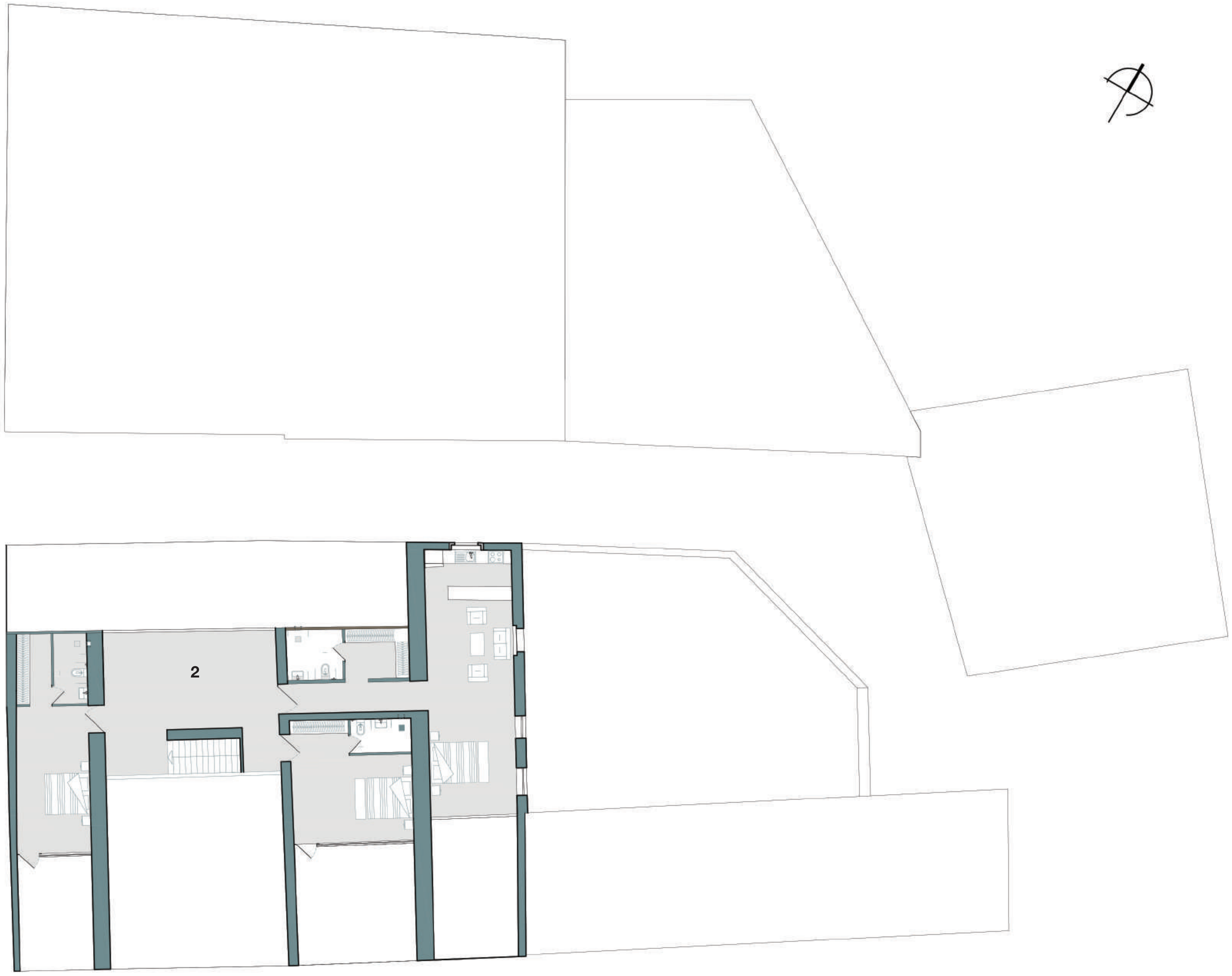
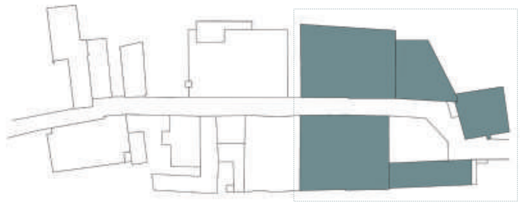


FIG.**61**-Second floor furniture plan alternative1

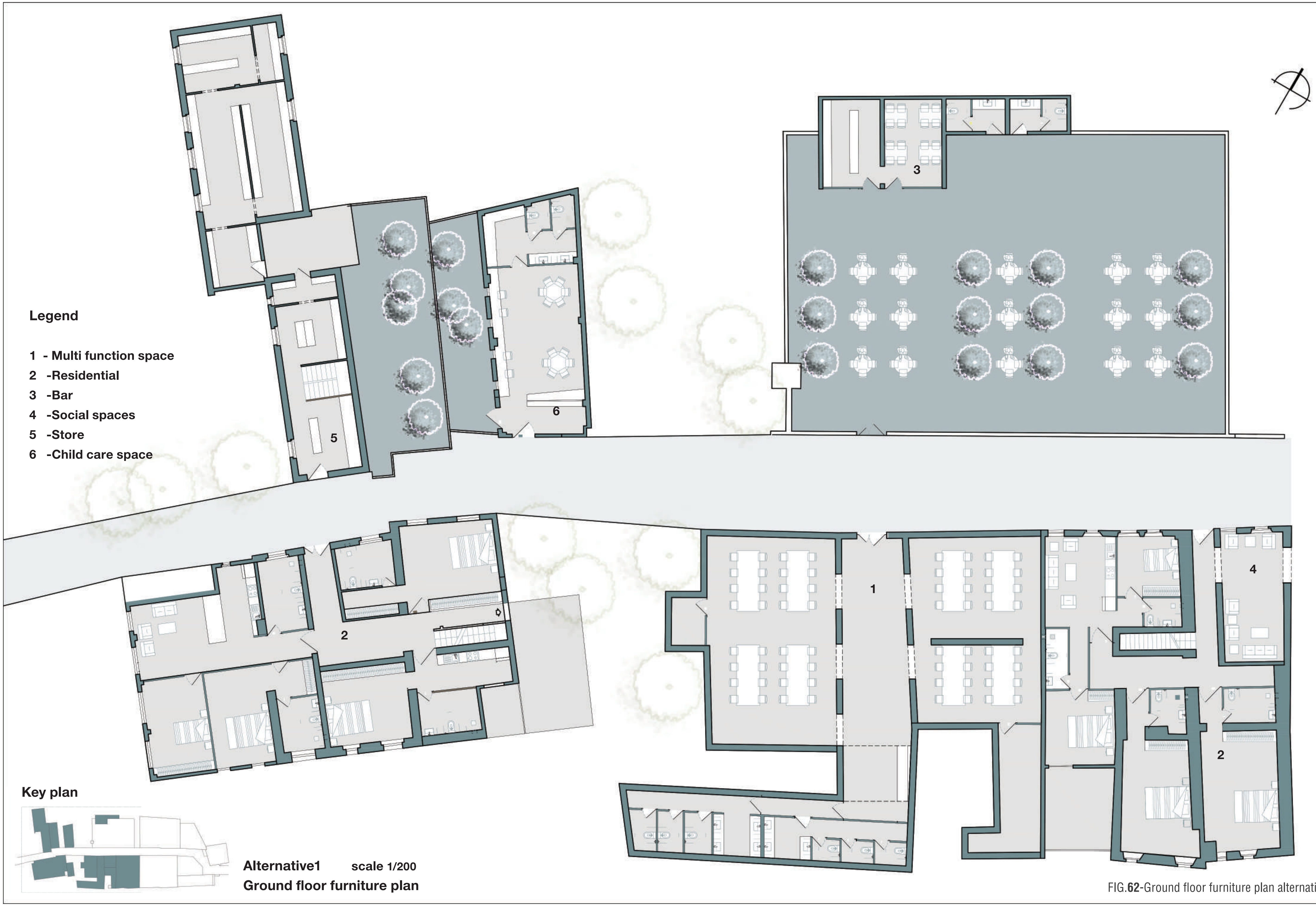
Key plan



Legend

1 - Resturant
2 -Residential
3 -Reception
4 -Social spaces

Alternative1 **scale 1/200**
Second floor furniture plan



Legend

1 - Multi function space
2 -Residential
3 -Bar
4 -Social spaces
5 -Store
6 -Child care space

Key plan

Alternative1 **scale 1/200**
Ground floor furniture plan

FIG.**62**-Ground floor furniture plan alternative1

Legend

1 - Multi function space
2 -Residential
3 -Bar
4 -Social spaces
5 -Store
6 -Child care space

Key plan

Alternative1 **scale 1/200**
First floor furniture plan

FIG.**63**-First floor furniture plan alternative1

Legend

1 - Multi function space
2 -Residential
3 -Bar
4 -Social spaces
5 -Store
6 -Child care space

Key plan

Alternative1 **scale 1/200**
Second floor furniture plan

FIG.**64**-Second floor furniture plan alternative1

Tecnical intervention

Requirements and prescriptions for envelope interventions

Commission Recommendation (EU) 2019/786 of 8 May 2019 on renovation, recalling Directive 2012/27/EU about energy efficiency, defines deep renovations as those that reduce, by a significant amount, the energy consumption of a building and lead to it being transformed into a very high energy performance building.

In Italy, major renovations are disciplined by Law No. 90/2013 and by the Ministerial Decree of 26 June 2015, involving demolition, reconstruction, and any enlargement beyond 15% of the original volume or 500 m^2 of already existing buildings, considered new construction projects. Major renovations are divided into the following:

- **First-level renovations**

Renovations that involve more than 50% of a building's gross dispersing surface and renovation of the heating and/or air conditioning system, to which all the energy performance requirements of the entire building shall apply.

- **Second-level renovations**

These involve 25%-50% of the gross dispersing surface of a building; some may include heating and air conditioning system refurbishments, with applicable requirements only to the components involved.

Other retrofitting measures affecting less than 25% of the building's gross dispersing surface or involving partial interventions shall be subject only to energy performance requirements for the components involved. Major renovations having nearly Zero Energy Building objectives are crucial because the 2050 European target is a building stock with nearly zero carbon emissions, which can be achieved by applying the nZEB standard to existing buildings. (Ministry for Ecological Transition, 2021)

This case study, based on the current situation, documentation, photos, and the extent of required intervention, categorizes the renovation as a first-level intervention. This is due to the fact that two buildings are almost demolished, while others are highly damaged and require comprehensive repairs to all structural elements, including the roof, walls, windows, and so on.

Reference or target building

A reference or target building refers to a building that is identical in terms of geometry (shape, volumes, floor area, surface areas of the structural elements and components), orientation, location, use, and surrounding conditions, with predetermined thermal characteristics and energy parameters.Therefore, a reference building means a building with a reference structure and reference technical systems.

The small village of Toiano, in the Tuscany region, falls under the Zone D climate classification. While Tuscany is generally famous for its mild Mediterranean climate, its hilly areas are cooler with cold winters and more temperate summers. The Zone D climate carves out a particular local environment and enables only certain cultivation and ways of life, as opposed to the lower and hotter parts of Tuscany.

Climate zone	U (w/m^2 k)	
	2015	2019/2021
A , B	0.45	0.43
C	0.38	0.34
D	0.34	0.29
E	0.30	0.26
F	0.28	0.24

FIG.**65**-Thermal transmittance (U) of vertical opaque structures, facing outside, non-climatized spaces, or ground (Appendix A, attachment 1, chapter 3)

Climate zone	U (w/m^2 k)	
	2015	2019/2021
A , B	0.38	0.35
C	0.36	0.33
D	0.30	0.26
E	0.25	0.22
F	0.23	0.20

FIG.**66**-Thermal transmittance (U) of horizontal or inclined opaque roof structures,facing outside and non-climatized spaces

Climate zone	U (w/m^2 k)	
	2015	2019/2021
A , B	0.46	0.44
C	0.40	0.38
D	0.32	0.29
E	0.30	0.26
F	0.28	0.24

FIG.**67**-Thermal transmittance (U) of horizontal opaque floor structures, facing outside, non-climatized spaces, or ground(Appendix A, attachment 1, Chapter 3)

Climate zone	U (W/m^2 K)	
	2015	2019/2021
A , B	3.20	3.00
C	2.40	2.20
D	2.00	1.80
E	1.80	1.40
F	1.50	1.10

FIG.**68**-Thermal transmittance (U) of transparent and opaque technical closures and shutters, including frames, facing outside and non-climatized spaces(Appendix A, Attachment 1, Chapter 3)

Climate zone	U (W/m^2 K)	
	2015	2019/2021
All zone	0.80	0.80

FIG.**69**-Thermal transmittance (U) of vertical and horizontal opaque structures separating buildings or units(Appendix A, attachment 1, chapter 3)

Climate zone	g_{gl+sh}	
	2015	2019/2021
All zone	0.35	0.35

FIG.**70**-Total solar energy transmittance factor ggl+shg_{gl+sh}ggl+sh for glazed components with orientation from east to west passing through south(Appendix A, attachment 1, chapter 3)

Average overall heat transfer coefficient

The overall average heat transfer coefficient is an index to evaluate the thermal performance of a building envelope. It is obtained by dividing the overall heat transfer coefficient for transmission of the building envelope, calculated according to UNI/TS 11300-1, by W/m2K. For the verification provided by the present attachment, the average heat transfer coefficient is obtained as shown:

$$H'_T = H_{tr,adj} / \Sigma_k A_k \ [W/m^2K]$$

- $H_{tr,adj}$ is the overall heat transfer coefficient for the transmission of the envelope, calculated according to UNI/TS 11300-1 W/m2K.
- A_k is the surface area of the k-th component (opaque or transparent) constituting the envelope (m²).

The value of H'_T should be less than the maximum allowed value, which depends on the climatic zone and the ratio S/V between the external surface of the building and its volume. This ensures that the erected structure will meet all the requirements set for energy performance and, therefore, improve energy efficiency by reducing consumption for heating and cooling.

	Shape ration(S/V) (m⁻¹)	Climate zone				
		A , B	C	D	E	F
1	S/V > 0.7	0.58	0.55	0.53	0.30	0.48
2	0.7 > S/V > 0.4	0.63	0.60	0.58	0.55	0.53
3	0.4 > S/V	0.80	0.80	0.80	0.75	0.70

	Type of intervention	A , B	C	Climate zone D	E	F
4	Major second level expansions and renovation for building types	0.73	0.70	0.68	0.65	0.62

FIG.**71**-Maximum allowable value of the overall heat transfer coefficient H'_T (W/m²·K)

Summer equivalent solar area

The Summer Equivalent Solar Area is a measure of how much of this radiation enters a building through windows or any other transparent material during summer. It refers to the glazing type, orientation, and shading when describing an area that is practically exposed directly to solar radiation. Designers can understand the possible solar heat gain by calculating ESA, which helps towards improving building energy efficiency and cooling strategies. Lowering the ESA with wise design decisions to reduce overheating, thereby reducing the demand for air-conditioning,can go a long way to save energy overall.

$$A_{\mathrm{sol,est}} = \Sigma_{\mathrm{k}} F_{\mathrm{sh,ob}} \times g_{\mathrm{gl+sh}} \times (1 - F_{\mathrm{F}}) \times A_{\mathrm{w,p}} \times F_{\mathrm{sol,est}} \quad [\mathrm{m}^2]$$

- $F_{\mathrm{sh,ob}}$ is the reduction factor for shading related to external elements for the effective solar capture area of the k-th glazed surface, referred to the month of July.
- $g_{\mathrm{gl+sh}}$ is the total solar energy transmittance of the window calculated in July when the solar shading is used;
- $A_{\mathrm{w,p}}$ is the total projected area of the glazed component (window opening area).
- F_{F} is the frame area fraction, the ratio between the projected area of the frame and the total projected area of the glazed component.
- $F_{\mathrm{sol,est}}$ is the correction factor for the incident solar radiation, derived as the ratio between the average irradiance in July, in the location and exposure considered, and the average annual irradiance in Rome, on the horizontal plane.

	Building category	All climate zone
1	Category E,1 excluding schools, convents, correctional facilities, barracks, as well as Category E,1(3)	< 0.030
2	All other buildings	< 0.040

FIG.**72**-Maximum allowable value of the ratio between the equivalent summer solar area of glazed components and the usable surface area

General requirements for the energy performance of buildings

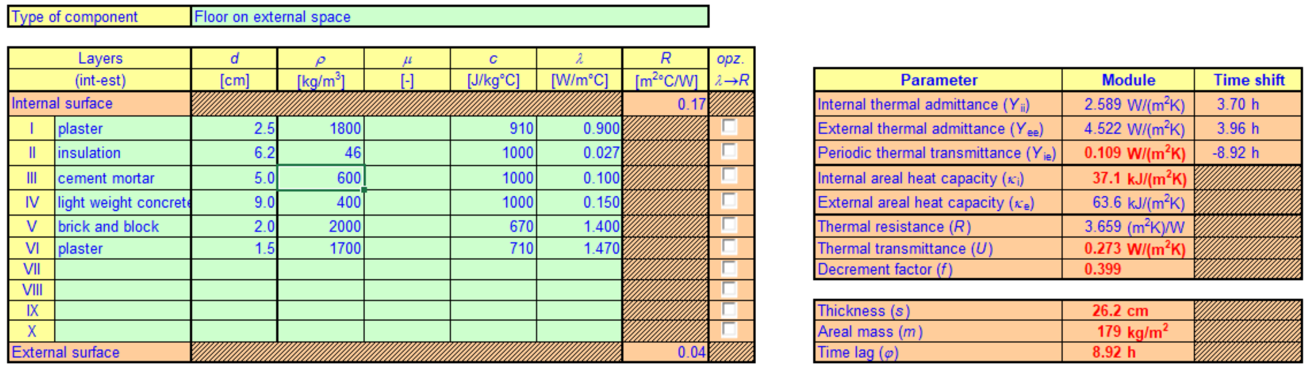
It is necessary to consider the following point according to the standards in Annex 1 (Articles 3 and 4):

- The value of the periodic thermal transmittance module (YIE), as referred to in letter d) of paragraph 2, Article 2 of this decree, must be less than 0.10 W/m²K for all opaque vertical walls, except those included in the northwest/north/northeast quadrant.
- The value of the periodic thermal transmittance module (YIE), as referred to in letter d) of paragraph 2, Article 2 of this decree, must be less than 0.18 W/m²K for all opaque horizontal and inclined walls.
- In all climatic zones except Zone F, for locations where the average monthly irradiance on the horizontal plane during the month of maximum summer insolation (I_m,s) is greater than or equal to 290 W/m², the following verification must be performed for all opaque vertical walls, except those in the northwest, north, and northeast quadrants: The surface mass (M_s), as specified in paragraph 29 of Annex A of the legislative decree, must be greater than 230 kg/m².

Efficiency parameters and energy performance indices

Parameter	Unit	Description
HT	W/m²K	Global average heat transfer coefficient per unit of dispersing surface
A solest/A sup utile	-	Equivalent summer solar area per unit of usable surface
EP H,nd	kWh/m²	Useful thermal performance index for heating
H	-	Average seasonal efficiency of the winter climate control system
EP H	kWh/m²	Energy performance index for winter climate control, expressed in non-renewable primary energy (index "nren") or total (index "tot")
EP W,nd	kWh/m²	Useful thermal performance index for domestic hot water production
W	-	Average seasonal efficiency of the domestic hot water production system
EP W	kWh/m²	Energy performance index for domestic hot water production, expressed in non-renewable primary energy (index "nren") or total (index "tot")
EP V	kWh/m²	Energy performance index for ventilation, expressed in non-renewable primary energy (index "nren") or total (index "tot")
EP C,nd	kWh/m²	Useful thermal performance index for cooling
C	-	Average seasonal efficiency of the summer climate control system (including possible humidity control)
EP C	kWh/m²	Energy performance index for summer climate control (including possible humidity control), expressed in non-renewable primary energy (index "nren") or total (index "tot")
EP L	kWh/m²	Energy performance index for artificial lighting. This index is not calculated for category E.1. except for colleges, convents, prisons, barracks, and category E.1(3). Expressed in non-renewable primary energy (index "nren") or total (index "tot")
EP T	kWh/m²	Energy performance index for the transport of people and goods (elevators, moving walkways, and escalators). This index is not calculated for category E.1. except for colleges, convents, prisons, barracks, and category E.1(3)
FP gl	kWh/m²	Global energy performance index of the building, expressed in non-renewable primary energy (index "nren") or total (index "tot")

FIG.**73**-Efficiencies, parameters, and energy performance indices



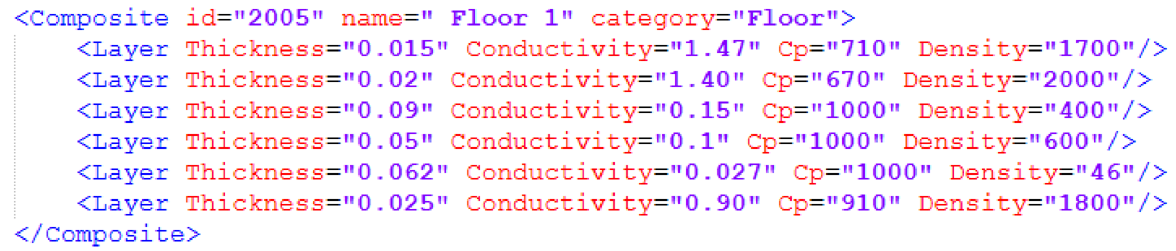
Type of component	Floor on external space

Layers (int-est)		d [cm]	ρ [kg/m³]	μ [-]	c [J/kg°C]	λ [W/m°C]	R [m²°C/W]	opz. λ→R
Internal surface							0.17	
I	plaster	2.5	1800		910	0.900		☐
II	insulation	6.2	46		1000	0.027		☐
III	cement mortar	5.0	600		1000	0.100		☐
IV	light weight concrete	9.0	400		1000	0.150		☐
V	brick and block	2.0	2000		670	1.400		☐
VI	plaster	1.5	1700		710	1.470		☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	2.589 W/(m²K)	3.70 h
External thermal admittance (Y_{ee})	4.522 W/(m²K)	3.96 h
Periodic thermal transmittance (Y_{ie})	0.109 W/(m²K)	-8.92 h
Internal areal heat capacity (κ_i)	37.1 kJ/(m²K)	
External areal heat capacity (κ_e)	63.6 kJ/(m²K)	
Thermal resistance (R)	3.659 (m²K)/W	
Thermal transmittance (U)	0.273 W/(m²K)	
Decrement factor (f)	0.399	

Thickness (s)	26.2 cm	
Areal mass (m)	179 kg/m²	
Time lag (φ)	8.92 h	

FIG.**74**-Characteristics and layers of the floor



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    <Layer Thickness="0.09" Conductivity="0.15" Cp="1000" Density="400"/>
    <Layer Thickness="0.05" Conductivity="0.1" Cp="1000" Density="600"/>
    <Layer Thickness="0.062" Conductivity="0.027" Cp="1000" Density="46"/>
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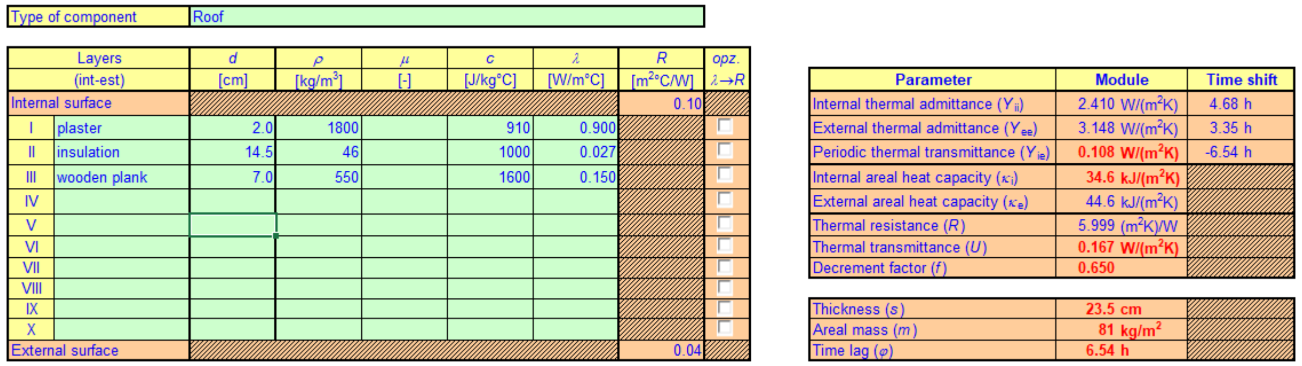
FIG.**75**-Composite floor layer in citysim pro



Type of component	Roof

Layers (int-est)		d [cm]	ρ [kg/m³]	μ [-]	c [J/kg°C]	λ [W/m°C]	R [m²°C/W]	opz. λ→R
Internal surface							0.10	
I	plaster	2.0	1800		910	0.900		☐
II	insulation	14.5	46		1000	0.027		☐
III	wooden plank	7.0	550		1600	0.150		☐
IV								☐
V								☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	2.410 W/(m²K)	4.68 h
External thermal admittance (Y_{ee})	3.148 W/(m²K)	3.35 h
Periodic thermal transmittance (Y_{ie})	0.108 W/(m²K)	-6.54 h
Internal areal heat capacity (κ_i)	34.6 kJ/(m²K)	
External areal heat capacity (κ_e)	44.6 kJ/(m²K)	
Thermal resistance (R)	5.999 (m²K)/W	
Thermal transmittance (U)	0.167 W/(m²K)	
Decrement factor (f)	0.650	

Thickness (s)	23.5 cm	
Areal mass (m)	81 kg/m²	
Time lag (φ)	6.54 h	

FIG.**76**-Characteristics and layers of the roof

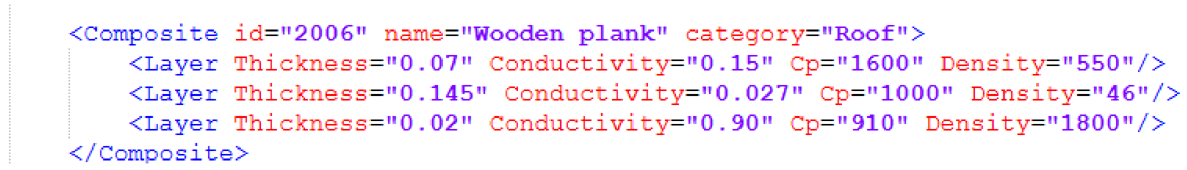


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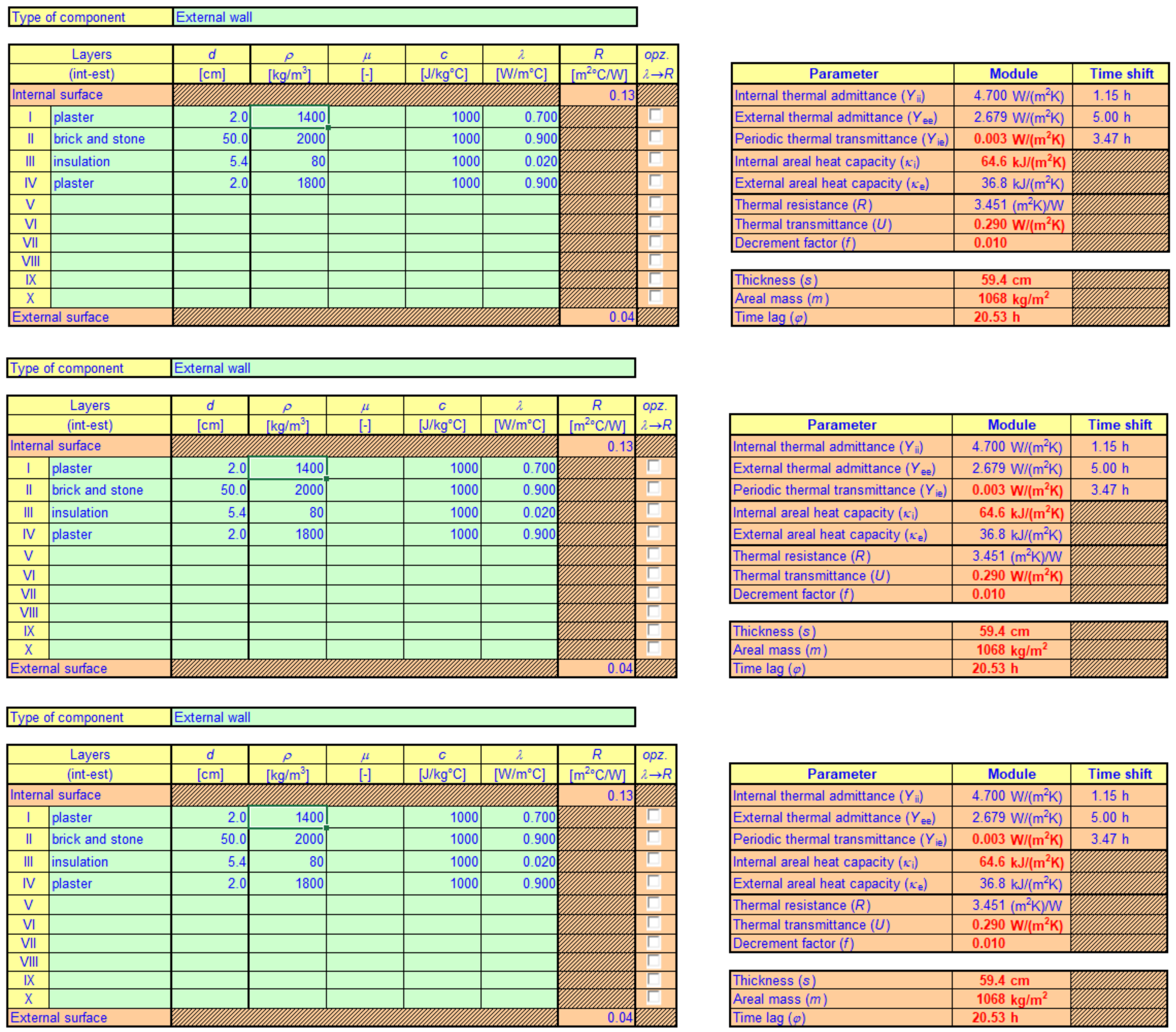
FIG.**77**-Composite roof layer in citysim pro



Type of component: External wall

Layers		d	ρ	μ	c	λ	R	opz.
(int-est)		[cm]	[kg/m^3]	[-]	[J/kg°C]	[W/m°C]	[m^2°C/W]	λ→R
Internal surface							0.13	
I	plaster	2.0	1400		1000	0.700		☐
II	brick and stone	50.0	2000		1000	0.900		☐
III	insulation	5.4	80		1000	0.020		☐
IV	plaster	2.0	1800		1000	0.900		☐
V								☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	4.700 W/(m^{2}K)	1.15 h
External thermal admittance (Y_{ee})	2.679 W/(m^{2}K)	5.00 h
Periodic thermal transmittance (Y_{ie})	0.003 W/(m^{2}K)	3.47 h
Internal areal heat capacity (κ_i)	64.6 kJ/(m^{2}K)	
External areal heat capacity (κ_e)	36.8 kJ/(m^{2}K)	
Thermal resistance (R)	3.451 (m^{2}K)/W	
Thermal transmittance (U)	0.290 W/(m^{2}K)	
Decrement factor (f)	0.010	

Thickness (s)	59.4 cm	
Areal mass (m)	1068 kg/m^2	
Time lag (φ)	20.53 h	

Type of component: External wall

Layers		d	ρ	μ	c	λ	R	opz.
(int-est)		[cm]	[kg/m^3]	[-]	[J/kg°C]	[W/m°C]	[m^2°C/W]	λ→R
Internal surface							0.13	
I	plaster	2.0	1400		1000	0.700		☐
II	brick and stone	50.0	2000		1000	0.900		☐
III	insulation	5.4	80		1000	0.020		☐
IV	plaster	2.0	1800		1000	0.900		☐
V								☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	4.700 W/(m^{2}K)	1.15 h
External thermal admittance (Y_{ee})	2.679 W/(m^{2}K)	5.00 h
Periodic thermal transmittance (Y_{ie})	0.003 W/(m^{2}K)	3.47 h
Internal areal heat capacity (κ_i)	64.6 kJ/(m^{2}K)	
External areal heat capacity (κ_e)	36.8 kJ/(m^{2}K)	
Thermal resistance (R)	3.451 (m^{2}K)/W	
Thermal transmittance (U)	0.290 W/(m^{2}K)	
Decrement factor (f)	0.010	

Thickness (s)	59.4 cm	
Areal mass (m)	1068 kg/m^2	
Time lag (φ)	20.53 h	

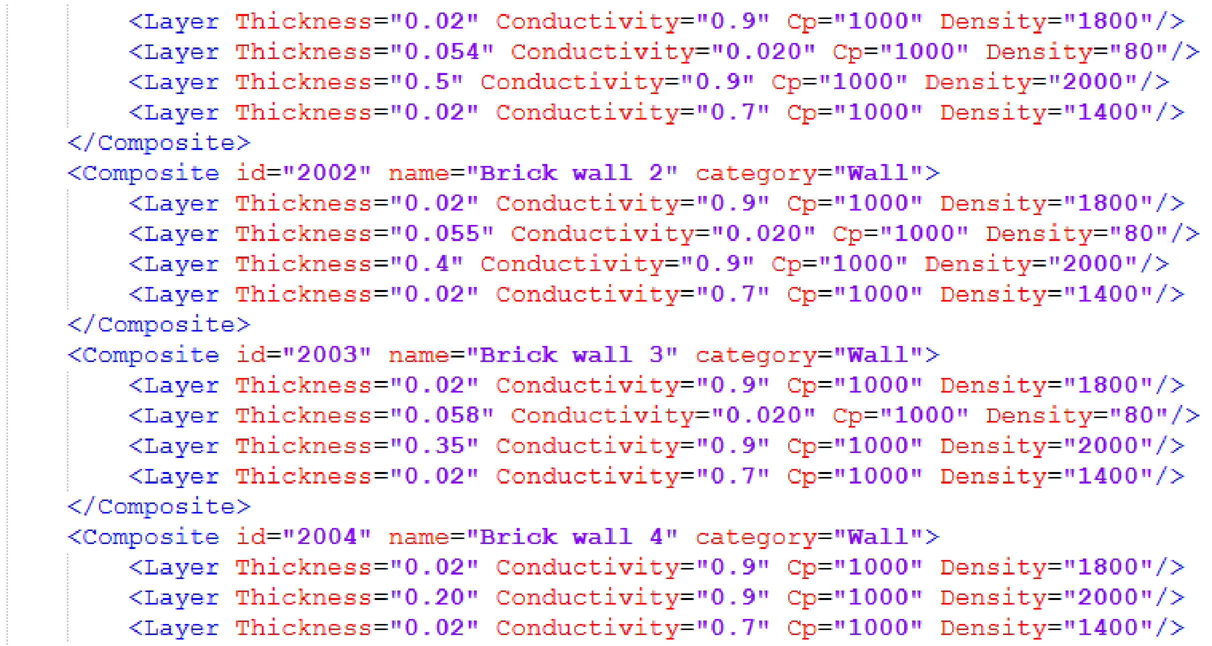
Type of component: External wall

Layers		d	ρ	μ	c	λ	R	opz.
(int-est)		[cm]	[kg/m^3]	[-]	[J/kg°C]	[W/m°C]	[m^2°C/W]	λ→R
Internal surface							0.13	
I	plaster	2.0	1400		1000	0.700		☐
II	brick and stone	50.0	2000		1000	0.900		☐
III	insulation	5.4	80		1000	0.020		☐
IV	plaster	2.0	1800		1000	0.900		☐
V								☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	4.700 W/(m^{2}K)	1.15 h
External thermal admittance (Y_{ee})	2.679 W/(m^{2}K)	5.00 h
Periodic thermal transmittance (Y_{ie})	0.003 W/(m^{2}K)	3.47 h
Internal areal heat capacity (κ_i)	64.6 kJ/(m^{2}K)	
External areal heat capacity (κ_e)	36.8 kJ/(m^{2}K)	
Thermal resistance (R)	3.451 (m^{2}K)/W	
Thermal transmittance (U)	0.290 W/(m^{2}K)	
Decrement factor (f)	0.010	

Thickness (s)	59.4 cm	
Areal mass (m)	1068 kg/m^2	
Time lag (φ)	20.53 h	

FIG.**78**-Characteristics and layers of the walls



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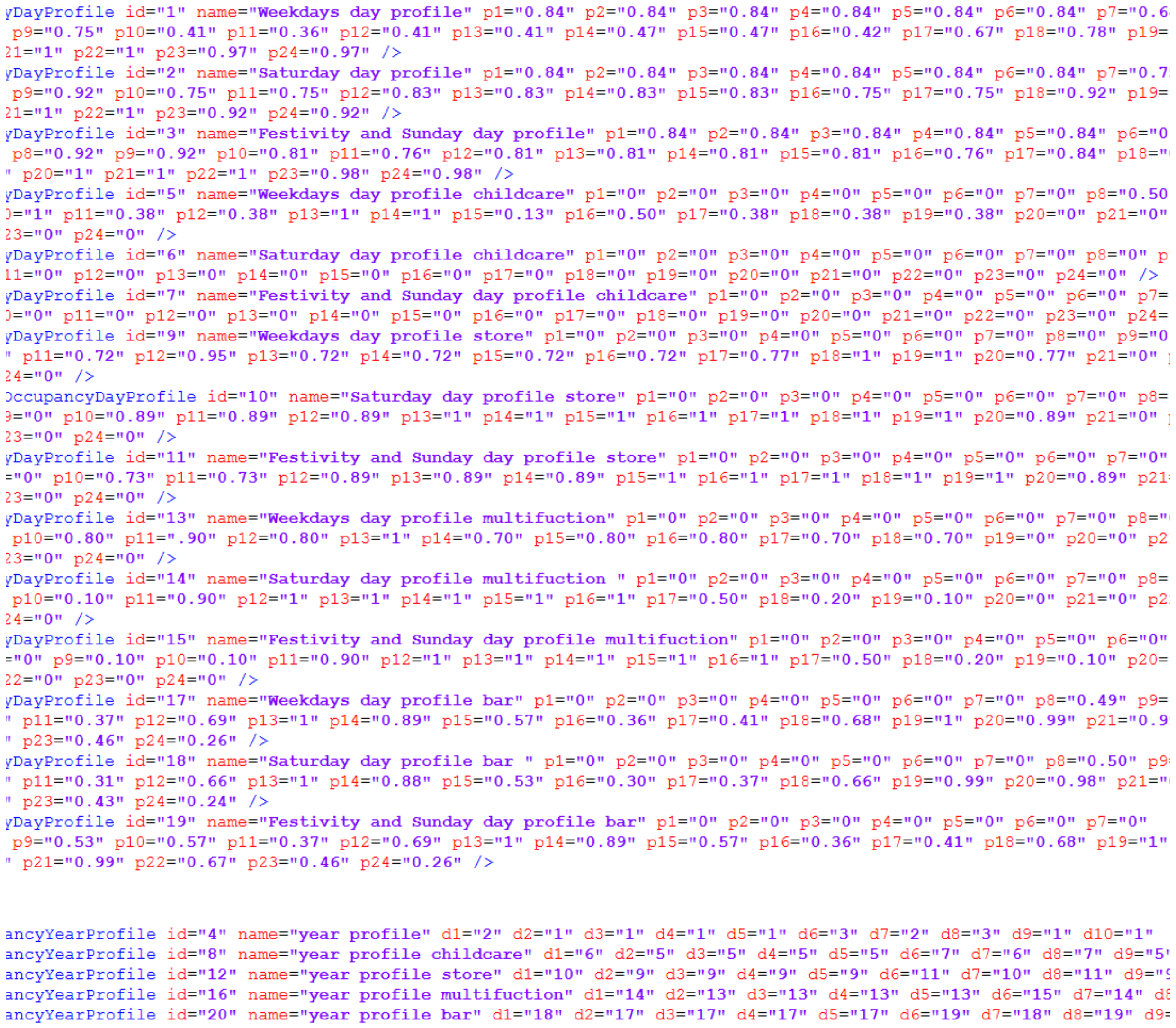
        <Layer Thickness="0.02" Conductivity="0.7" Cp="1000" Density="1400"/>
```

FIG.**79**-Composite walls layer in citysim pro

Time profile

In the next step, after the master plan has been designed and the function of each building has been verified, a yearly profile is defined for each function. According to the EN 16798-1:2019 standard, profiles are established for various functions, including bars, restaurants, stores, multifunctional spaces, childcare areas, and single-family residential units. These profiles are then incorporated into the CitySim Pro XML files for the subsequent simulation.



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ancyYearProfile id="20" name="year profile bar" d1="18" d2="17" d3="17" d4="17" d5="17" d6="19" d7="18" d8="19" d9=
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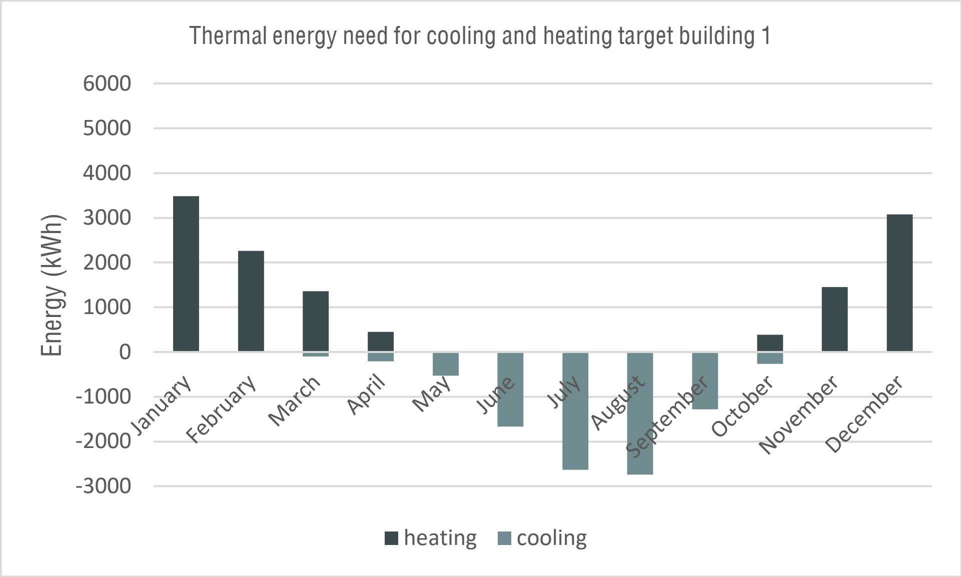
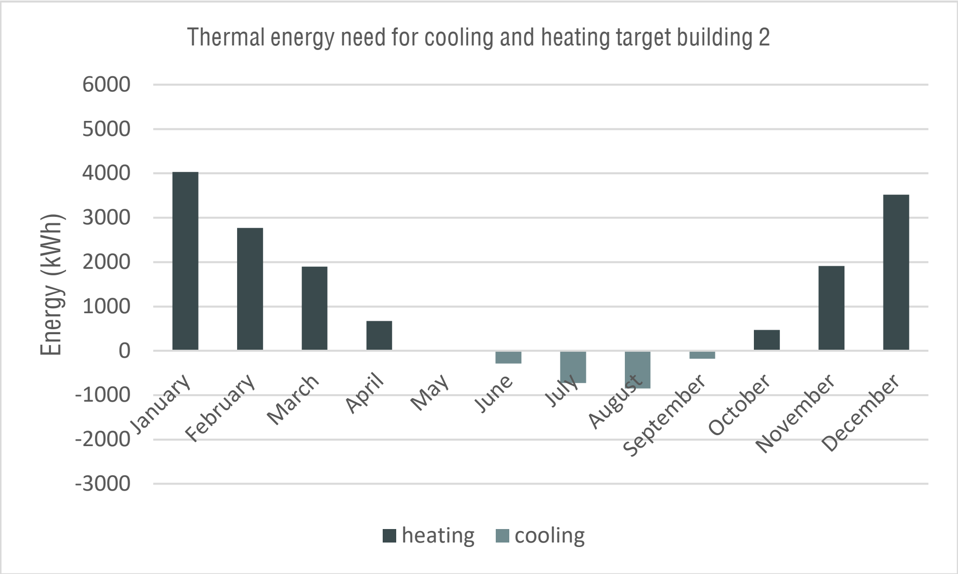
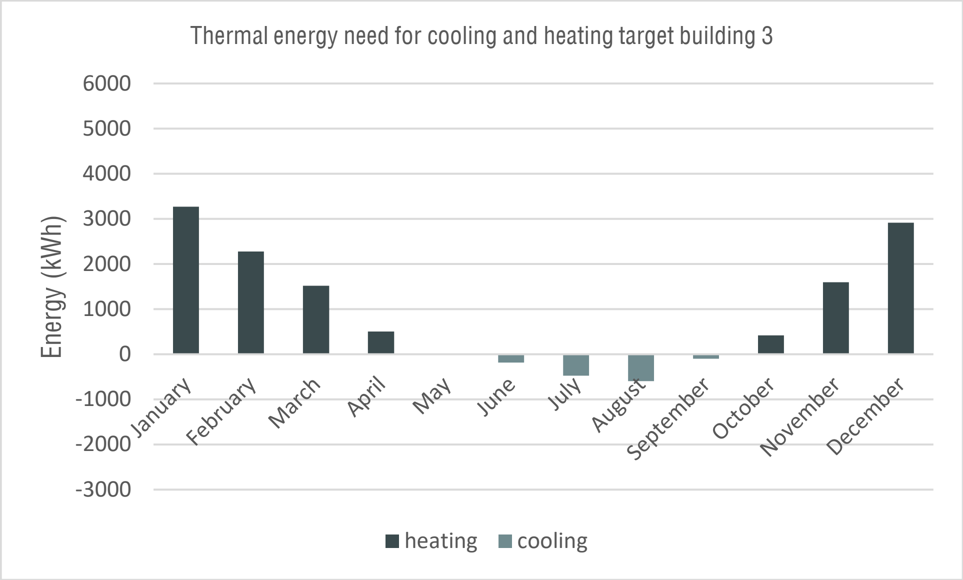
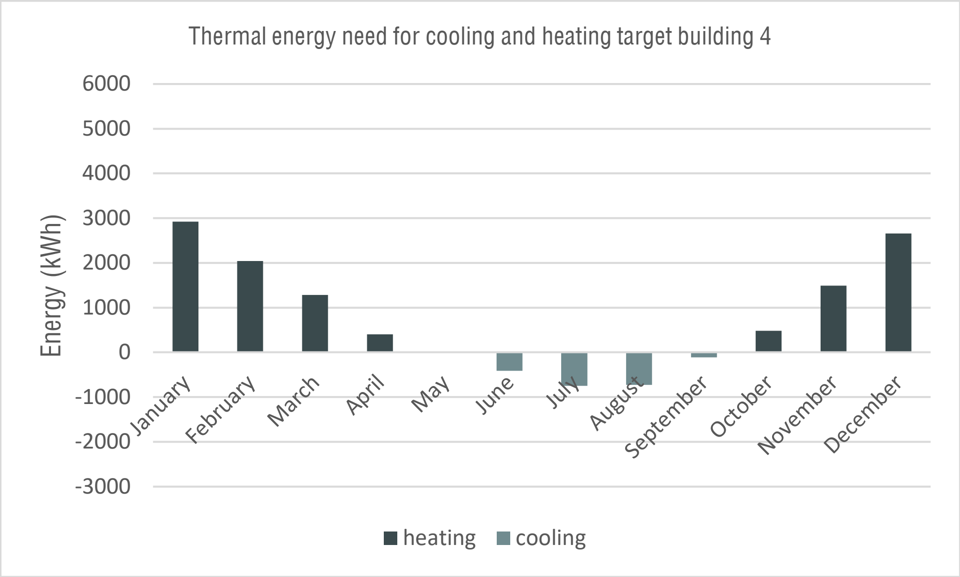
FIG.**80**-Time profile in citysim pro

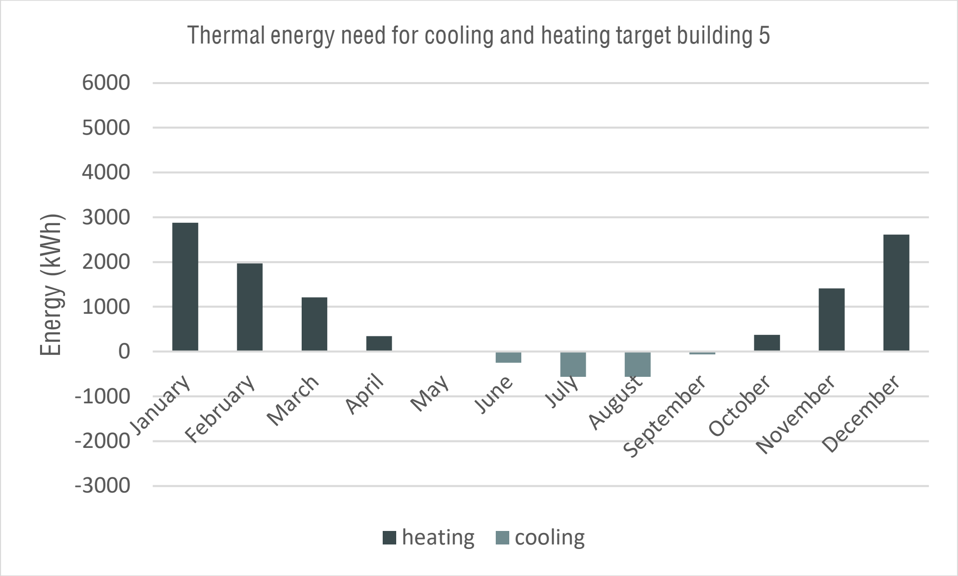
Simulation results of thermal energy needs for space heating and cooling in target buildings


Thermal energy need for cooling and heating target building 1


Thermal energy need for cooling and heating target building 2


Thermal energy need for cooling and heating target building 3


Thermal energy need for cooling and heating target building 4


Thermal energy need for cooling and heating target building 5

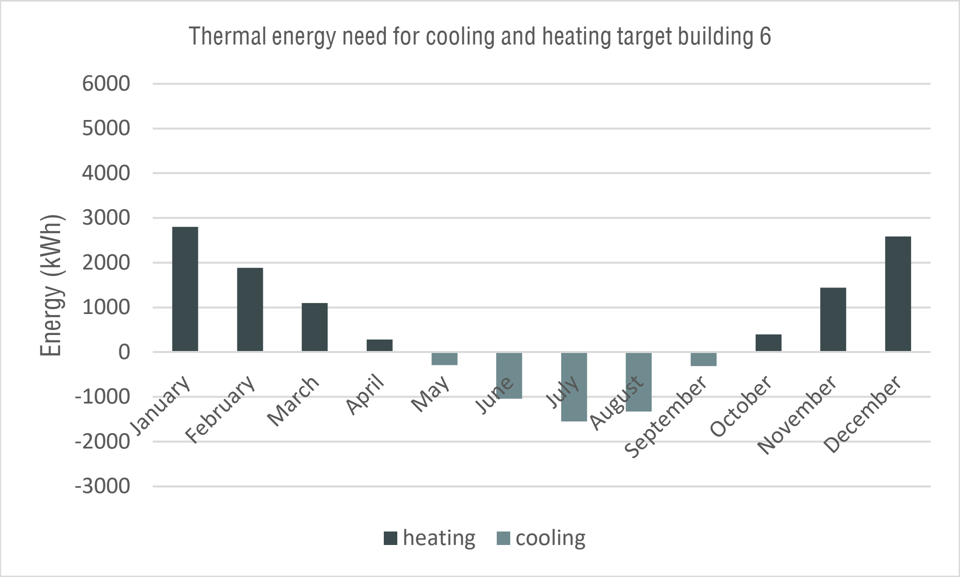
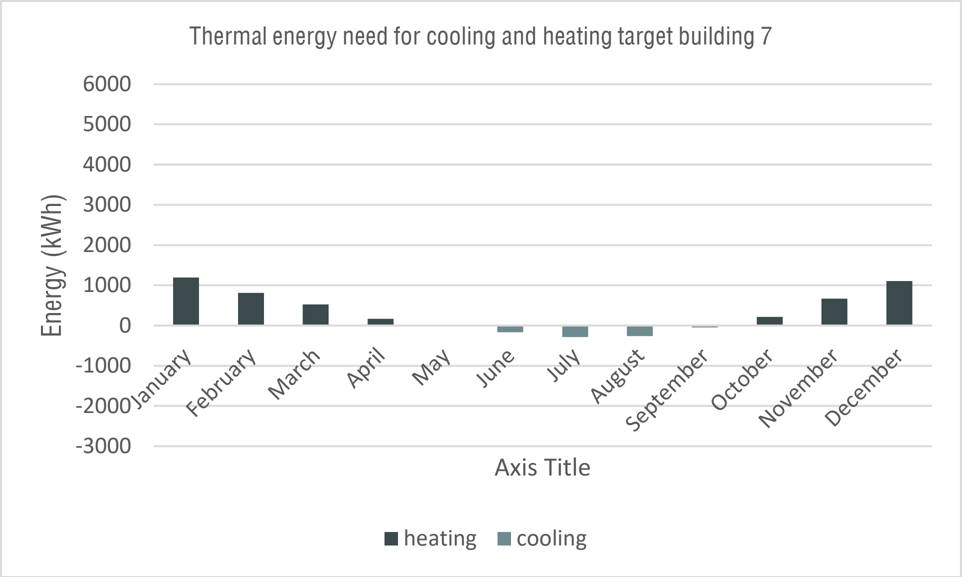
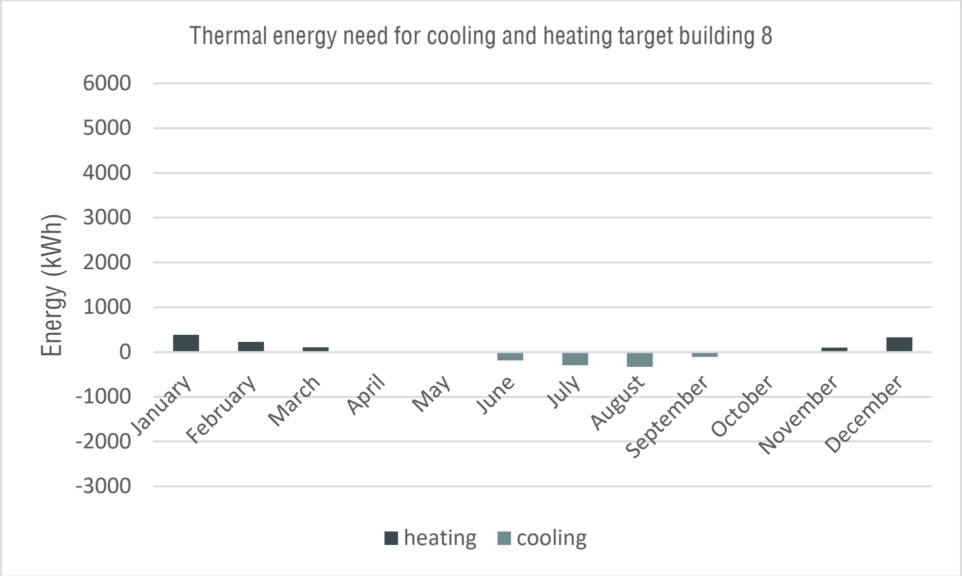
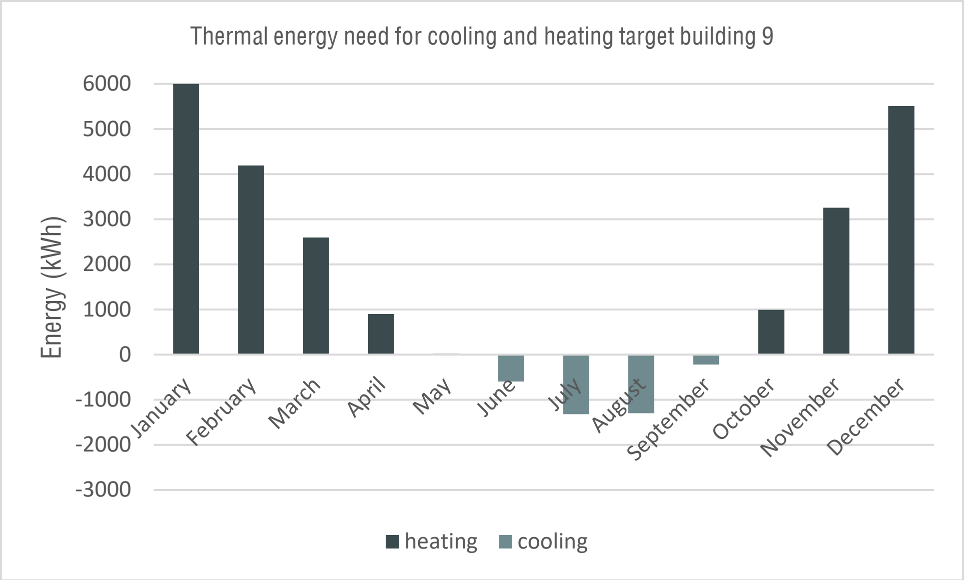
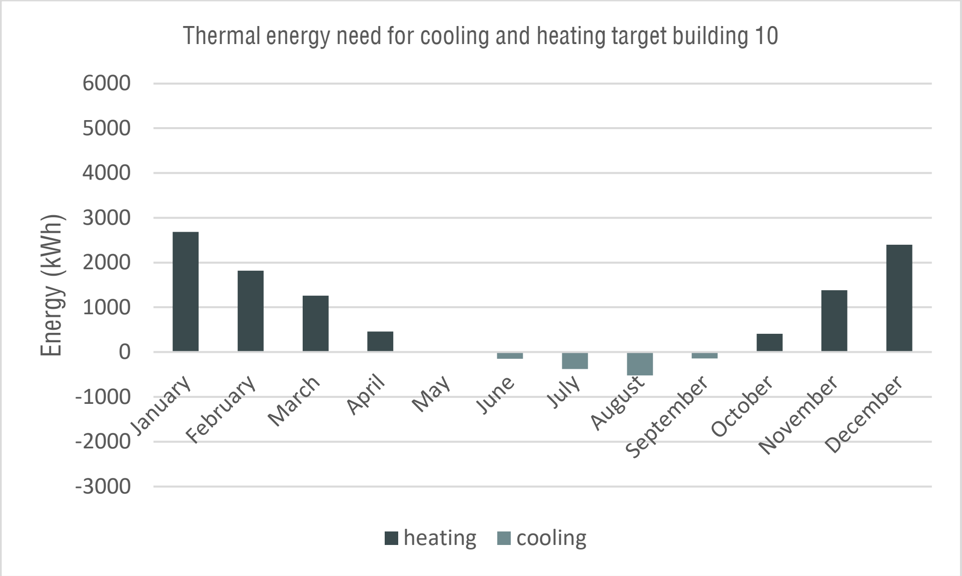

Thermal energy need for cooling and heating target building 6

FIG.**81**-Results of thermal energy need for space heating and cooling for buildings in target buildings1-6


Thermal energy need for cooling and heating target building 7


Thermal energy need for cooling and heating target building 8


Thermal energy need for cooling and heating target building 9


Thermal energy need for cooling and heating target building 10

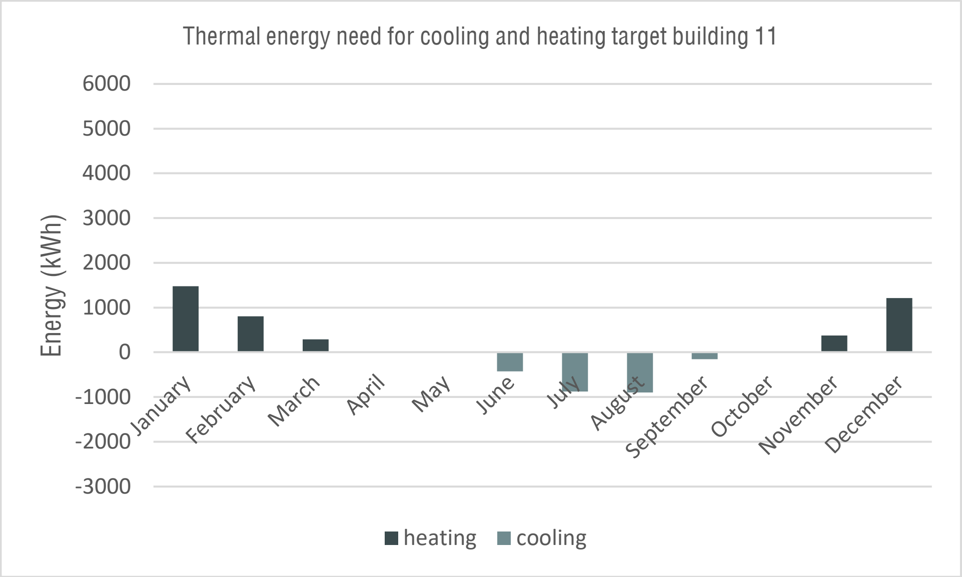

Thermal energy need for cooling and heating target building 11

FIG.**82**-Results of thermal energy need for space heating and cooling for buildings in target buildings7-11

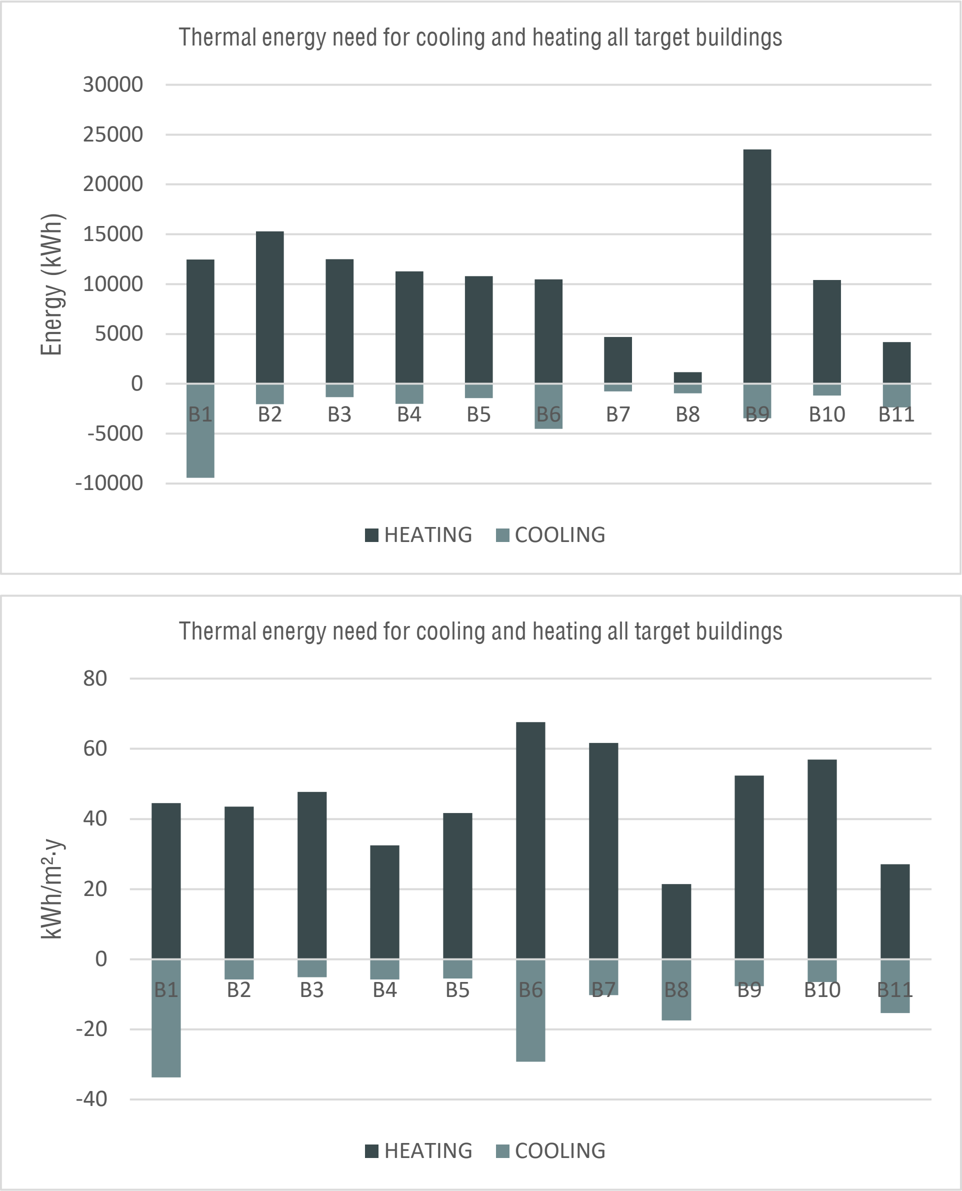
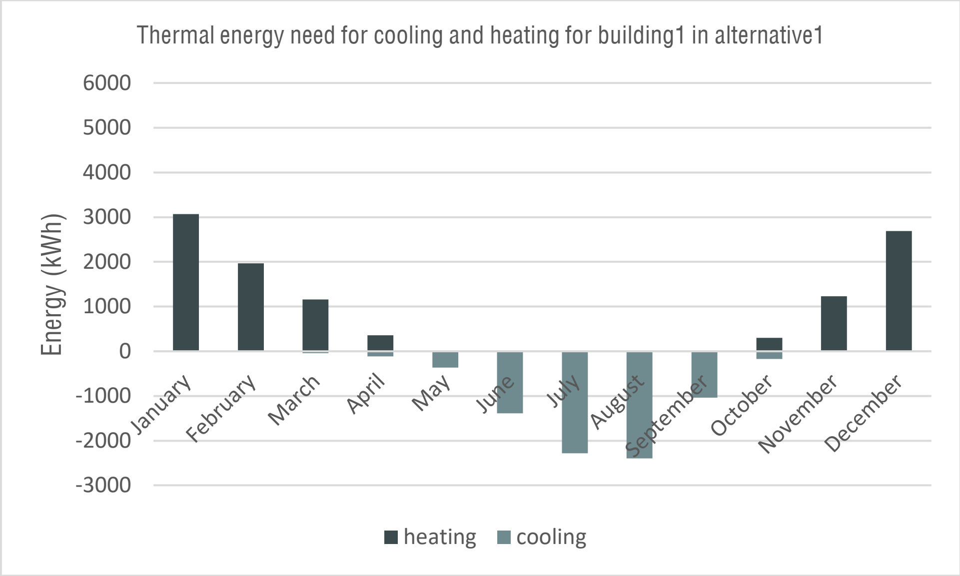
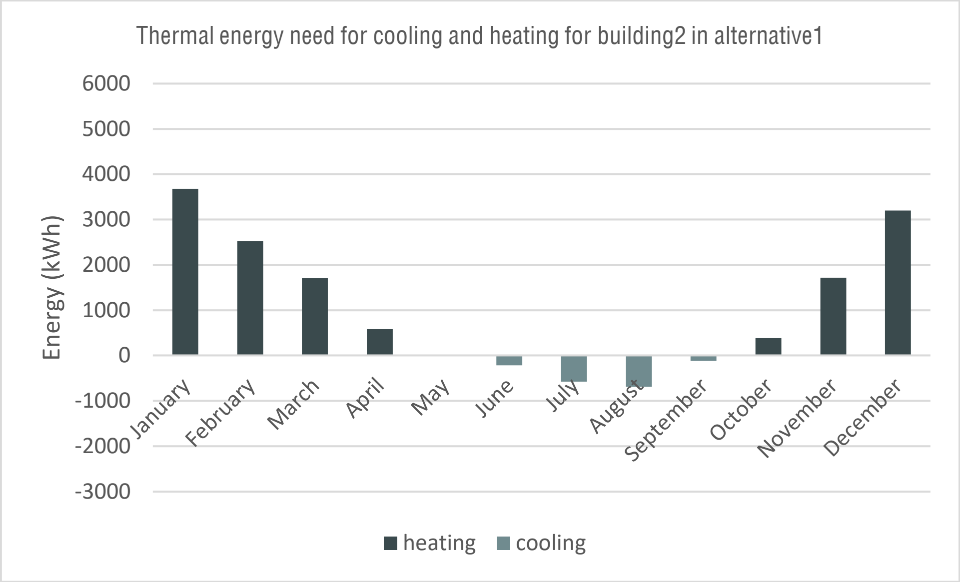


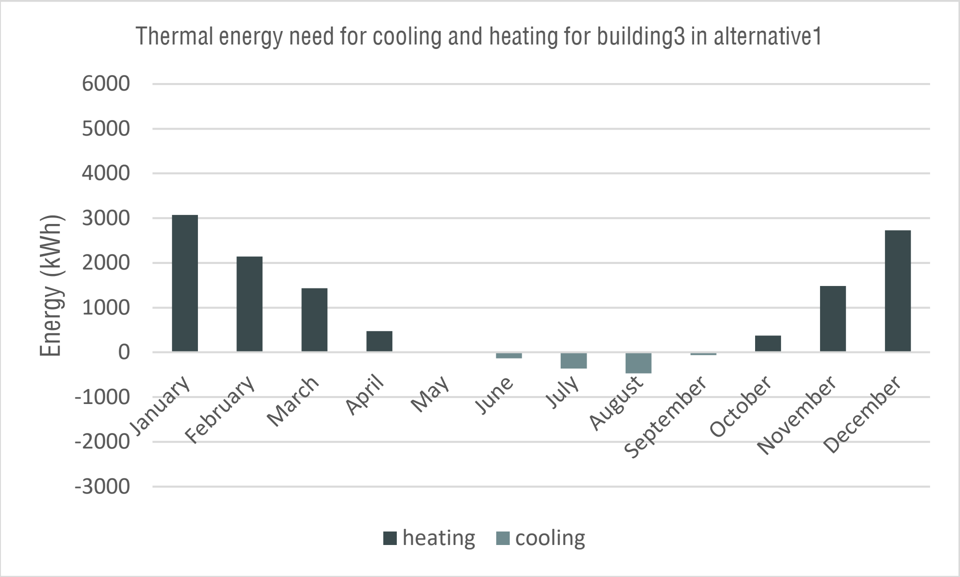
FIG.**83**-Comparison of thermal energy need for space heating and cooling for all target buildings

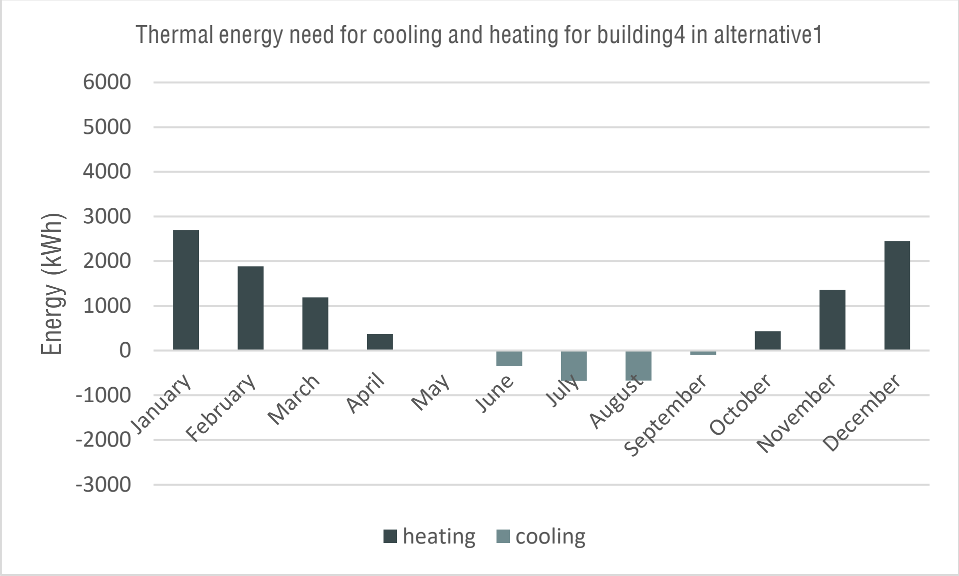
In the present step, following the identification of the exact indicators necessary for nZEB (nearly Zero Energy Building) status attainment in each building, these indicators are embedded into an XML file representing their current state. It also includes new functions, occupancy patterns, and time profiles specific to each building. After running the simulation, the results for primary energy consumption will then be shown in a detailed table. The table provides a full breakdown of the energy consumption month by month for each building in comparison with others. It also presents an analysis of the energy consumption per square meter (m^2), to explain the efficiency of every building relative to its size and usage. This provides a comparison to identify trends and possible areas for further energy optimization among buildings.

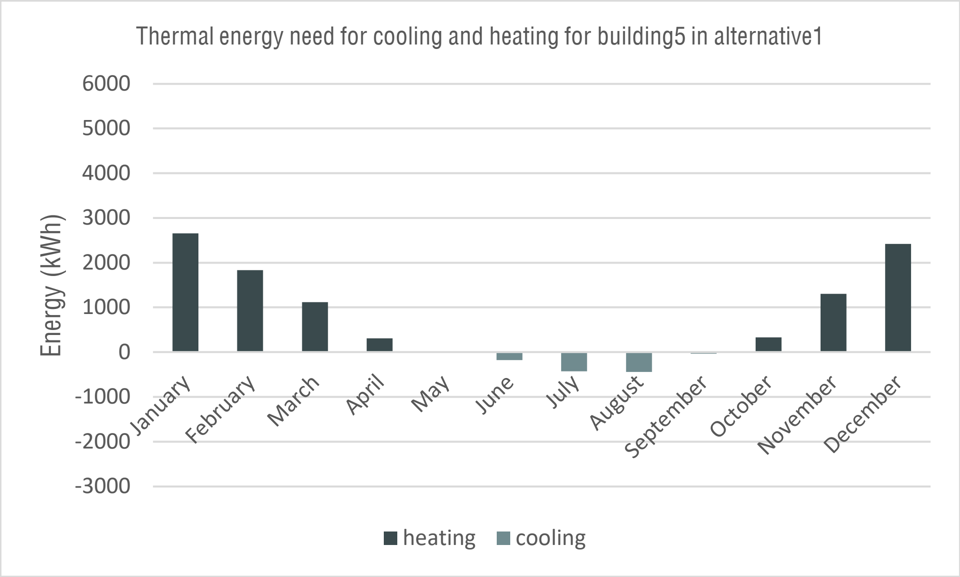
Simulation results of thermal energy needs for space heating and cooling in alternative 1 buildings


Thermal energy need for cooling and heating for building1 in alternative1


Thermal energy need for cooling and heating for building2 in alternative1


Thermal energy need for cooling and heating for building3 in alternative1


Thermal energy need for cooling and heating for building4 in alternative1


Thermal energy need for cooling and heating for building5 in alternative1

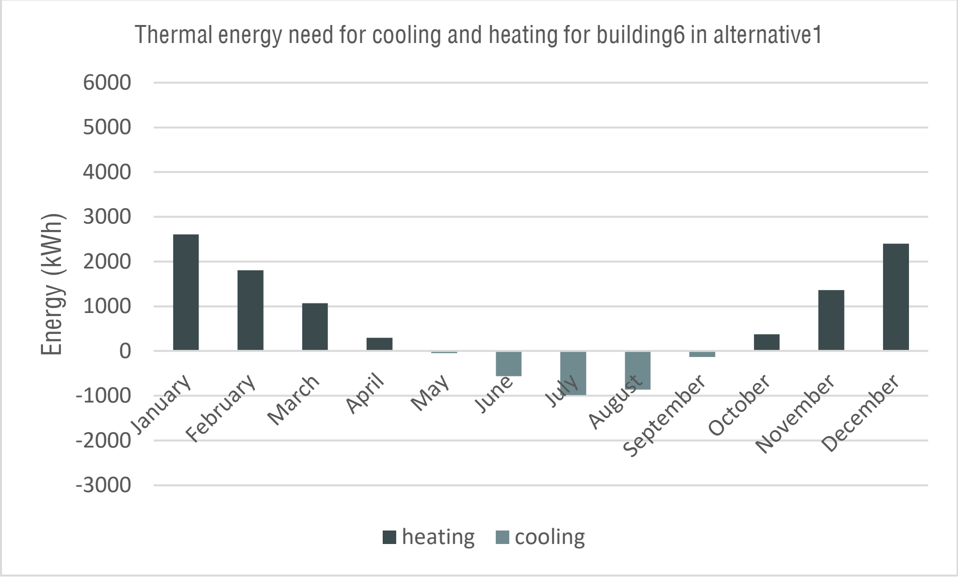
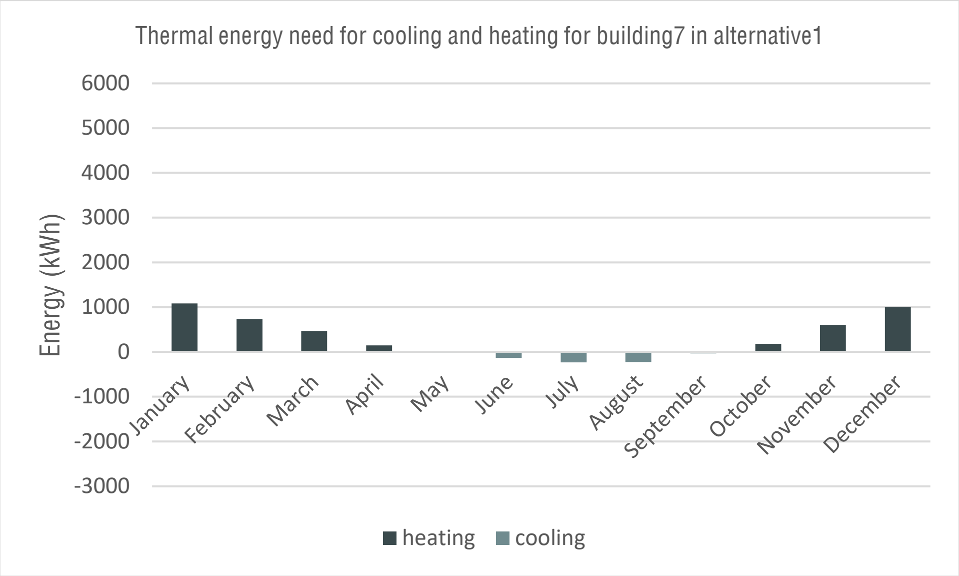
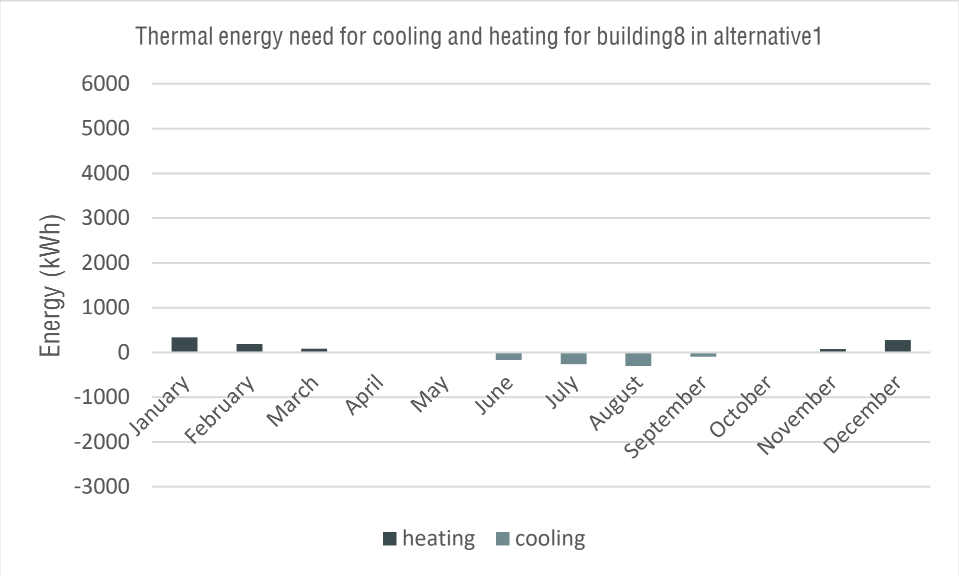
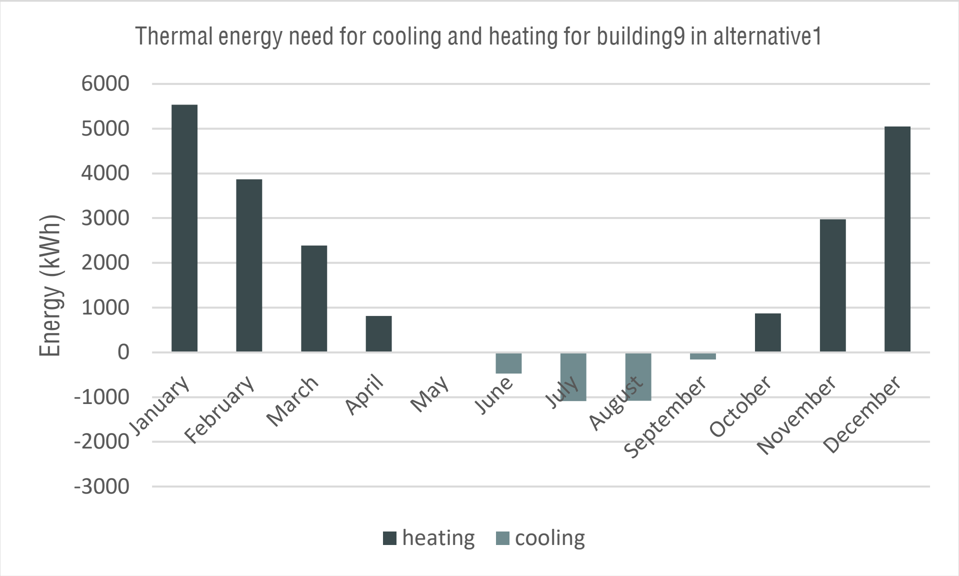
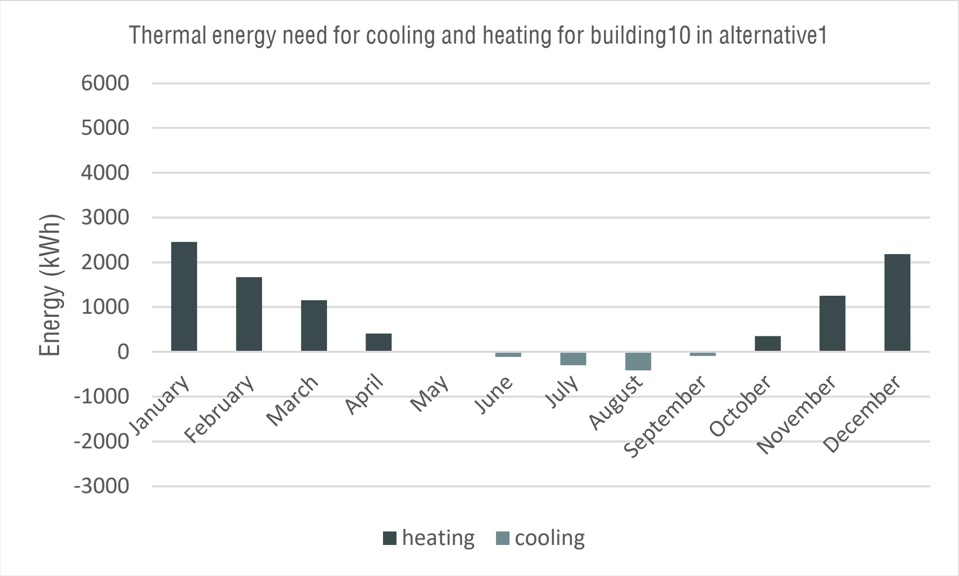

Thermal energy need for cooling and heating for building6 in alternative1

FIG.**84**-Results of thermal energy need for space heating and cooling for buildings in alternative1 buildings1-6


Thermal energy need for cooling and heating for building7 in alternative1


Thermal energy need for cooling and heating for building8 in alternative1


Thermal energy need for cooling and heating for building9 in alternative1


Thermal energy need for cooling and heating for building10 in alternative1

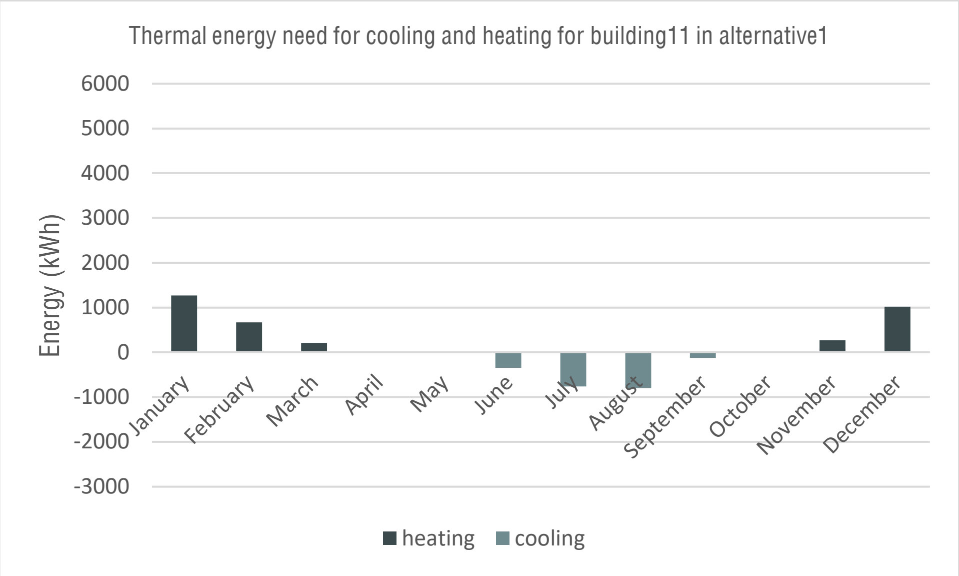

Thermal energy need for cooling and heating for building11 in alternative1

FIG.**85**-Results of thermal energy need for space heating and cooling for buildings in alternative1 buildings 7-11

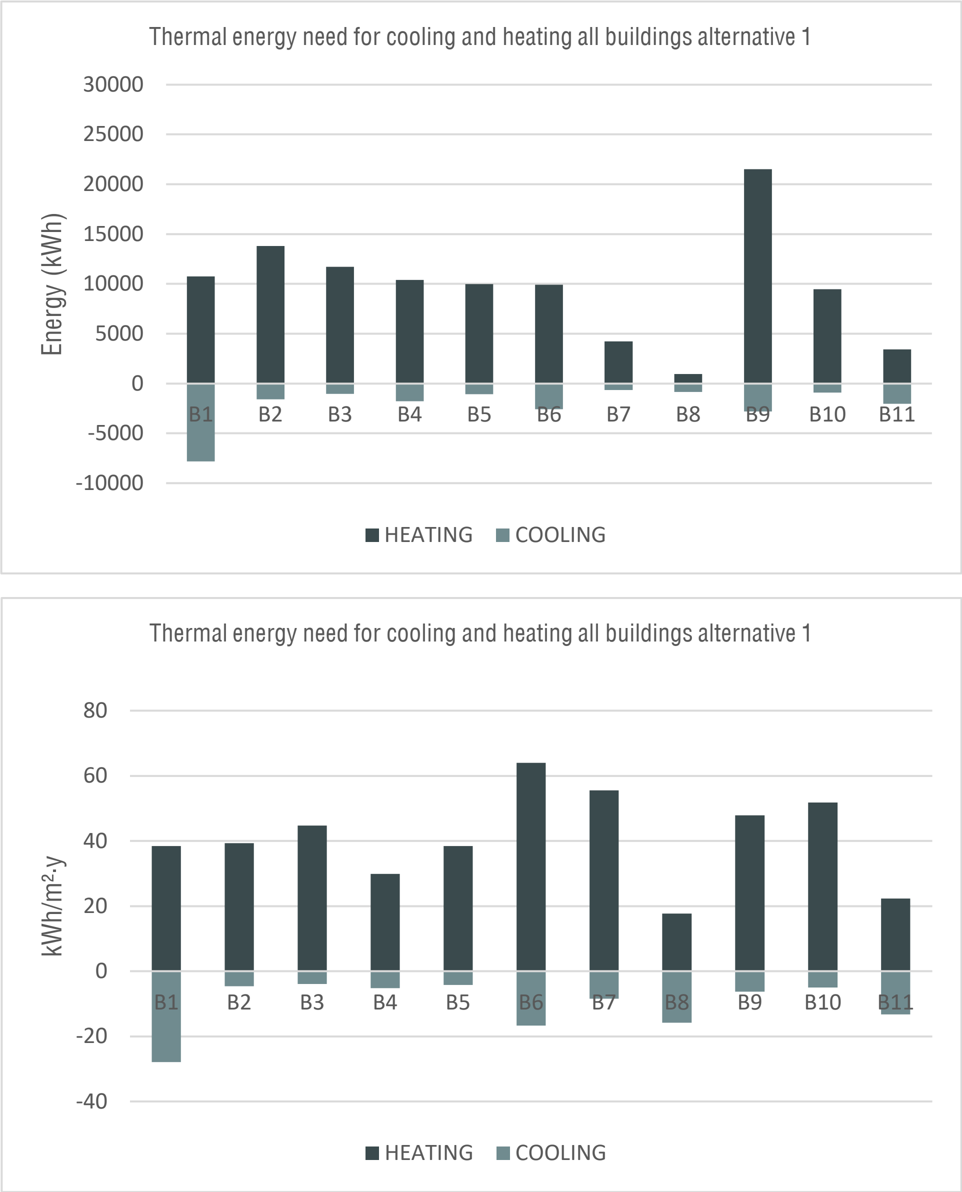


FIG.**86**-Comparison of thermal energy need for space heating and cooling for all buildings alternative1

Alternative 1 involved updating the XML file with the new feature and implementing a new time profile that matched each building's occupancy and usage. The buildings' overall volume is unchanged, but their occupant count has gone up.
A number of technological advancements have also been made, including modifications to the layers of the composite material and new window varieties. In order to handle the increased occupancy, these updates are intended to improve performance. The following tables will include thorough explanations of how these changes affect the energy dynamics and efficiency of the buildings.

BUILDING 1	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.52	0.30	0.9	19.2	0.218104	0.587939
E	1	0.30	0.9	9.6	0.568136	1.472608
S	1	0.30	0.9	22.4	0.680584	4.116173
						6.17672

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
280	6.17672	✓ 0.02206	.03

Building 1	U value	Area	H t	H' t
Wall	0.250 W/m2K	719 m^2	201.32 W/K	-
Roof	0.157 W/m2K	337 m^2	77.51 W/K	-
Floor	0.258 W/m2K	280 m^2	78.4 W/K	-
Window	1.6 W/m2K	51.2 m^2	78.4 W/K	-
			439.15 W/K	0.34069 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 1	1289 m^2	1992 m^3	0.647088 m^{-1}	H' t <0.58	✓ 0.34069 W/m2K

Building 1	Wall	Roof	Floor
Periodic thermal transmittance for all opaque vertical walls must be less than 0.10	✓ Wall 1 0.003 ✓ Wall 2 0.009 ✓ Wall 3 0.006		
Periodic thermal transmittance for opaque horizontal and inclined walls must be less than 0.18		✓ 0.098	✓ 0.101
The areal mass of all opaque vertical walls must be greater than or equal to 230 kg/m²	✓ Wall 1 1055 ✓ Wall 2 753 ✓ Wall 3 869		

FIG.**87**-Calculation of A sol, total estimation, and H' t for building1 alternative 1

- The type of material and the layers of the roof, walls, and floor are the same in all buildings, so the areal mass of all opaque vertical walls and the periodic thermal transmittance do not need to be repeated for other buildings.

BUILDING 2	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.52	0.30	0.9	38.4	0.218104	1.175878
S	1	0.30	0.9	38.4	0.662281	6.866527
						8.042404

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
351	8.042404	✓ 0.022913	.03

Building 2	U value	Area	H t	H' t
Wall	0.250 W/m2K	719 m^2	201.32 W/K	-
Roof	0.157 W/m2K	337 m^2	77.51 W/K	-
Floor	0.258 W/m2K	351 m^2	98.28 W/K	-
Window	1.6 W/m2K	76.8 m^2	122.88 W/K	-
			499.99 W/K	0.355359 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 2	14007 m^2	2062 m^3	0.682347 m^{-1}	H' t <0.58	✓ 0.355359 W/m2K

FIG.**88**-Calculation of A sol, total estimation, and H' t for building2 alternative 1

BUILDING 3	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.82	0.30	0.9	25.6	0.358159	2.029987
S	1	0.30	0.9	19.2	0.689224	3.572937
						5.602923

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
262	5.602923	✓ 0.021385	.03

Building 3	U value	Area	H t	H' t
Wall	0.250 W/m2K	719 m^2	201.32 W/K	-
Roof	0.157 W/m2K	337 m^2	77.51 W/K	-
Floor	0.258 W/m2K	351 m^2	98.28 W/K	-
Window	1.6 W/m2K	76.8 m^2	122.88 W/K	-
			499.99 W/K	0.355359 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 3	14007 m^2	2062 m^3	0.682347 m^{-1}	H' t <0.58	✓ 0.355359 W/m2K

FIG.**89**-Calculation of A sol, total estimation, and H' t for building3 alternative 1

BUILDING 2	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.82	0.30	0.9	19.2	0.242495	1.030819
S	1	0.30	0.9	6.4	0.57633	0.995898
						2.026717

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
347	2.026717	✓ 0.005841	.03

Building 4	U value	Area	H t	H' t
Wall	0.250 W/m2K	513 m^2	143.64 W/K	-
Roof	0.157 W/m2K	356 m^2	81.88 W/K	-
Floor	0.258 W/m2K	347 m^2	97.16 W/K	-
Window	1.6 W/m2K	25.6 m^2	40.96 W/K	-
			363.64 W/K	0.299046 W/m2K

	A_{env}	V_g	A_{env} / V_g	A env /V g ≥ 0.7	H' t
Building 4	1216 m^2	1564 m^3	0.778988 m^{-1}	H' t <0.53	✓ 0.299046 W/m2K

FIG.**90**-Calculation of A sol, total estimation, and H' t for building4 alternative 1

BUILDING 5	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.82	0.30	0.9	19.2	0.348272	0.782357
W	1	0.30	0.9	6.4	0.906053	1.565659
S	1	0.30	0.9	6.4	0.671675	2.321308
						4.669324

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
259	4.669324	✓ 0.018028	.03

Building 5	U value	Area	H t	H' t
Wall	0.250 W/m2K	501 m^2	140.28 W/K	-
Roof	0.157 W/m2K	272 m^2	62.56 W/K	-
Floor	0.258 W/m2K	259 m^2	72.52 W/K	-
Window	1.6 W/m2K	35.2 m^2	56.32 W/K	-
			331.68 W/K	0.321395 W/m2K

	A_{env}	V_g	A_{env} / V_g	0.7 > A env /V g ≥ 0.4	H' t
Building 5	1032 m^2	1556 m^3	0.663239 m^{-1}	H' t <0.58	✓ 0.321395 W/m2K

FIG.**91**-Calculation of A sol, total estimation, and H' t for building5 alternative 1

BUILDING 6	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
W	1	0.30	0.9	6.4	1.013049	1.750548
E	1	0.30	0.9	3.2	0.679312	0.586925
S	0.74	0.30	0.9	6.4	0.470062	0.601077
N	1	0.30	0.9	3.2	0.37696	0.325693
						3.264244

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
155	3.264244	✓ 0.02106	.03

Building 6	U value	Area	H t	H' t
Wall	0.250 W/m2K	444 m^2	124.32 W/K	-
Roof	0.157 W/m2K	160 m^2	36.80 W/K	-
Floor	0.258 W/m2K	155 m^2	34.40 W/K	-
Window	1.6 W/m2K	19.2 m^2	30.72 W/K	-
			235.24 W/K	0.309934 W/m2K

	A_{env}	V_g	A_{env} / V_g	A env /V g ≥ 0.7	H' t
Building 6	759 m^2	816 m^3	0.930147 m^{-1}	H' t <0.53	✓ 0.309934 W/m2K

FIG.**92**-Calculation of A sol, total estimation, and H' t for building6 alternative 1

Building 7	U value	Area	H t	H' t
Wall	0.250 W/m2K	156 m^2	43.68 W/K	-
Roof	0.157 W/m2K	76 m^2	17.48 W/K	-
Floor	0.258 W/m2K	76 m^2	21.28 W/K	-
Window	1.6 W/m2K	12.8 m^2	20.48 W/K	-
			102.92 W/K	0.334156 W/m2K

	A_{env}	V_g	A_{env} / V_g	A env /V g ≥ 0.7	H' t
Building 7	308 m^2	342 m^3	0.900585 m^{-1}	H' t <0.53	✓ 0.334156 W/m2K

BUILDING 7	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
E	0.55	0.30	0.9	9.6	0.743796	1.060356
S	1	0.30	0.9	3.2	0.606177	0.523737
						1.584093

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
76	1.584093	✓ 0.020843	.03

FIG.**93**-Calculation of A sol, total estimation, and H' t for building7 alternative 1

BUILDING 8	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	1	0.30	0.9	6.4	0.442705	0.764995
S	0.82	0.30	0.9	3.2	0.624021	0.442106
						1.207101

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
54	1.207101	✓ 0.022354	.03

Building 8	U value	Area	H t	H' t
Wall	0.250 W/m2K	157 m^2	43.96 W/K	-
Roof	0.157 W/m2K	54 m^2	12.42 W/K	-
Floor	0.258 W/m2K	54 m^2	15.12 W/K	-
Window	1.6 W/m2K	9.6 m^2	15.36 W/K	-
			86.86 W/K	0.327774 W/m2K

	A_{env}	V_g	A_{env} / V_g	$A_{env} / V_g \geq 0.7$	H' t
Building 8	265 m^2	270 m^3	0.981481 m^{-1}	H' t <0.53	✓ 0.327774 W/m2K

FIG.**94**-Calculation of A sol, total estimation, and H’ t for building8 alternative 1

BUILDING 9	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	1	0.30	0.9	38.4	0.43451	4.505004
S	0.82	0.30	0.9	38.4	0.481681	4.095135
E	1	0.30	0.9	9.6	0.417704	1.082688
						9.682827

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
449	9.682827	✓ 0.021565	.03

Building 9	U value	Area	H t	H' t
Wall	0.250 W/m2K	719 m^2	201.32 W/K	-
Roof	0.157 W/m2K	455 m^2	104.65 W/K	-
Floor	0.258 W/m2K	449 m^2	125.72 W/K	-
Window	1.6 W/m2K	86.4 m^2	138.24 W/K	-
			269.93 W/K	0.35115 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 9	1623 m^2	3592 m^3	0.451837 m^{-1}	H' t <0.58	✓ 0. 35115 W/m2K

FIG.**95**-Calculation of A sol, total estimation, and H’ t for building9 alternative 1

BUILDING 10	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	1	0.30	0.9	12.8	0.364559	1.259916
S	0.86	0.30	0.9	19.2	0.498151	2.220879
						3.480794

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
183	3.480794	✓ 0.019021	.03

Building 10	U value	Area	H t	H' t
Wall	0.250 W/m2K	473 m^2	132.44 W/K	-
Roof	0.157 W/m2K	186 m^2	42.78 W/K	-
Floor	0.258 W/m2K	183 m^2	51.24 W/K	-
Window	1.6 W/m2K	32 m^2	51.2 W/K	-
			277.66 W/K	0. 329762 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 10	842 m^2	1464 m^3	0.575137 m^{-1}	H' t <0.58	✓ 0. 329762 W/m2K

FIG.**96**-Calculation of A sol, total estimation, and H’ t for building10 alternative 1

BUILDING 11	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	1	0.30	0.9	12.8	0.300626	1.038964
E	1	0.30	0.9	6.4	0.783711	1.354253
S	1	0.30	0.9	6.4	0.552979	0.955548
						3.348764

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
154	3.348764	✓ 0.021745	.03

Building 11	U value	Area	H t	H' t
Wall	0.250 W/m2K	419 m^2	117.32 W/K	-
Roof	0.157 W/m2K	156 m^2	35.88 W/K	-
Floor	0.258 W/m2K	154 m^2	43.12 W/K	-
Window	1.6 W/m2K	25.6 m^2	40.96 W/K	-
			237.28 W/K	0. 325487 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 11	729 m^2	1232 m^3	0.591721 m^{-1}	H' t <0.58	✓ 0. 325487 W/m2K

FIG.**97**-Calculation of A sol, total estimation, and H’ t for building11 alternative 1

Requirements and prescriptions for tecnical interventions

It can be applicable and guarantee that the installations make use of renewable energy sources in conjunction with high-efficiency HVAC systems, condensing boilers, air-source or ground-source heat pumps, or CHP systems. Utilizing both mechanical and manual ventilation is crucial for meeting building requirements and maintaining a high standard of indoor air quality. Therefore, indoor ideal conditions cannot be guaranteed when solely depending on manual ventilation. Lighting systems need to be planned for both artificial and natural lighting, based on the luminance specifications for each area.

The actions on building equipment have been improved to include the following:

- **Artificial lighting**

The use of both natural and artificial lighting requires strategies to ensure energy savings, comfort, and efficiency. Some key ideas and approaches include:

Photosensors are used to automatically reduce artificial lighting based on continuous monitoring of natural light levels. Dimming systems significantly lower energy consumption by lowering the intensity of artificial lights when there is plenty of daylight.

Introduce light shelves and make use of interior reflective surfaces to increase daylight penetration deeper into the building, reducing the need for artificial lighting in interior spaces.

Adopt energy-efficient LED lighting; it uses less power compared to other traditional lighting methods and has a longer lifespan as well.

Install task lighting in work areas to minimize the effect of high-intensity general lighting. This ensures that there is light only at the places where it is precisely needed, hence the overall consumption of energy is reduced.

Fit occupancy sensors in rooms and corridors to switch off lights when the areas are not occupied. This prevents unnecessary cost of energy in places that are not occupied all the time.

Integrate the lighting system with a Building Management System for central control and monitoring. This would make it easier to handle lighting schedules, maintenance, and energy consumption analytics and also could help to save energy.

- **Heating and cooling**

ome innovative heat and cooling technologies can be employed to minimize energy use while keeping the quality of comfort at required levels. One of the most effective strategies is the use of heat pump systems capable of providing both heating and cooling from one device, thereby making use of the feature of transferring heat between the building and the external environment. Ground-source heat pump systems are, in particular, efficient since they make use of the relative constant moderate temperature that maintains the earth’s mass to provide a higher efficient performance. Moreover, the incorporation of radiant floor heating and cooling can enhance the comfort levels of an interior underfloor heating environment with even temperature radiations and decrease energy use for heating compared to traditional air-based systems. Other passive solutions can further reduce the need for active heating and cooling by promoting optimal building orientation, adequate and efficient use of thermal mass, and the use of shading devices where applicable. In uniting these advanced technologies with advanced design processes, an NZEB has the potential to be excellently performing in energy, reduce dependence on fossil fuels, and ensure a comfortable indoor environment throughout all seasons.

- **Ventilation**

Ventilation systems play a very key role in getting energy efficiency and indoor air quality in the designing of Nearly Zero-Energy Buildings. Mechanical ventilation with heat recovery has turned out to be quite an effective solution for doing this. MVHR systems are designed to extract stale air from a building and use its heat to warm up the incoming fresh air. This ensures improved energy savings while supplying constant volumes of fresh air to the occupants for better comfort and health. Moreover, natural ventilation strategies, such as operable windows and vents at strategical positions, may also support the MVHR system to provide cooling and fresh air during mild weather, limiting the use of mechanical cooling, and thereby improving the energy performance of a building. These approaches make it quite possible to optimize ventilation for an energy-efficient, comfortable, and healthy indoor environment in nZEBs.(Ferrari & Beccali, 2024)

In this thesis, a detailed analysis and simulation of technical interventions will not be conducted. The main focus is on improving the envelope intervention, and this topic will be considered and verified in the following sections.

Alternative 2
Design and integration with adding 25% volume

In this alternative, as a second proposal to present to the municipality, the benefit of a 25% increase in volume is considered. This increase is achieved by adding one floor to Building 4 and designing a two-floor building for Building 8. These two buildings are almost destroyed in the current situation.
The function remains almost the same, primarily residential, with a total of 122 number of occupants. The other functions include a restaurant, multifunction, store, and childcare space.
The technical intervention and the goal of this scenario remain the same as in Scenario 1, following the same reference or target building and the same requirements and prescriptions for envelope interventions as well as for technical interventions.

Alternative2
Ground floor plan **scale 1/350**

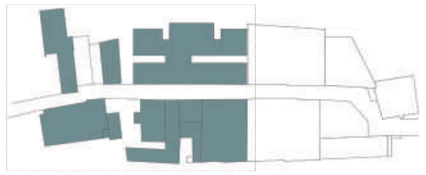
FIG.**98**-Ground floor plan alternative2

Legend

1 - Multi function space
2 -Residential
3 -Social spaces
4 -Store
5 -Child care space

The only difference between Alternatives 1 and 2 is in Buildings 4 and 8, so to avoid repetition, only this part is represented in Alternative 2

Key plan



Alternative2 **scale 1/200**
Ground floor furniture plan

FIG.**99**-Ground floor furniture plan alternative1

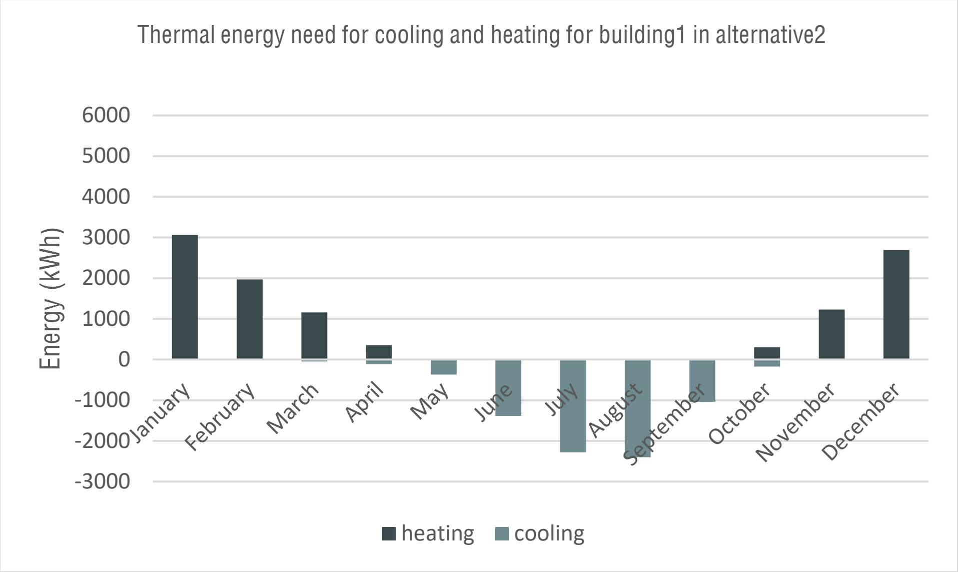
Legend

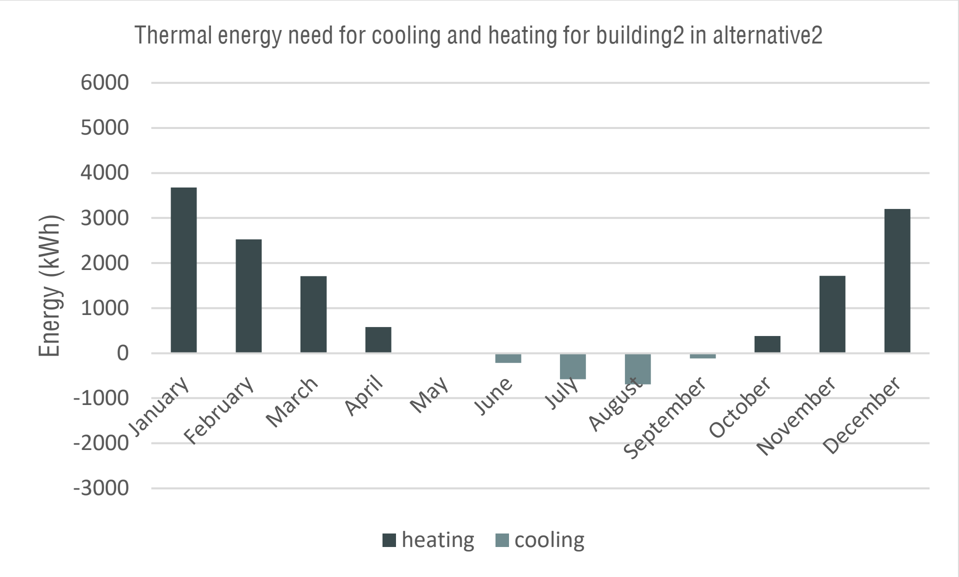
1 - Multi function space
2 -Residential
3 -Social spaces
4 -Store
5 -Child care space

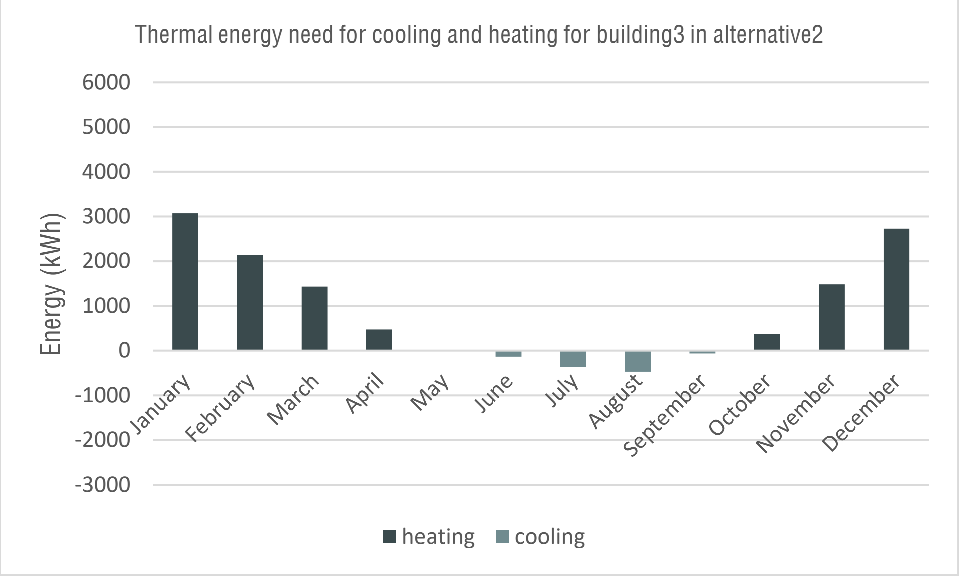
Alternative2 **scale 1/200**
First floor furniture plan

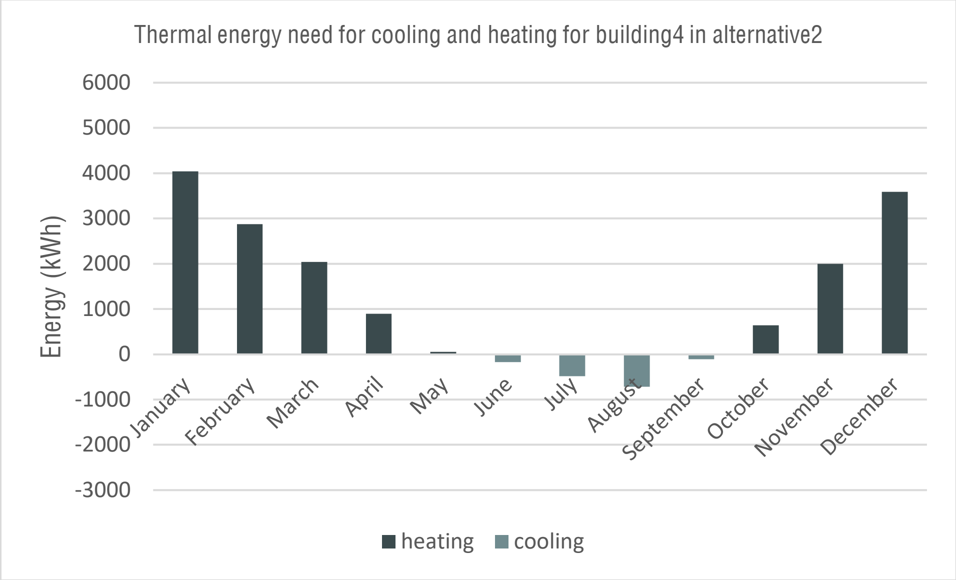
FIG.**100**-First floor furniture plan alternative1

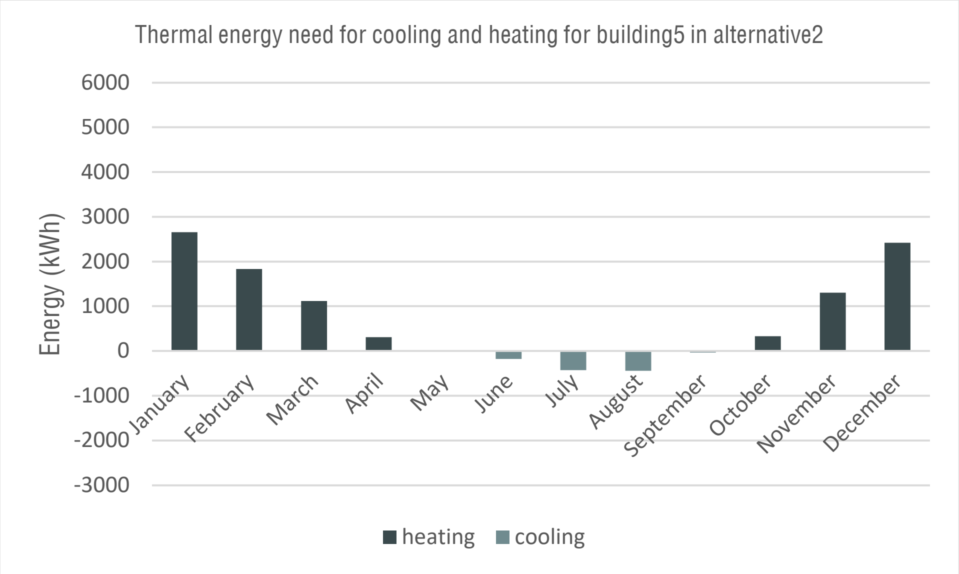
Simulation results of thermal energy needs for space heating and cooling in alternative 2 buildings











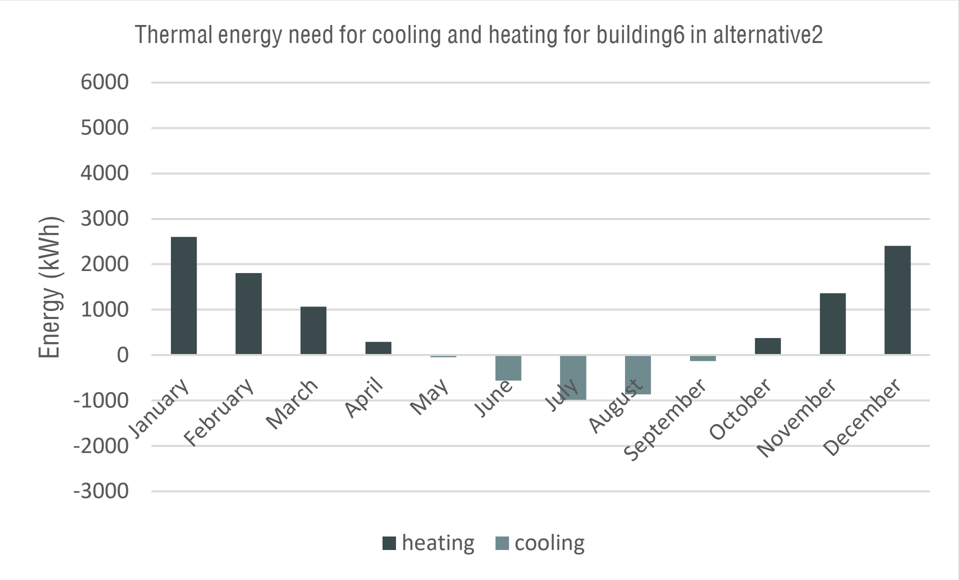
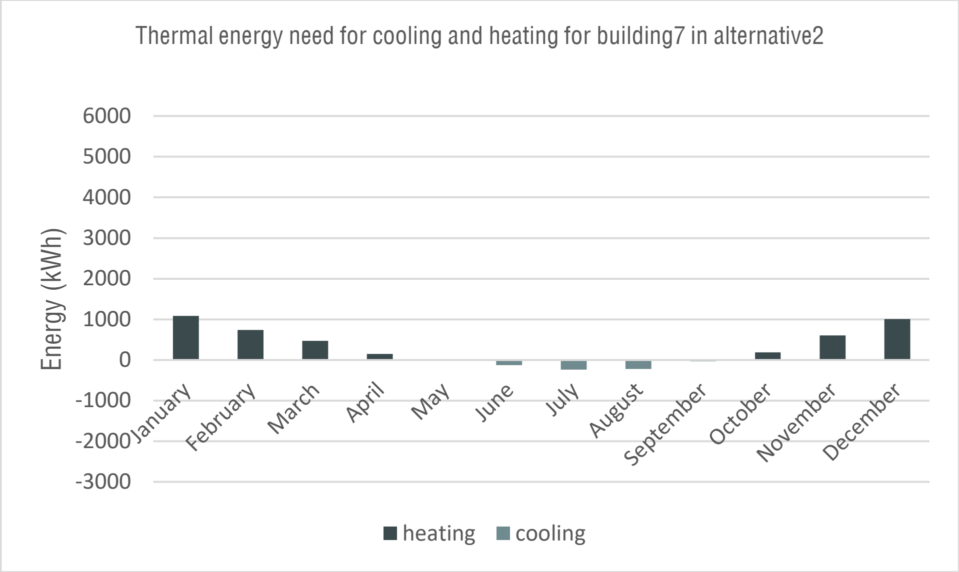
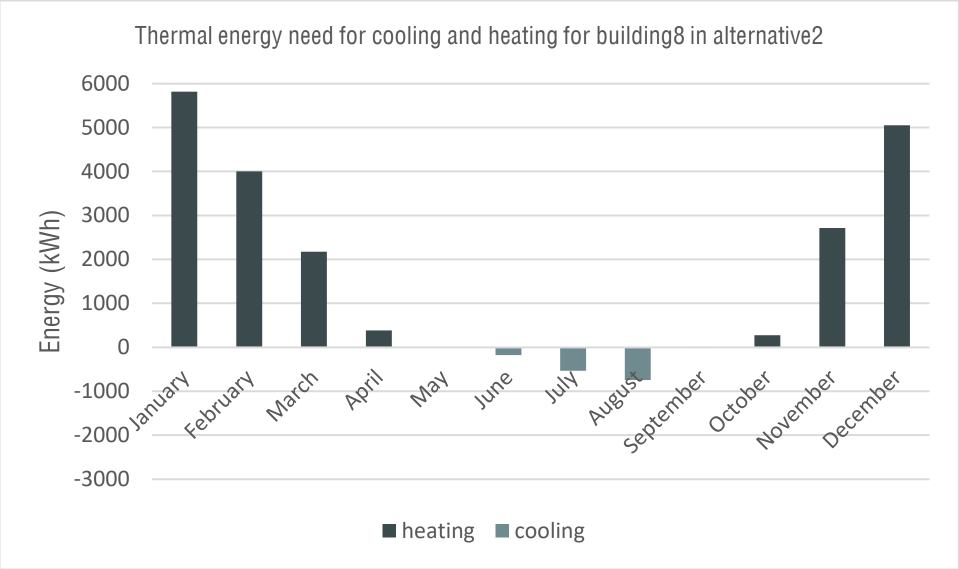


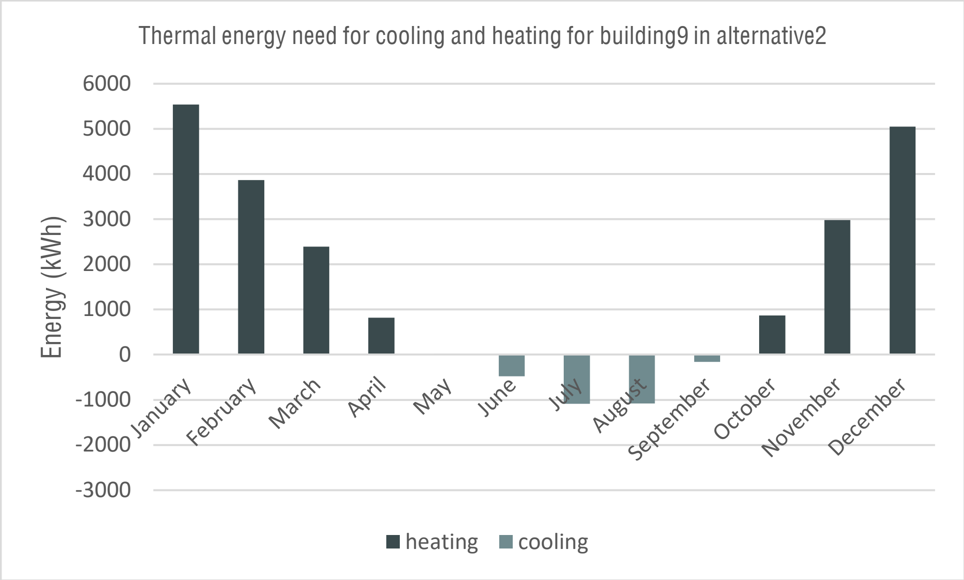
FIG.**101**-Results of thermal energy need for space heating and cooling in alternative2 buildings



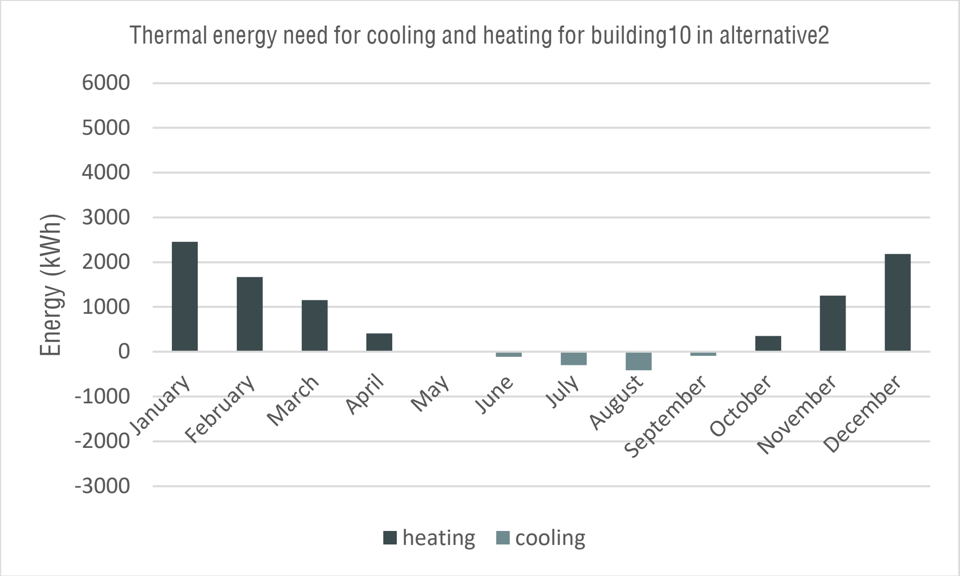
Thermal energy need for cooling and heating for building7 in alternative2



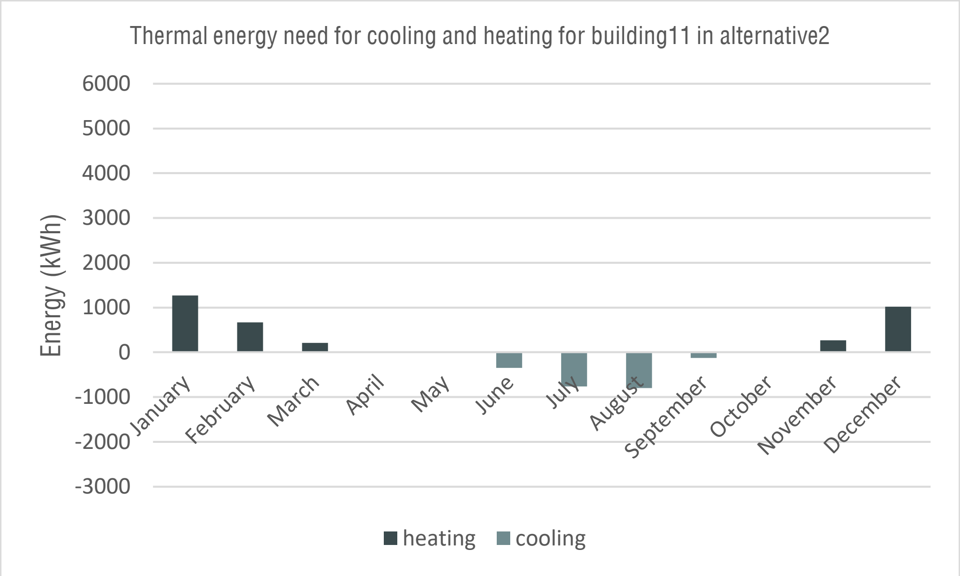
Thermal energy need for cooling and heating for building8 in alternative2



Thermal energy need for cooling and heating for building9 in alternative2



Thermal energy need for cooling and heating for building10 in alternative2



Thermal energy need for cooling and heating for building11 in alternative2

FIG.**102**-Results of thermal energy need for space heating and cooling in alternative2 buildings 7-11

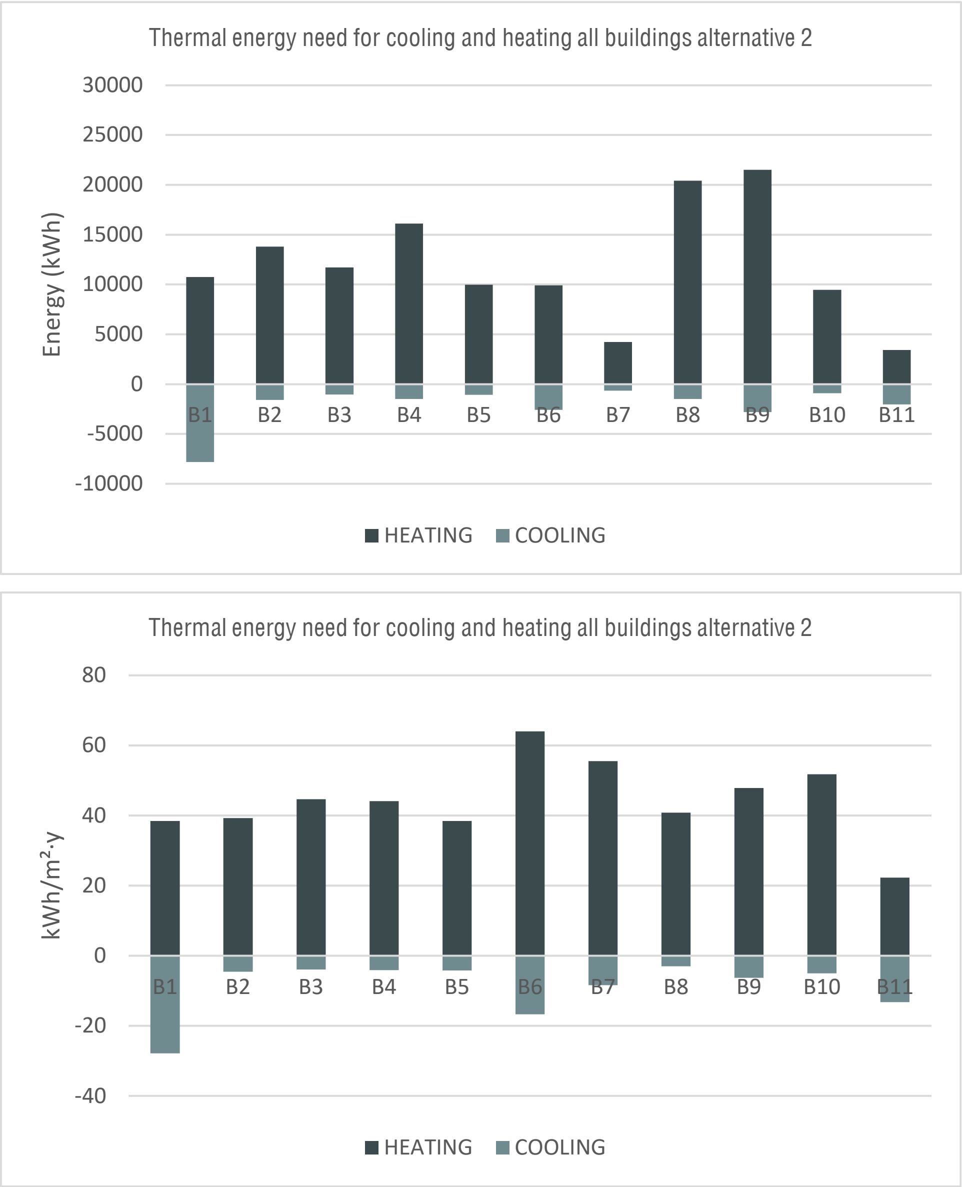


FIG.**103**-Comparison of thermal energy need for space heating and cooling for all buildings alternative2

In Senior 2, all the buildings were repeated except for 4 and 8, so in this part of the calculation, only buildings 4 and 8 are represented.

BUILDING 4	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.82	0.30	0.9	33	0.184644	1.349046
S	1	0.30	0.9	25.6	0.517741	3.578632
						4.927679

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
347	4.927679	✓ 0.014201	.03

Building 4	U value	Area	H t	H' t
Wall	0.250 W/m2K	955 m^2	267.4 W/K	-
Roof	0.157 W/m2K	376 m^2	86.48 W/K	-
Floor	0.258 W/m2K	365 m^2	102.2 W/K	-
Window	1.6 W/m2K	57.6 m^2	92.16 W/K	-
			548.24 W/K	0.323255 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 4	1696 m^2	2764 m^3	0.613606 m^{-1}	H' t <0.58	✓ 0.323255 W/m2K

FIG.**104**-Calculation of A sol, total estimation, and H' t for building4 alternative 2

BUILDING 8	F sh,ob	g gl+sh	(1-F F)	A w	F sol,est	A sol,est
N	0.82	0.30	0.9	38.4	0.299644	2.547502
S	1	0.30	0.9	38.4	0.394945	4.094795
						6.642297

AF	A sol,est total	A sol,est total/AF	Residential buildings all climate zone A sol,est total/AF <
347	6.642297	✓ 0.019142	.03

Building 8	U value	Area	H t	H' t
Wall	0.250 W/m2K	1392 m^2	389.76 W/K	-
Roof	0.157 W/m2K	638 m^2	146.74 W/K	-
Floor	0.258 W/m2K	500 m^2	140 W/K	-
Window	1.6 W/m2K	76.8 m^2	122.88 W/K	-
			799.38 W/K	0.31596 W/m2K

	A_{env}	V_g	A_{env} / V_g	$0.7 > A_{env} / V_g \geq 0.4$	H' t
Building 8	2530 m^2	4000 m^3	0.6325 m^{-1}	H' t <0.58	✓ 0.31596 W/m2K

FIG.**105**-Calculation of A sol, total estimation, and H' t for building8 alternative 2

PV panel

Since the buildings have great exposure to sunlight, it's assumed that designing a photovoltaic system with solar panels on the roof and the south-facing façade will be very effective. The type of solar panel accommodated by the model and included in the calculations is the PV Module EST-440. The PV panels in the buildings are placed on the roof, facing south, to capture as much solar energy as possible.
They have also been installed on the roof of an agrivoltaic farm, on parking spaces, and urban furniture on a bridge. Total surface utilization in the installation of PV panels, and hence maximum energy production, is considered in terms of architectural and urban design, which includes renewable energy solutions for the area sustainably and efficiently. The use of the PV Module EST-440 in every installation ensures both high efficiency and reliability for different applications in buildings and surrounding urban infrastructures.

Manufacturer: ENN Solar Energy
Model Number: EST-440
Production Status: unknown
CSI Approved: Yes
CSI Model Number: EST-440
Description: 440W Thin Film Tandem Junction Module

In this PV system design, all the energy created by the solar panels is fed into the grid. This conception then ensures that during the right time of the year – shining eras – all the excess energies are not wasted but are, instead made for use during times when the sunshine is deficient, either at night or in less sunny months. With a grid connection, the system guarantees an energy reserve for the supply of energy continuously and efficiently, although with no direct availability of solar energy. This ensures that the building's energy management is sustainable and maximizes the benefits that the PV system offers through the integration.

Mechanical

Power at STC (W)	440
Power at PTC (W)	403.5
Bifacial	No
Bifaciality (%)	-
Lower Power Tolerance (%)	-
Upper Power Tolerance (%)	-
Power Density at STC (W / m2)	76.923
Power Density at PTC (W / m2)	70.542
Module Efficiency (%)	-
Cell Efficiency (%)	-
Vmp: Voltage at Max Power (V)	214.0
Imp: Current at Max Power (A)	2.06
Voc: Open Circuit Voltage (V)	280.0
Isc: Short Circuit Current (A)	2.58
Max System Voltage (V)	-
Series Fuse Rating (A)	-
Bypass Diode	-
Nominal Operating Cell Temp (°C)	44.1
Open Circuit Voltage Temp Coefficient (% / °C)	-0.401
Short Circuit Current Temp Coefficient (% / °C)	0.104
Max Power Temp Coefficient (% / °C)	-0.368

Electrical

Cell Type	a-Si + Micro-c
Connector Type	-
Connector Cable Length (mm)	-
Length (mm)	2600.0
Width (mm)	2200.0
Module area (m2)	5.72
Depth (mm)	-
Weight (kg)	-
BIPV	No
Frame Color	-
Backsheet Color	-

Warranties & Listings

Material Warranty (years)	-
80% Power Warranty (years)	-
90% Power Warranty (years)	-
UL 1703 Compliance	Yes
NRTL Certifying UL 1703	-
Other Compliance Information	-

FIG.**106**-Technical information of PV panel(https://www.solarhub.com/product-catalog/pv-modules)

PV panel production for alternative 1

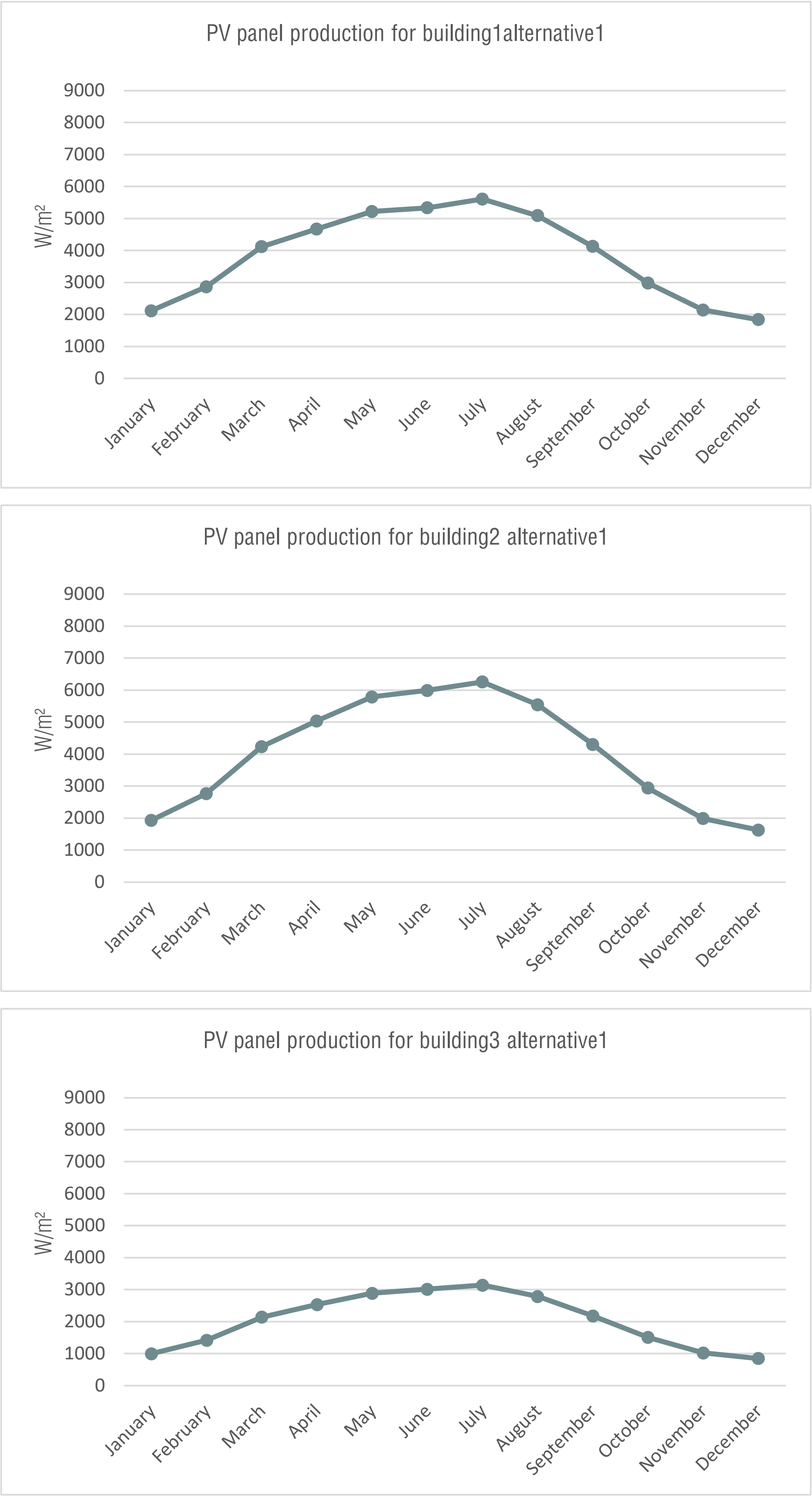
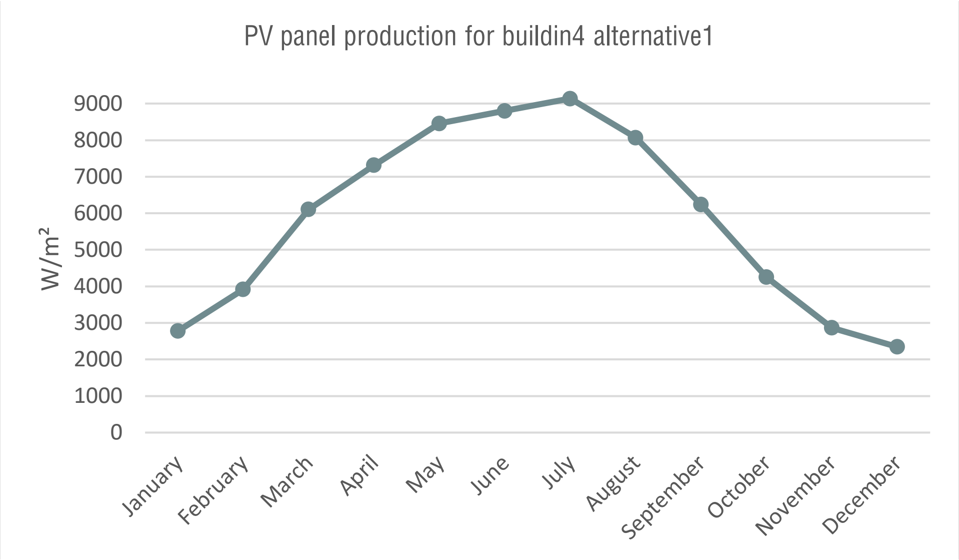
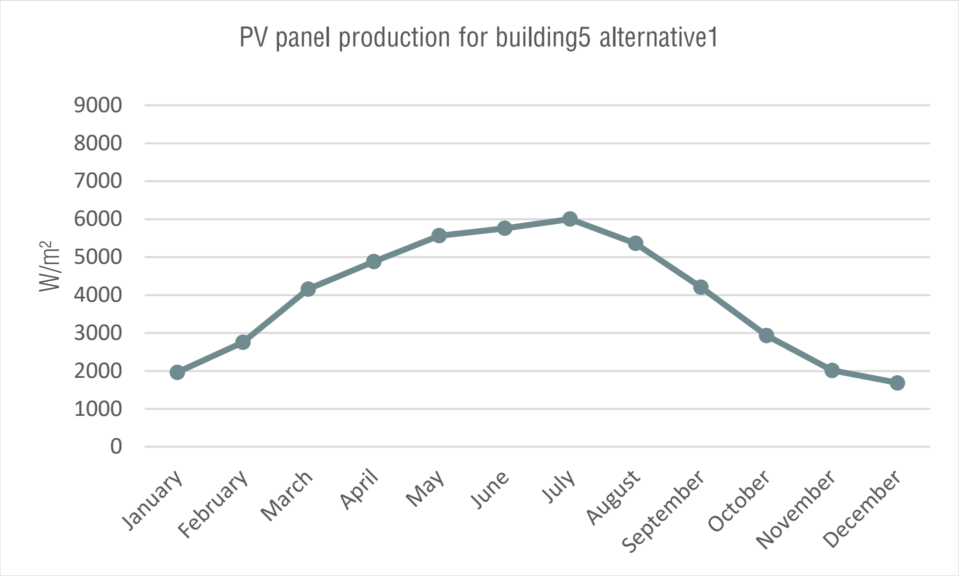
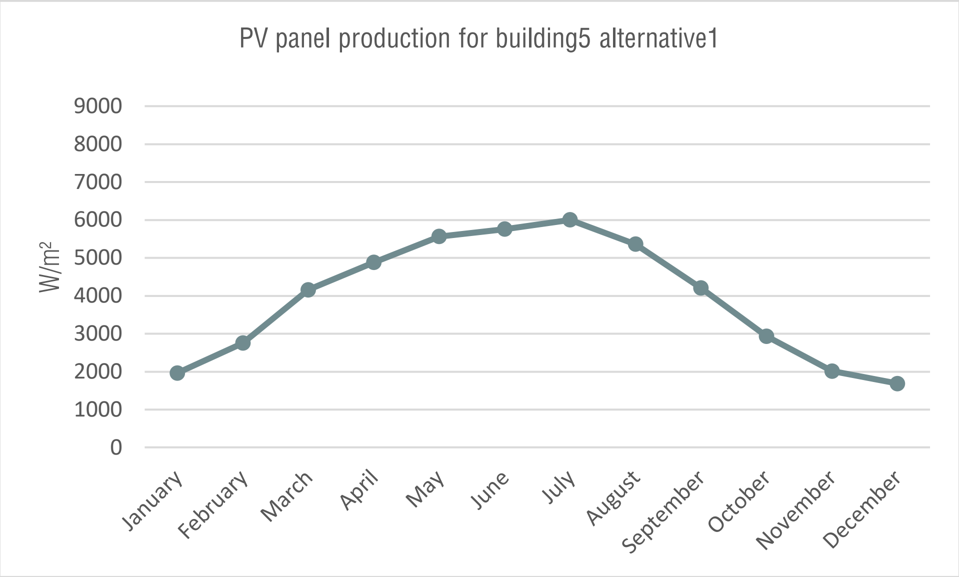
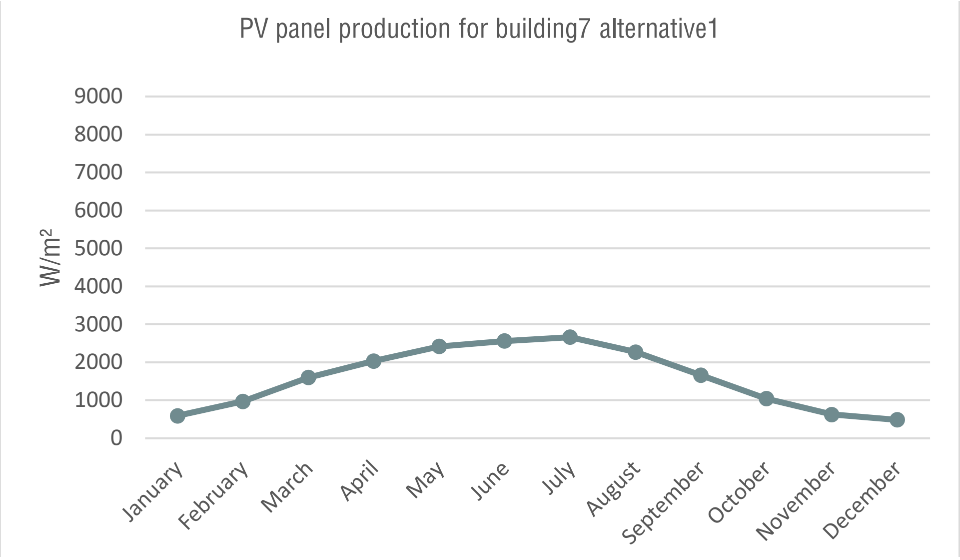


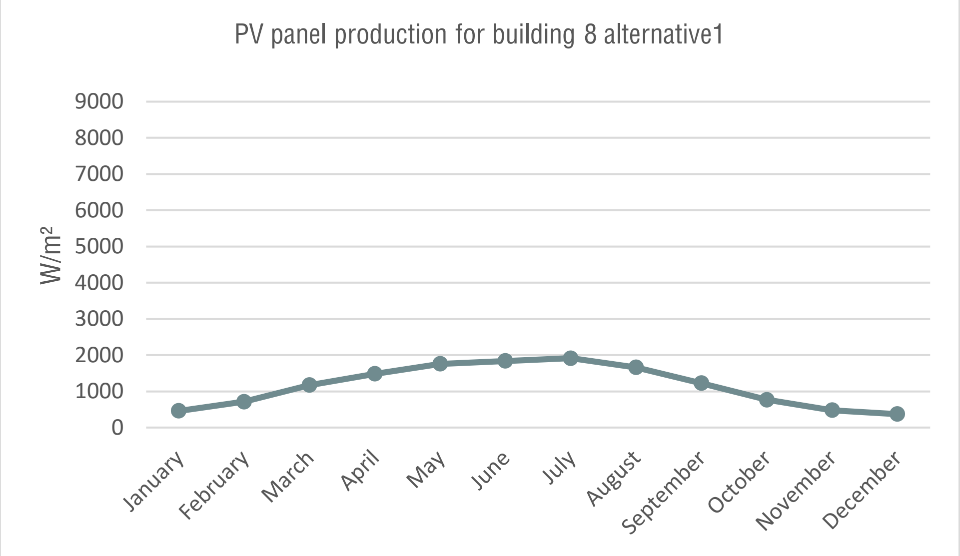
FIG.**107**-PV panel production for building1-3 in alternative 1


PV panel production for buildin4 alternative1


PV panel production for building5 alternative1


PV panel production for building5 alternative1


PV panel production for building7 alternative1


PV panel production for building 8 alternative1

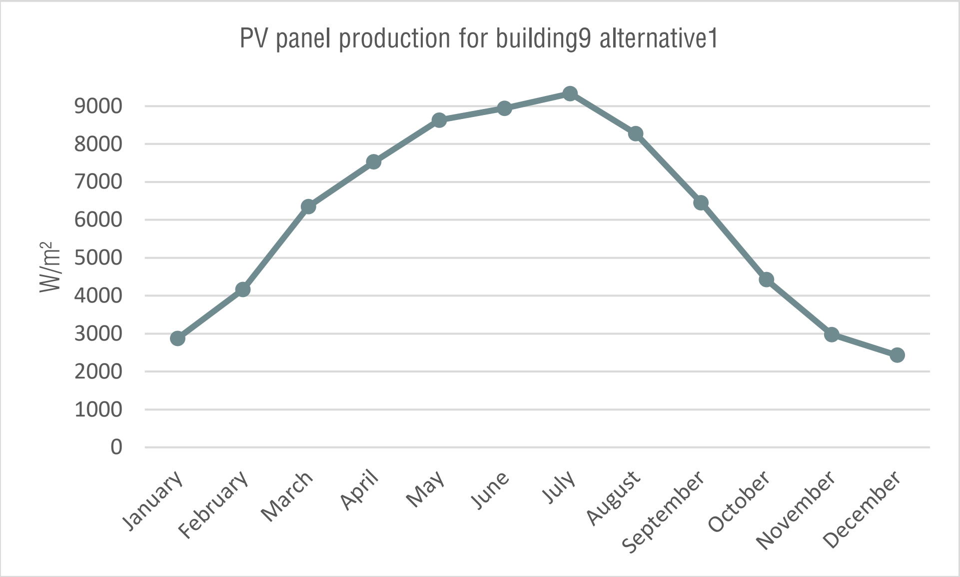
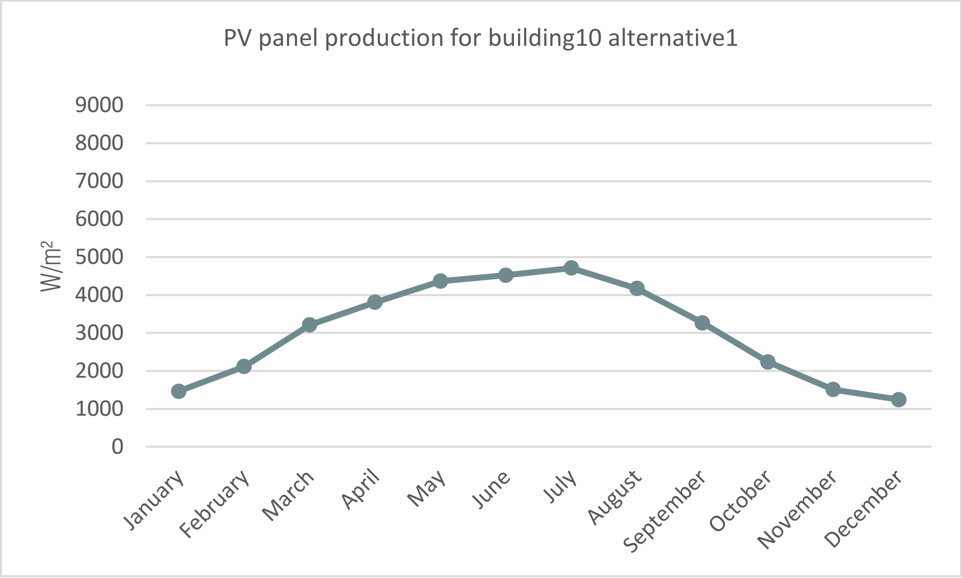

PV panel production for building9 alternative1

FIG.**108**-PV panel production for building4-9 in alternative 1


PV panel production for building10 alternative1

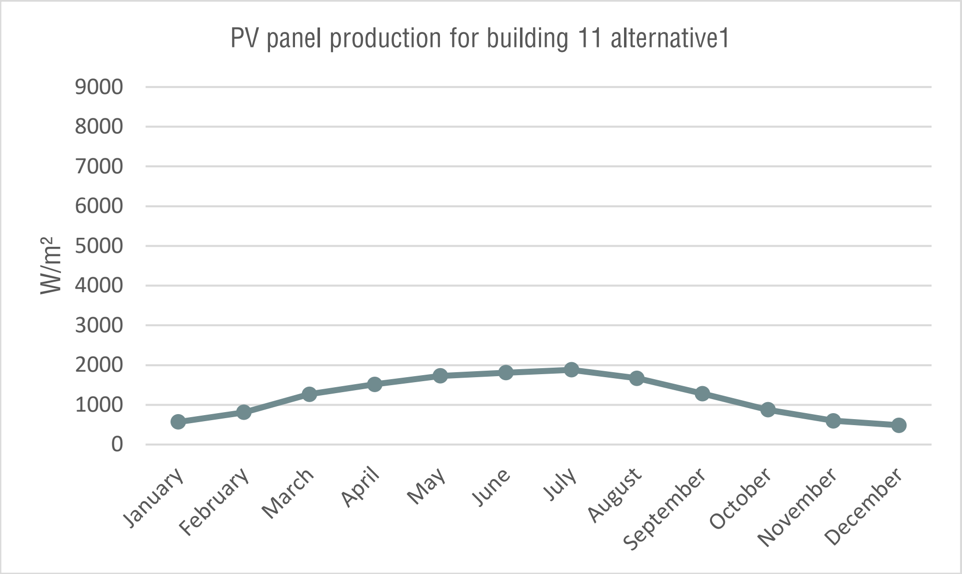
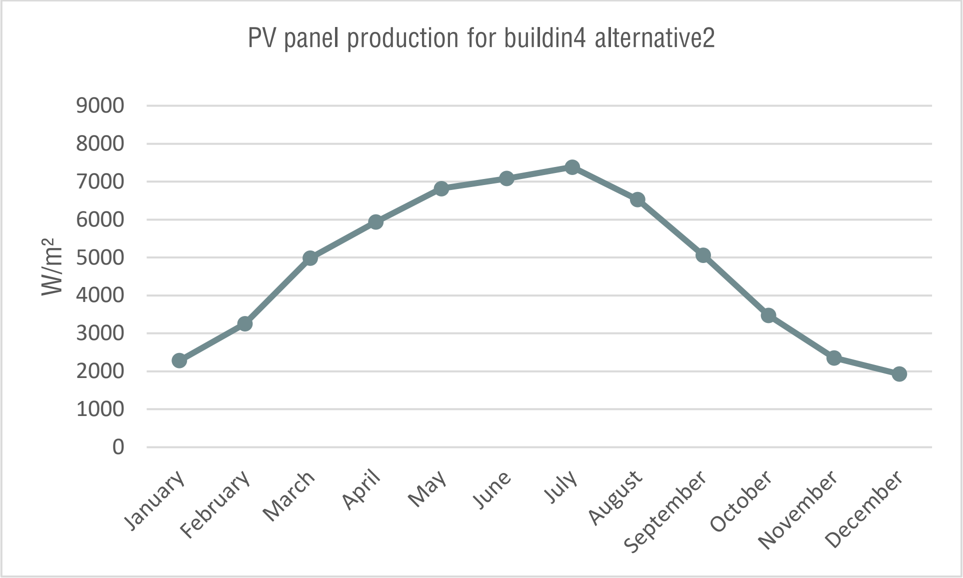

PV panel production for building 11 alternative1

FIG.**109**-PV panel production for each building9-11 in alternative 1

PV panel production for Alternative 2


PV panel production for buildin4 alternative2

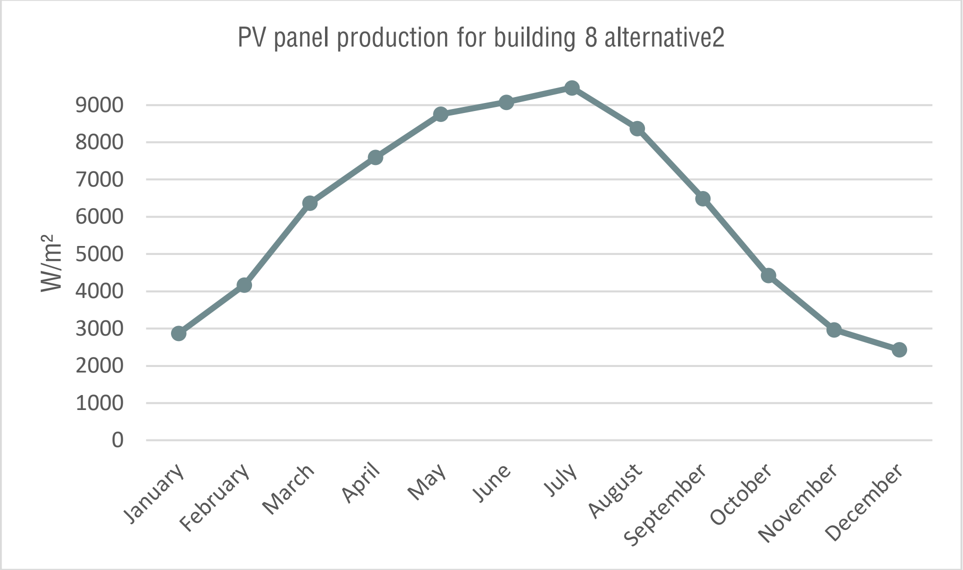

PV panel production for building 8 alternative2

FIG.**110**-PV panel production for each building4 and 8 in alternative 2

In Alternative 2, only Buildings 4 and 8 differ from the previous configuration. To avoid repetition, only the details of these two buildings are presented for Alternative 2. The other buildings remain unchanged from the initial plan.

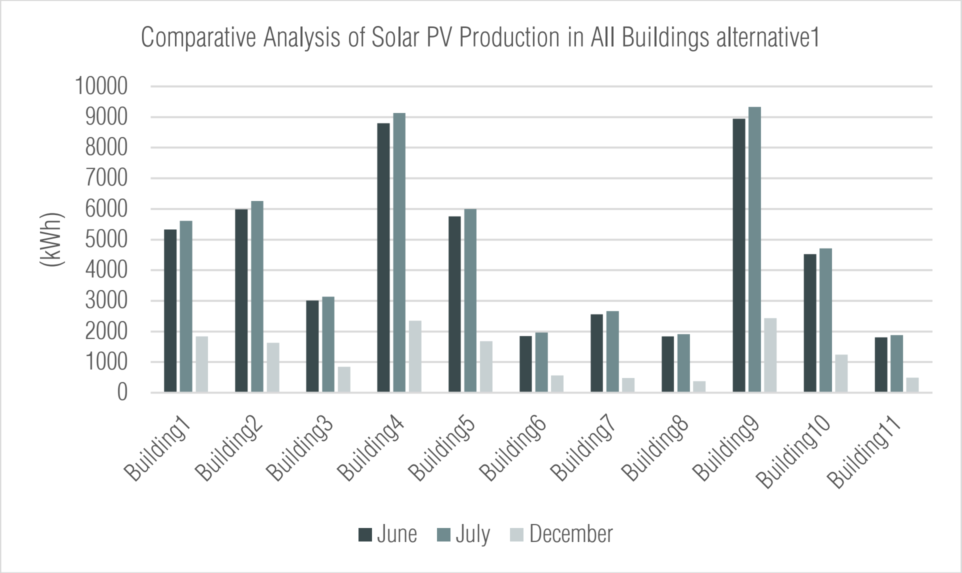


FIG.**111**-Solar PV production comparison across all buildings in alternative 1 for june, july, and december

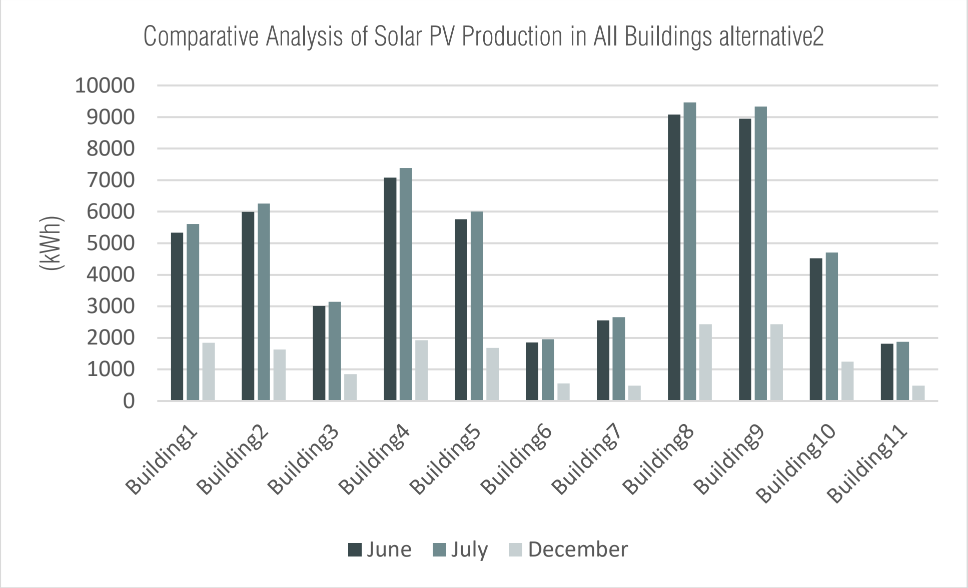


FIG.**112**-Solar PV production comparison across all buildings in alternative 2 for june, july, and december

The simulation indicates that December has the least amount of solar energy produced by PV panels. June and July, on the other hand, are the peak months for energy production across different buildings because they receive more solar irradiance. Only Building 8 in Alternative 2 exhibits higher energy production between the two options. The reason for this improvement is that the extra volume in this alternative leads to an increase in the surface area facing the sun, which increases the amount of energy generated.

	Alternative1 (W/m²)	Alternative2 (W/m²)
Building	408691	444269
Urban furniture	86	86
Parking lot	8144	8144
Agri voltaic Farm	23345	23345
	440266	475844

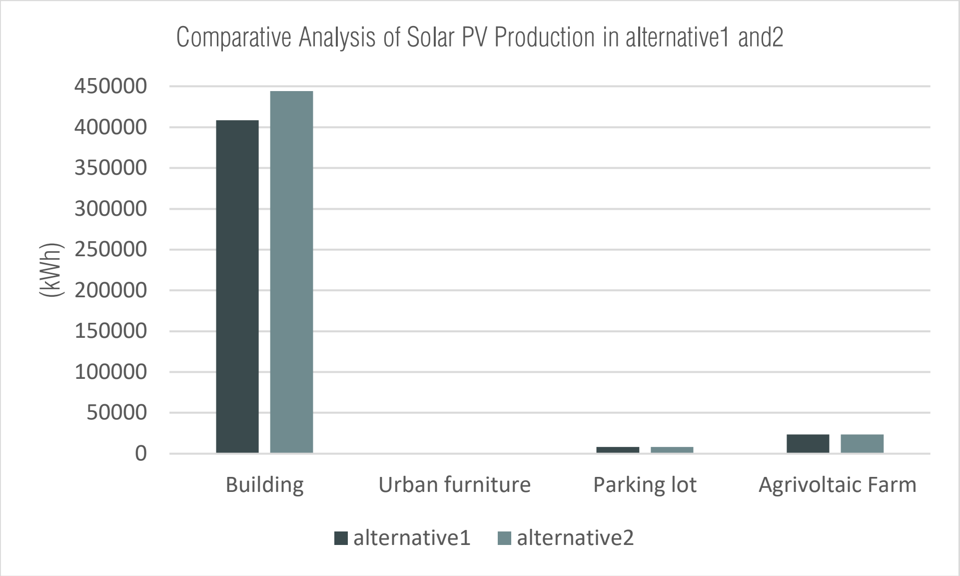


FIG.**113**-Solar PV production comparison in alternative 1and alternative 2

Rural areas offer many potentials, including diverse types of farms, pure natural settings, abandoned land, and pathways for cars and pedestrians. This case study outlines these components.

As a result, plans include installing photovoltaic panels on shading structures over a parking area at the village entrance. These panels could serve the village's lighting needs and store energy for future use.

Another significant opportunity is the use of PV panels on farms. Given the village's layout and location, it is preferable to install PV panels on border farms along the main street rather than on a single large farm, which could effect the natural beauty of the area.

Additionally, light structures and urban furniture, such as sitting spaces and exhibition modules with PV panels on their roofs, could provide lighting for public spaces, including bridges. These roofs would be designed with a north-south slope to optimize solar energy capture. These examples show just a few of the potential ways to produce energy in rural areas.

It is crucial that each building contributes some energy from renewable sources in order for the case study on achieving Net Zero Energy Buildings (NZEB). This methodology adheres to energy performance standards and promotes sustainability.

One of the suggested fixes in this situation is to install photovoltaic (PV) panels. In order to verify that every building satisfies the NZEB requirements, the potential energy output of the PV system must be estimated using the subsequent formula:

$$P = K * S$$

P: the potential energy
K :Constant for existing buildings = 0.025
K :Constant for new buildings = 0.05
S :Surface area or solar irradiance

The potential energy needed for each building is determined based on the type of PV panels chosen for the simulation, the size of the solar irradiance area, and the characteristics of the PV panels. The required number of photovoltaic (PV) panels is then calculated using these factors. As explained in the technical data in the last table it is considered as 5.72 m². The total energy production for each building is calculated by considering the energy output of each panel and the area of each panel. The energy production for the entire building is also aggregated.

Comparison of energy requirements and provision in alternative1

Building	Solar irradiance area (m^2)	Potential Energy (Kw)
Building 1	155	3.875
Building 2	176	4.4
Building 3	87	2.175
Building 4	275	6.875
Building 5	210	5.25
Building 6	55	1.375
Building 7	76	1.9
Building 8	53	1.325
Building 9	255	6.375
Building 10	131	3.275
Building 11	101	2.525

FIG.**114**-Energy requirements of PV panels for each building in alternative1

Building	Number of PV panel	Potential Energy (Kw)
Building 1	24	✓ 10.56
Building 2	27	✓ 11.88
Building 3	10	✓ 4.4
Building 4	32	✓ 14.08
Building 5	23	✓ 10.12
Building 6	8	✓ 3.52
Building 7	10	✓ 4.4
Building 8	7	✓ 3.08
Building 9	36	✓ 15.84
Building 10	16	✓ 7.04
Building 11	4	✓ 3.52
		88.44

FIG.**115**-Energy provision of PV panels for each building in alternative1

Comparison of energy requirements and provision in alternative 2

Building	Solar irradiance area (m^2)	Potential Energy (Kw)
Building 1	155	3.875
Building 2	176	4.4
Building 3	87	2.175
Building 4	209	5.225
Building 5	210	5.25
Building 6	55	1.375
Building 7	76	1.9
Building 8	263	6.575
Building 9	255	6.375
Building 10	131	3.275
Building 11	101	2.525

FIG.**116**-Energy requirements of PV panels for each building in alternative 2

Building	Number of PV panel	Potential Energy (Kw)
Building 1	24	✓ 10.56
Building 2	27	✓ 11.88
Building 3	10	✓ 4.4
Building 4	34	✓ 14.96
Building 5	23	✓ 10.12
Building 6	8	✓ 3.52
Building 7	10	✓ 4.4
Building 8	36	✓ 15.84
Building 9	36	✓ 15.84
Building 10	16	✓ 7.04
Building 11	8	✓ 3.52
		102.08

FIG.**117**-Energy provision of PV panels for each building in alternative 2

Work flow chapter 4

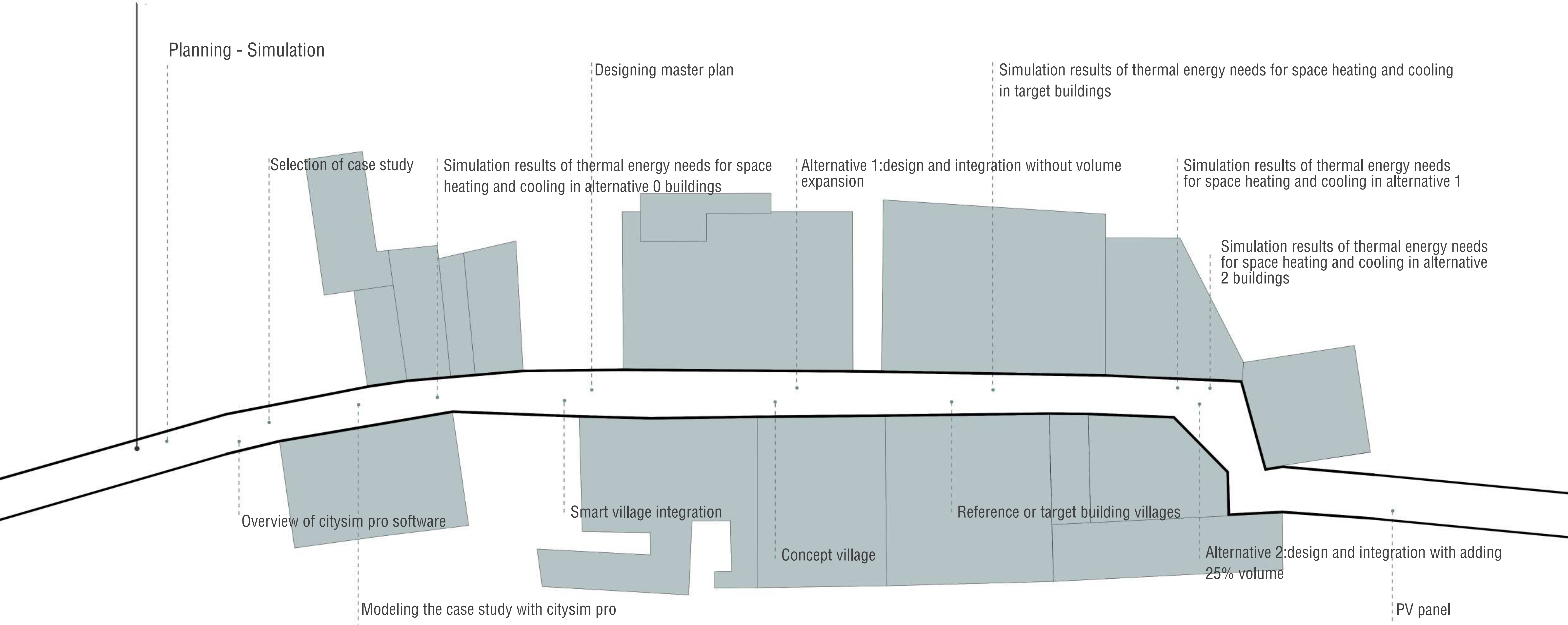


FIG.**118**-Work flow chapter 4

Conclusion - Recommendations

Conclusion

In the final stretch of this journey, the work presented aims to establish the relationship between achieving a nearly Zero-Energy Building (nZEB) village and the thermal needs for heating and cooling, as well as the energy performance of buildings in rural areas. This research focuses on reducing the energy consumption of buildings by enhancing their thermal performance. According to Italian legislation, it is necessary to focus on three main aspects to achieve energy efficiency in buildings: the energy performance of the building envelope, the design of technical systems such as lighting, HVAC, and other energy systems to ensure the building operates efficiently, and the integration of renewable energy sources, with at least 60% of the energy being provided by renewables. In this study, the main focus is on the energy performance of the building and the use of renewable energy. In the final conclusion, it is assumed that the technical systems are designed according to nZEB standards, and this is verified.

To improve energy performance, due to insufficient technical details about the building, the thermophysical parameters for both opaque and transparent parts of the envelope are determined using the UNI/TR 11552 standard from 2014. According to this standard, and based on the dimensions of each element in the base plan provided by the municipality, one type of floor, one type of roof, and four types of walls are considered. The windows are considered single-wood frame windows of the same size in all the buildings. In this step, the Glazing G Value is 0.85, the Glazing U Value is 4.80 W/m²K, and the U Value of the walls ranges from 1.6 to 1.28 W/m²K, depending on the thickness of the walls. Under these conditions, the thermal needs for heating and cooling for each building fall within the range of 300-200 kWh/m²·y for heating and 200-50 kWh/m²·y for cooling, depending on the geometry and function of the buildings. In the next step, after designing two alternatives (where the only difference is adding volume), insulation is added to the walls, roof, and floor. Before initiating the simulation for these design alternatives, it is important to base the target buildings on the climate zone D of Toiano, as specified in Appendix A, attachment 1, chapter 3. The values indicated for target buildings in that section must be adhered to.

In Alternatives 1 and 2, the Glazing G Value is reduced to 0.30, and the Glazing U Value is improved to 1.60 W/m²K by changing the window type to double glazing with low-emissivity coating. Additionally, insulation is added, and the U Value of the walls in all four types is reduced to 0.25 W/m²K. The simulation results in this step show a significant decrease in energy consumption, with values ranging from 60 to 20 kWh/m²·y for heating and 25 to 5 kWh/m²·y for cooling. These values are also lower than those for the target buildings, which range from 65 to 22 kWh/m²·y for heating and 27 to 7 kWh/m²·y for cooling. After calculating the energy performance for all buildings and verifying the results, both alternatives meet the nZEB village criteria. Overall, compared to the first step of the simulation with the current situation, there is a significant improvement in energy efficiency for heating and cooling across all buildings, which is a great result in terms of energy consumption savings.

Furthermore, to provide renewable energy, all south-facing roofs are considered for the installation of photovoltaic (PV) panels. Additionally, an agri-voltaic farm, parking lot, and urban furniture are utilized to generate energy. A storage system is also incorporated to save energy for use during the night or times when it is not possible to produce sufficient energy. In Alternative 1, a total of 440,266 kWh is produced, while in Alternative 2, 475,844 kWh is generated. To ensure compliance with nZEB standards, it is calculated that each building provides the necessary amount of energy, and this is verified.

Both alternatives are confirmed to meet the criteria for nZEB villages. While there are many options to consider when determining which alternative is more appropriate, Alternative 2 is the better option due to its higher number of occupants (122 compared to 66 in Alternative 1), better energy production, and overall energy performance. Although the differences between the last two alternatives are not substantial, Alternative 2 offers a more efficient solution.

Rebuilding Toiano based on nZEB standards is a strategic step toward achieving more ambitious environmental objectives and has become a necessity. The project, while ensuring compliance with both national and EU legislation, addresses the thermal needs for heating and cooling in the village's buildings, thereby guaranteeing the long-term and sustainable renovation of Toiano.

Recommendations

To effectively support the renovation, two requirements for building renovations are cost-effective and nearly zero-energy building. The second goal is to create support strategies and practices that will encourage building owners to finance economically sound upgrades. For example, measures with a short payback period should not be subsidized, as these can be easily financed either by the investor or through external capital. The renovation level for nZEB should be clearly defined, and its technical requirements should be highly detailed to ensure that energy efficiency improvements can be achieved without incurring excessively high costs.

The second important point deals with the overall strategy for technical design interventions in ventilation, lighting, heating, and air conditioning, where cost and efficacy are critical factors. Designing and analyzing the various options in terms of cost and energy savings could be beneficial in selecting the final alternative that provides a general overview of cost, energy performance, and architectural design. This approach will integrate the technical, architectural, and urban perspectives and combine them with economic considerations, greatly simplifying the decision-making processes for projects, especially those involving interventions in an urban or village setting. In this manner, better project planning and more informed decision-making can be achieved by taking into account a more thorough multi-scale perspective.

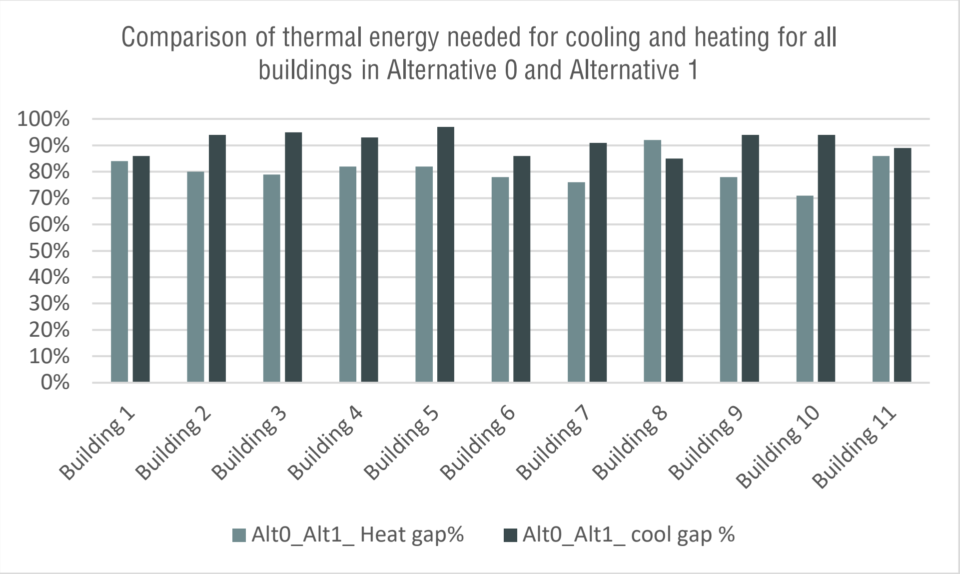
This could be further developed by having a standardized approach to the renovation of rural spaces, considering the specific climatic characteristics of the area, whether Tuscany or any other region in Italy. All regions in Italy are rich in architecture and heritage; therefore, renovation patterns should be such that they preserve and respect these cultural assets. By doing this, we can ensure that future generations may marvel at the historical legacy of Italy while also being impressed by the technological advancements over the years—not just to conserve what remains of Italy's heritage, but also to demonstrate progress over time. Renovation works should be carried out with thought and respect.

In summary, technical, architectural, and economic perspectives in building renovation, with special attention to rural and historically rich areas, are important, and they will help strike a balance between preserving cultural heritage and moving forward toward energy-efficient, cost-effective solutions.

Comparison of results

Building	Heating (kWh)	Cooling (kWh)	Area (m^2)	Heating/Area (kWh/m^2·y)	Cooling/Area (kWh/m^2·y)
Building 1	78236.8	-65542.2	280	279.4	-234
Building 2	75178.3	-34973.3	351	214.1	-99.6
Building 3	59879.1	-28771.8	262	228.5	-109.8
Building 4	61724.3	-27458.2	347	177.8	-79.1
Building 5	60567.3	-45999.2	259	233.8	-177.6
Building 6	47069.1	-32437.3	155	303.6	-209.2
Building 7	19425.9	-9088.2	76	255.6	-119.5
Building 8	14248.8	-6413.5	54	263.8	-118.7
Building 9	108722.2	-54211.9	449	242.1	-120.7
Building 10	35470	-18394.8	183	193.8	-100.5
Building 11	30264.3	-20609.1	154	196.5	-133.8

Building	Alt0_Alt1_ Heat gap	Alt0_Alt1_ Heat gap%	Alt0_Alt1_ Cool gap	Alt0_Alt1_ cool gap %
Building 1	-234.8	+84%	200.3	+86%
Building 2	-170.6	+80%	93.8	+94%
Building 3	-180.8	+79%	104.6	+95%
Building 4	-145.3	+82%	73.3	+93%
Building 5	-192.1	+82%	172	+97%
Building 6	-236	+78%	180	+86%
Building 7	-193.9	+76%	109.3	+91%
Building 8	-242.4	+92%	101.3	+85%
Building 9	-189.7	+78%	113	+94%
Building 10	-136.9	+71%	93.9	+94%
Building 11	-169.4	+86%	118.4	+89%



Comparison of thermal energy needs for space heating and cooling between alternative 0 and alternative 1 buildings

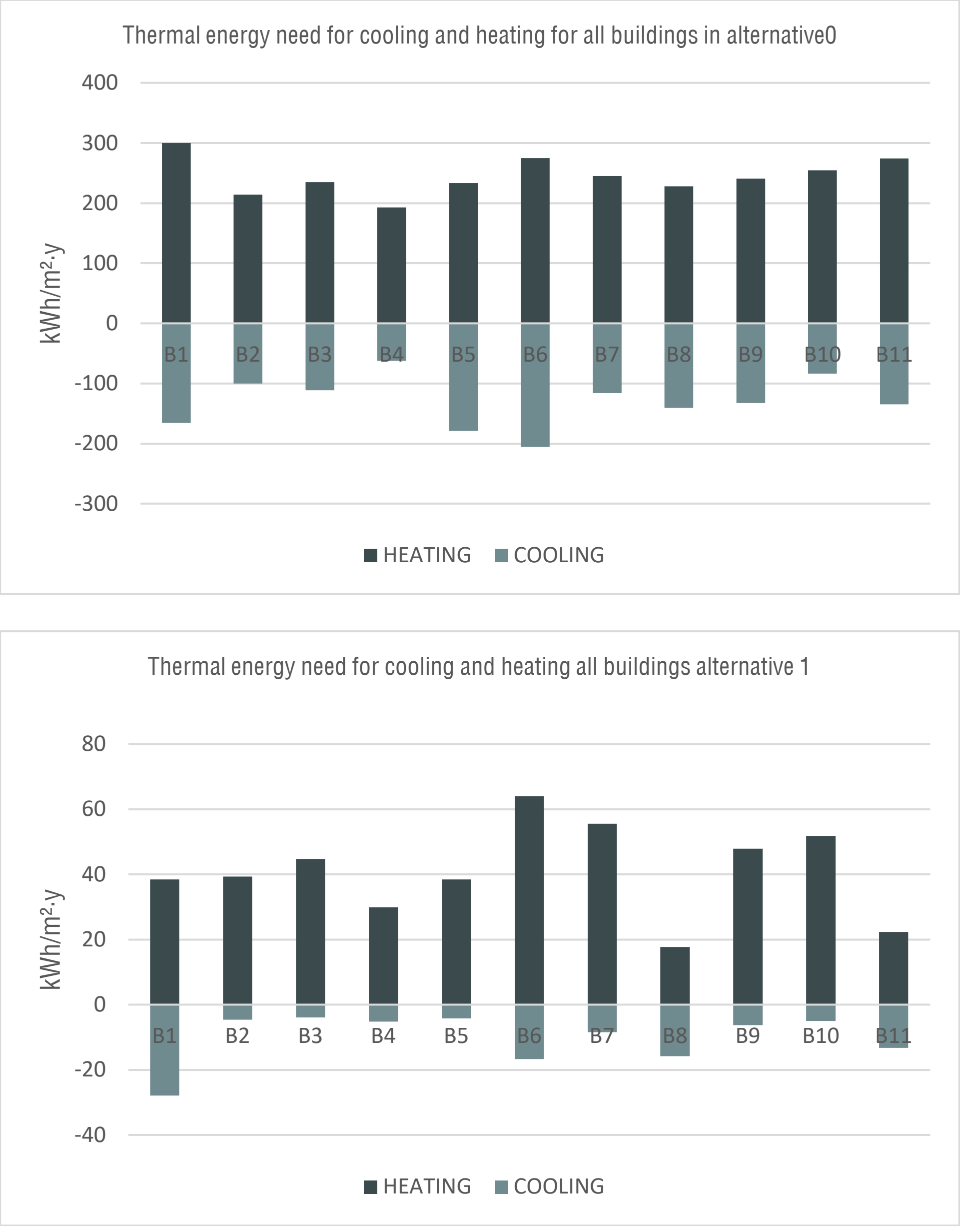
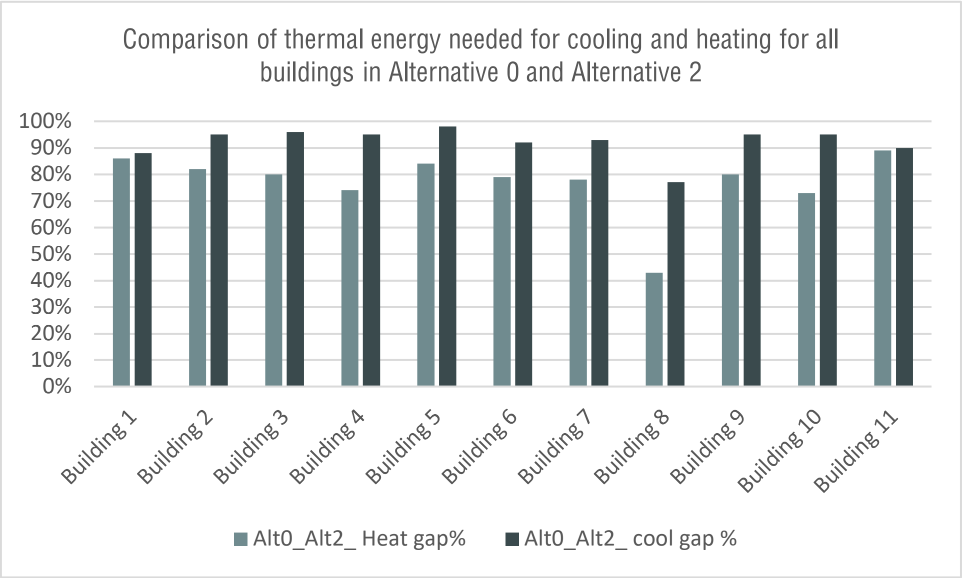


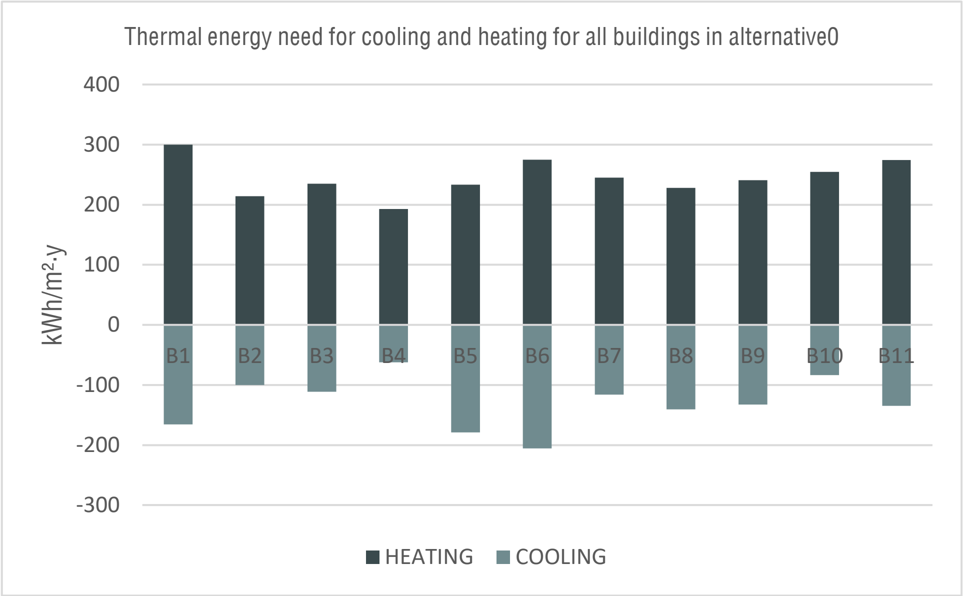
FIG.**119**-Comparative analysis of thermal energy needs for space heating and cooling for building alternatives 0 and 1

Comparison of thermal energy needs for space heating and cooling between alternative 0 and alternative 2 buildings

Building	Heating (kWh)	Cooling (kWh)	Area (m²)	Heating/Area (kWh/m²·y)	Cooling/Area (kWh/m²·y)
Building 1	78236.8	-65542.2	280	279.4	-234
Building 2	75178.3	-34973.3	351	214.1	-99.6
Building 3	59879.1	-28771.8	262	228.5	-109.8
Building 4	61724.3	-27458.2	347	177.8	-79.1
Building 5	60567.3	-45999.2	259	233.8	-177.6
Building 6	47069.1	-32437.3	155	303.6	-209.2
Building 7	19425.9	-9088.2	76	255.6	-119.5
Building 8	14248.8	-6413.5	54	263.8	-118.7
Building 9	108722.2	-54211.9	449	242.1	-120.7
Building 10	35470	-18394.8	183	193.8	-100.5
Building 11	30264.3	-20609.1	154	196.5	-133.8

Building	Alt0_Alt2_ Heat gap	Alt0_Alt2_ Heat gap%	Alt0_Alt2_ Cool gap	Alt0_Alt2_ cool gap %
Building 1	-240.9	+86%	206.2	+88%
Building 2	-174.8	+82%	95	+95%
Building 3	-183.8	+80%	105.8	+96%
Building 4	-124.9	+74%	71.1	+95%
Building 5	-195.3	+84%	173.4	+98%
Building 6	-239.6	+79%	192.6	+92%
Building 7	-200	+78%	111.1	+93%
Building 8	-12.3	+43%	9.8	+77%
Building 9	-194.2	+80%	114.4	+95%
Building 10	-142	+73%	95.5	+95%
Building 11	-174.1	+89%	120.5	+90%





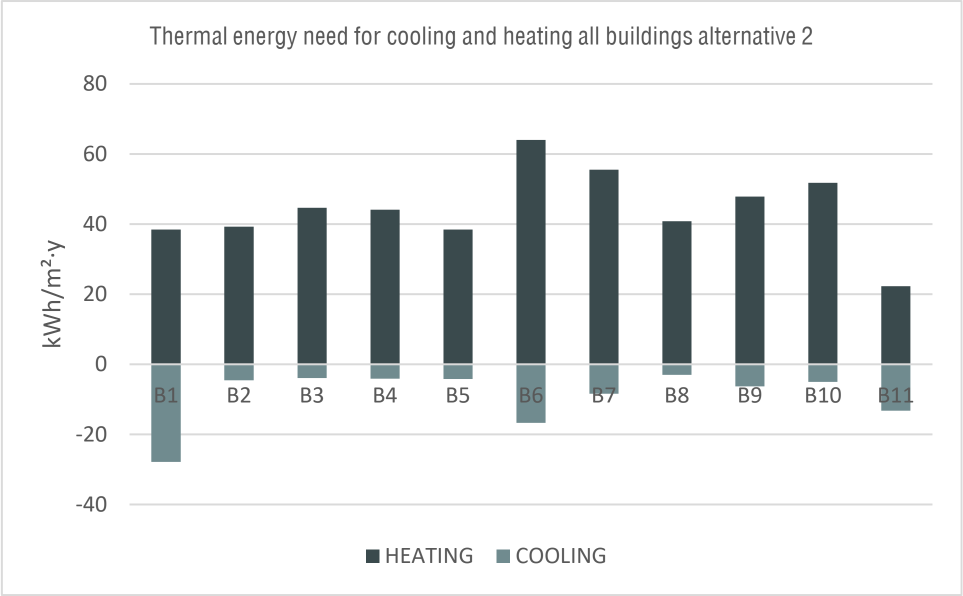
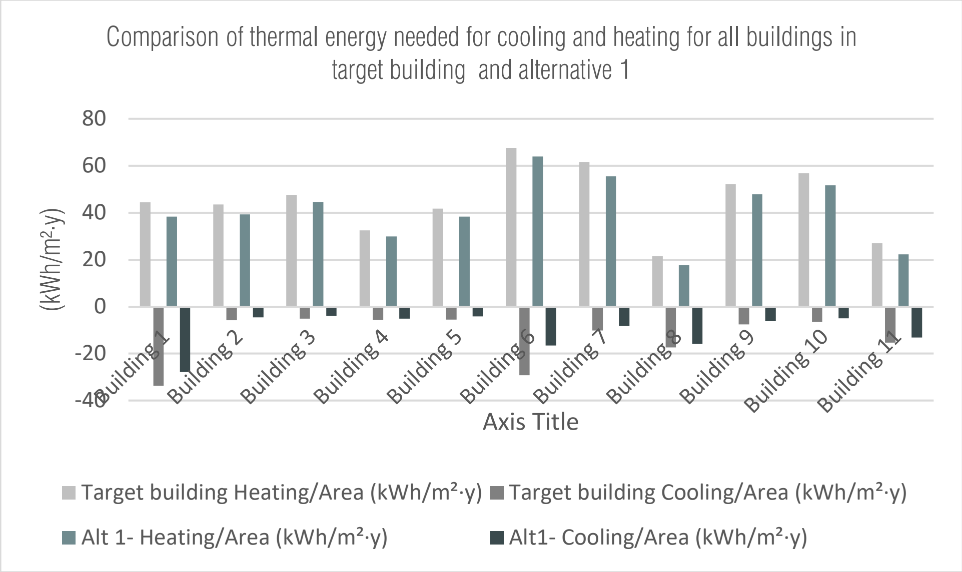


FIG.**120**-Comparative analysis of thermal energy needs for space heating and cooling for building alternatives 0 and 2

Comparison of thermal energy needs for space heating and cooling between target buildings and alternative 1 and alternative 2

		Target building				comparison	Alternative 1			
Building	Area (m²)	Heating (kWh)	Cooling (kWh)	Heating/Area (kWh/m²·y)	Cooling/Area (kWh/m²·y)	$EP_{H/C;nd;target\_building}$ > $EP_{H/C;nd;alt\_1}$	Heating (kWh)	Cooling (kWh)	Heating/Area (kWh/m²·y)	Cooling/Area (kWh/m²·y)
Building 1	280	12477.1	-9440.1	44.5	-33.7	✓	10763.6	-7799.1	38.4	-27.8
Building 2	351	15282.5	-2041.2	43.5	-5.8	✓	13797.5	-1596.6	39.3	-4.5
Building 3	262	12494	-1357.4	47.6	-5.1	✓	11709.9	-1029.6	44.6	-3.9
Building 4	347	11277.6	-2003	32.5	-5.7	✓	10392.1	-1784.3	29.9	-5.1
Building 5	259	10803.9	-1439.1	41.7	-5.5	✓	9968.9	-1080.3	38.4	-4.1
Building 6	155	10487.3	-4535.4	67.6	-29.2	✓	9919.9	-2578.3	63.9	-16.6
Building 7	76	4687.9	-780.2	61.6	-10.2	✓	4220.2	-638.2	55.5	-8.3
Building 8	54	1156.1	-942.5	21.4	-17.4	✓	958.2	-854.4	17.7	-15.8
Building 9	449	23508.9	-3455.8	52.3	-7.6	✓	21512.7	-2805.7	47.9	-6.2
Building 10	183	10416.4	-1193.8	56.9	-6.5	✓	9475	-910.5	51.7	-4.9
Building 11	154	4171.6	-2367.2	27	-15.3	✓	3441.7	-2039.2	22.3	-13.2


Comparison of thermal energy needed for cooling and heating for all buildings in target building and alternative 1

		Target building				comparison	Alternative 2			
Building	Area (m²)	Heating (kWh)	Cooling (kWh)	Heating/Area (kWh/m²·y)	Cooling/Area (kWh/m²·y)	$EP_{H/C;nd;target\_building}$ > $EP_{H/C;nd;alt\_1}$	Heating (kWh)	Cooling (kWh)	Heating/Area (kWh/m²·y)	Cooling/Area (kWh/m²·y)
Building 1	280	12477.1	-9440.1	44.5	-33.7	✓	10763.6	-7799.1	38.4	-27.8
Building 2	351	15282.5	-2041.2	43.5	-5.8	✓	13797.5	-1596.6	39.3	-4.5
Building 3	262	12494	-1357.4	47.6	-5.1	✓	11709.9	-1029.6	44.6	-3.9
Building 4	347	11277.6	-2003	32.5	-5.7	✓	16123.2	-1482.2	44.1	-4
Building 5	259	10803.9	-1439.1	41.7	-5.5	✓	9968.9	-1080.3	38.4	-4.1
Building 6	155	10487.3	-4535.4	67.6	-29.2	✓	9919.9	-2578.3	63.9	-16.6
Building 7	76	4687.9	-780.2	61.6	-10.2	✓	4220.2	-638.2	55.5	-8.3
Building 8	54	1156.1	-942.5	21.4	-17.4	✓	20423.9	-1474.1	40.8	-2.9
Building 9	449	23508.9	-3455.8	52.3	-7.6	✓	21512.7	-2805.7	47.9	-6.2
Building 10	183	10416.4	-1193.8	56.9	-6.5	✓	9475	-910.5	51.7	-4.9
Building 11	154	4171.6	-2367.2	27	-15.3	✓	3441.7	-2039.2	22.3	-13.2

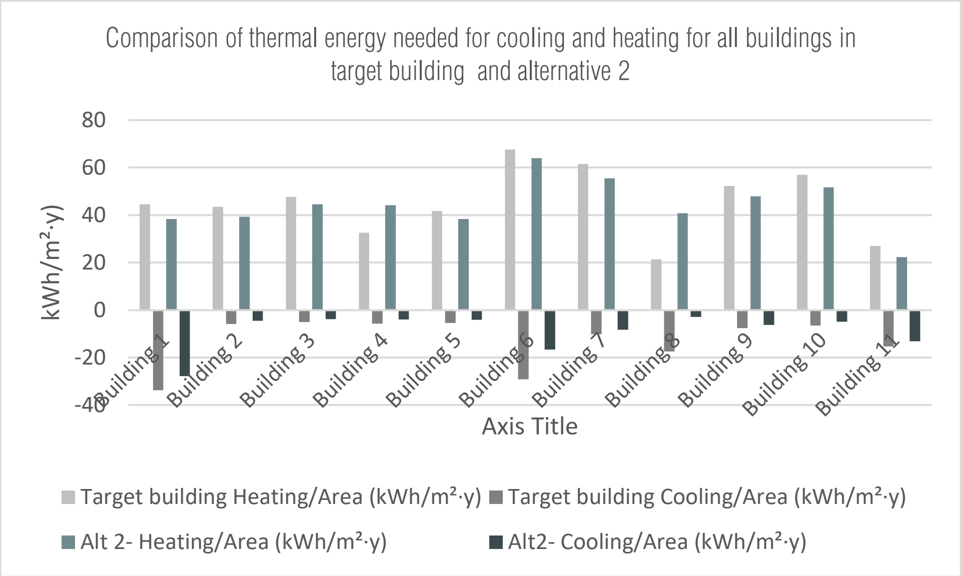
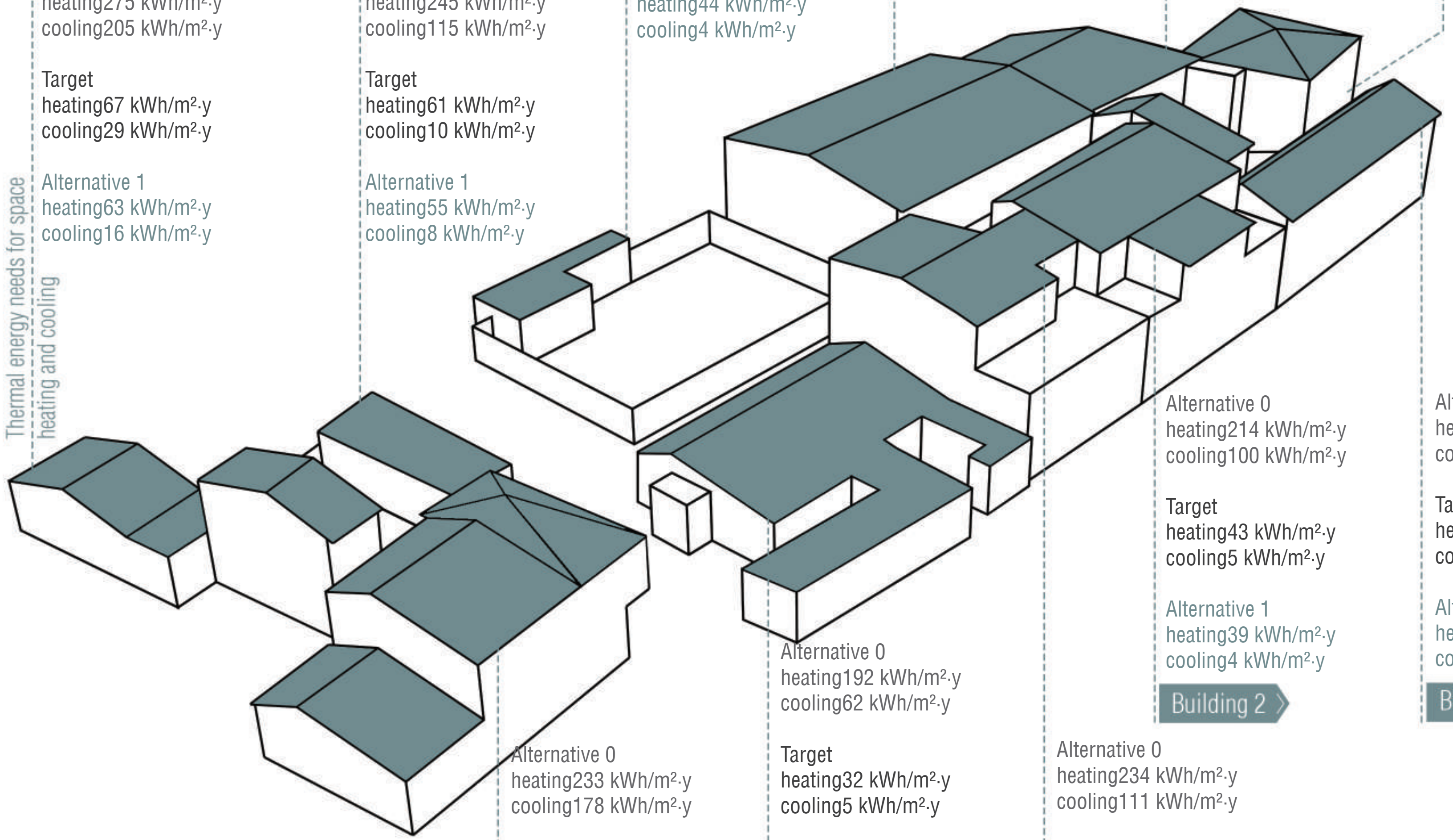

Comparison of thermal energy needed for cooling and heating for all buildings in target building and alternative 2

FIG.**121**-Comparative analysis of thermal energy needs for space heating and cooling for building alternatives1and target buildings



Building 6
Alternative 0
heating275 kWh/m^2·y
cooling205 kWh/m^2·y

Target
heating67 kWh/m^2·y
cooling29 kWh/m^2·y

Alternative 1
heating63 kWh/m^2·y
cooling16 kWh/m^2·y

Building 7
Alternative 0
heating245 kWh/m^2·y
cooling115 kWh/m^2·y

Target
heating61 kWh/m^2·y
cooling10 kWh/m^2·y

Alternative 1
heating55 kWh/m^2·y
cooling8 kWh/m^2·y

Building 8
Alternative 0
heating228 kWh/m^2·y
cooling140 kWh/m^2·y

Target
heating21 kWh/m^2·y
cooling17 kWh/m^2·y

Alternative 1
heating17 kWh/m^2·y
cooling15 kWh/m^2·y

Alternative 2
heating44 kWh/m^2·y
cooling4 kWh/m^2·y

Building 9
Alternative 0
heating240 kWh/m^2·y
cooling132 kWh/m^2·y

Target
heating52 kWh/m^2·y
cooling 7 kWh/m^2·y

Alternative 1
heating47 kWh/m^2·y
cooling6 kWh/m^2·y

Building 10
Alternative 0
heating254 kWh/m^2·y
cooling83 kWh/m^2·y

Target
heating56 kWh/m^2·y
cooling 6 kWh/m^2·y

Alternative 1
heating51 kWh/m^2·y
cooling4 kWh/m^2·y

Building 11
Alternative 0
heating274 kWh/m^2·y
cooling134 kWh/m^2·y

Target
heating27 kWh/m^2·y
cooling 15 kWh/m^2·y

Alternative 1
heating22 kWh/m^2·y
cooling13 kWh/m^2·y

Alternative 0
heating214 kWh/m^2·y
cooling100 kWh/m^2·y

Target
heating43 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 1
heating39 kWh/m^2·y
cooling4 kWh/m^2·y
Building 2

Alternative 0
heating299 kWh/m^2·y
cooling165 kWh/m^2·y

Target
heating43 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 1
heating38 kWh/m^2·y
cooling27 kWh/m^2·y
Building 1

Alternative 0
heating233 kWh/m^2·y
cooling178 kWh/m^2·y

Target
heating41 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 1
heating38 kWh/m^2·y
cooling4 kWh/m^2·y
Building 5

Alternative 0
heating192 kWh/m^2·y
cooling62 kWh/m^2·y

Target
heating32 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 1
heating29 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 2
heating40 kWh/m^2·y
cooling2 kWh/m^2·y
Building 4

Alternative 0
heating234 kWh/m^2·y
cooling111 kWh/m^2·y

Target
heating47 kWh/m^2·y
cooling5 kWh/m^2·y

Alternative 1
heating44 kWh/m^2·y
cooling3 kWh/m^2·y
Building 3

FIG.**122**-Comparative analysis of thermal energy needs for space heating and cooling

Work flow chapter 5

Conclusion and Recommendations

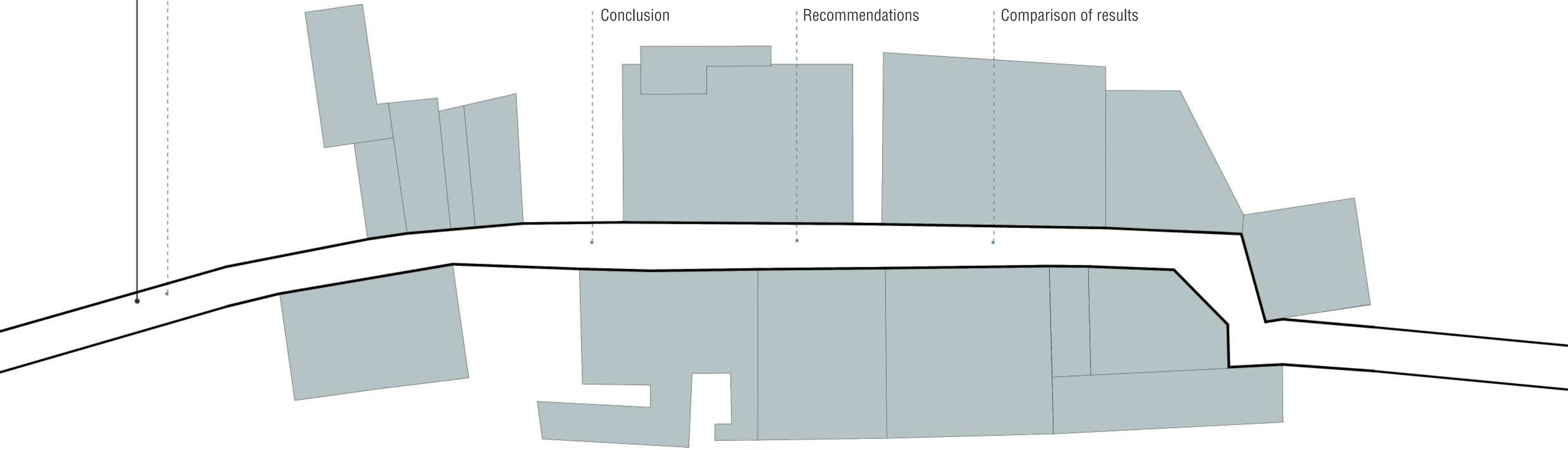


FIG.**123**-Work flow chapter 5

References

- Chiozzi, V., & Latini, T. (2015). The village of Toiano: Regeneration of an agricultural landscape: Sustainable tourism and wine production (Master's thesis, Polytechnic of Milan, School of Architecture and Society). Polytechnic of Milan.
- Smart Village Strategy of Ostana (Italy). (2020). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Guarneri, E. (2021). Smart villages and energy communities: A real case study in Valle d'Aosta (Master's thesis, Politecnico di Milano, School of Industrial and Information Engineering).
- Die Stanz Smart Village Strategy. (2021). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Torup Smart Village Strategy. (2021). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Tomaszyn Smart Village Strategy. (2021). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Action Plan on Geographical Balance, Poland. (2023). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Ansó Smart Village Strategy. (2020). Prepared in the framework of the 'Preparatory Action on Smart Rural Areas in the 21st Century' project funded by the European Union.
- Poggi, F., Firmino, A., & Amado, M. (2018). Planning renewable energy in rural areas: Impacts on occupation and land use. CICS.NOVA - Interdisciplinary Center of Social Sciences, FCSH-UNL.
- Chiaroni, D., & Guiducci, M. (2017). Nearly zero energy buildings: Comparison of the targets set by the European countries and analysis of their diffusion (Master's thesis, Politecnico di Milano).
- Boermans, T., Hermelink, A., Schimschar, S., Grözinger, J., Offermann, M., Engelund Thomsen, K., Rose, J., & Aggerholm, S. O. (2011). Principles for nearly zero-energy buildings: Final draft. Buildings Performance Institute Europe (BPIE).
- van Dijk, D., & Hogeling, J. (2019). The new EN ISO 52000 family of standards to assess the energy performance of buildings put in practice. EPB Center.
- Socal, L., & Project Team. (2021). Report on case study to EN ISO 52000-1: Overarching standard (Final report, Service Contract ENER/C3/2017-437/SI2-785.185). Stichting ISSO.
- Ferrando, M., Causone, F., Hong, T., & Chen, Y. (2020). Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches. Sustainable Cities and Society.
- Robinson, D. (Ed.). (2011). Computer modelling for sustainable urban design: Physical principles, methods and applications. Earthscan.
- Ballarini, I., Corrado, V., & Piro, M. (2021). Building stock energy models and ICT solutions for urban energy systems. Politecnico di Torino, Italy.
- Piro, M., Ballarini, I., & Corrado, V. (2023). From building energy models (BEM) to urban building energy models (UBEM): Input data and modelling approaches. In Proceedings of Building Simulation 2023: 18th Conference of IBPSA. Politecnico di Torino, Italy.
- Kristensen, H. M. (2018). Urban building energy modelling for retrofit analysis under uncertainty (Doctoral dissertation, PhD thesis, Aarhus University).
- Kämpf, J. H. (2009). On the modelling and optimisation of urban energy fluxes (Doctoral dissertation, École Polytechnique Fédérale de Lausanne). École Polytechnique Fédérale de Lausanne.

- Perez, D. (2014). A framework to model and simulate the disaggregated energy flows supplying buildings in urban areas (Doctoral dissertation, École Polytechnique Fédérale de Lausanne). École Polytechnique Fédérale de Lausanne.
- Emmanuel, W., & Kämpf, J. (2015). A verification of CitySim results using the BESTEST and monitored consumption values. Kaemco LLC; LESO-PB / EPFL. La Riaz 6, 1426 Corcelles-Concise, Switzerland; Station 18, 1015 Lausanne, Switzerland.
- Ruggiero, B. (2021). Methodology and tools for the assessment of energy consumption in building stocks (Master's thesis, Politecnico di Torino). Politecnico di Torino.
- Ministry for Ecological Transition. (2021). Strategy for energy retrofitting of national building stock. Italy.
- Ferrari, S., & Beccali, M. (2024). Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. Politecnico di Milano; Università degli Studi di Palermo.
- Tzortzaki, A. (2017). Nearly zero energy buildings: Comparison of the targets set by the European countries and analysis of their diffusion (Master's thesis, Politecnico di Milano). Politecnico di Milano.
- Ruggiero, B. (2021). Methodology and tools for the evaluation of energy consumption in building complexes (Master's thesis, Politecnico di Torino). Politecnico di Torino.
- Ferrari, S., & Beccali, M. (2017). Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. Politecnico di Milano, Department ABC; Università degli Studi di Palermo, Department DEIM.
- Guarneri, E. (2021). Smart villages and energy communities: A real case study in Valle d'Aosta (Master's thesis, Politecnico di Milano, School of Industrial and Information Engineering).
- Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, D., Rasheed, A., & Wilke, U. (2009). From the neighbourhood to the city: Resource flow modelling for urban sustainability. Solar Energy and Building Physics Laboratory (LESO-PB), EPFL, Lausanne, Switzerland.
- Dassori, E., Messico, A., Morbiducci, R., Morini, A., Polverino, S., & Vite, C. (2019). A smart village model for the Italian coastal territory. TEMA.
- Robinson, D. (2011). Computer modelling for sustainable urban design: Physical principles, methods, and applications.
- Global Building Performance Network (GBPN). (2013). What is a deep renovation? [Technical Report]. Global Building Performance Network. Paris, France.
- Firlag, S., & Piasecki, M. (2018). NZEB renovation definition in a heating dominated climate: Case study of Poland. Applied Sciences, 8(9), 1605.
- Mutani, G., Coccolo, S., Kämpf, J., & Bilardo, M. (2018). CitySim guide: Urban energy modelling. CreateSpace Independent Publishing Platform.
- D'Agostino, D., Tsemekidi Tzeiranaki, S., Zangheri, P., & Bertoldi, P. (2021). Assessing Nearly Zero Energy Buildings (NZEBs) development in Europe. Energy Strategy Reviews, 36, 100680.
- Magrini, A., Lentini, G., Cuman, S., Bodrato, A., & Marenco, L. (2020). From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example. Developments in the Built Environment, 3, 100019.
- Santos-Herrero, J. M., Lopez-Guede, J. M., & Flores-Abascal, I. (2021). Modeling, simulation, and control tools.

References

- Asdrubali, F., & Desideri, U. (Eds.). (2018). Handbook of energy efficiency in buildings: A life cycle approach. Butterworth-Heinemann.
- Polettini, F. (2019). Smartness assessment of rural areas: Multicriteria rating with Alpine stakeholders (Master's thesis). Politecnico di Milano, School of Civil, Environmental and Land Management Engineering.
- Lytras, M. D., Visvizi, A., & Mudri, G. (2019). Smart villages: Mapping the emerging field and setting the course of action. In Smart villages in the EU and beyond. Emerald Publishing Limited. https://doi.org/10.1108/978-1-78769-845-120191013
- Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, D., Rasheed, A., & Wilke, U. (2009). From the neighbourhood to the city: Resource flow modelling for urban sustainability. In Proceedings of the CISBAT 2009 Conference: Renewables in a Changing Climate. Lausanne, Switzerland: Solar Energy and Building Physics Laboratory (LESO-PB), EPFL.
- Franconi, E., Tupper, K., Herrschaft, B., Schiller, C., & Hutchinson, R. (2013, August 30). Building energy modeling for owners and managers: A guide to specifying and securing services. Rocky Mountain Institute.
- Panagiotidou, M., & Fuller, R. J. (2013). Progress in ZEBs—A review of definitions, policies and construction activity. Energy Policy, 62, 196-206. https://doi.org/10.1016/j.enpol.2013.06.099.
- Maile, T., Steinacker, H., Stickel, M. W., Ott, E., & Kley, C. (2023). Automated generation of energy profiles for urban simulations. Energies, 16(16), 6115. https://doi.org/10.3390/en16166115.
- Widyawati, & Anggraini, Y. (2023). Village institutions in sustainable village development. Jurnal Administrare: Jurnal Pemikiran Ilmiah dan Pendidikan Administrasi Perkantoran.

- International Organization for Standardization. (2017). ISO 52000-1: Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures. International Organization for Standardization.
- European Parliament and Council. (2024, April 24). Directive (EU) 2024/1275 on the energy performance of buildings (recast). Official Journal of the European Union. Text with EEA relevance.
- European Committee for Standardization (CEN). (2019). EN 16798-1: Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6. CEN.
- International Organization for Standardization. (2017). ISO 52000-1:2017 Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures.
- Appendix A (Attachment 1, Chapter 3). Description of the Reference Building and Verification Parameters.
- Building Performance Institute Europe (BPIE). (2014). Renovation strategies of selected EU countries: A status report on compliance with Article 4 of the Energy Efficiency Directive. BPIE. Brussels, Belgium.
- European Committee for Standardization. (2019). EN 16798-1: Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters (ICS 91.120.10; 91.140.01). https://www.cen.eu
- Annex A: National recommended criteria for indoor environment.
- Allegato 1: Criteri generali e requisiti delle prestazioni energetiche degli edifici.
- Allegato 2: Norme tecniche di riferimento per il calcolo della prestazione energetica degli edifici.
- Appendice A: Descrizione dell'edificio di riferimento e parametri di verifica. In Allegato 1, Capitolo 3.
- Appendice B: Requisiti specifici per gli edifici esistenti soggetti a riqualificazione energetica.

- CitySim Solver. (2020). CitySim Solver official code. https://github.com/kaemco/CitySim-Solver.
- https://www.spiritoinvolo.it/urbex-toiano.html