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Designing Net zero energy Building and district

by

Faezeh Sadeghi

Tutor

Prof. Mario Artuso

Tutor

Prof. Giacomo Chiesa

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Abstract

Advancements in the realm of residential net-zero energy buildings (NZEBs) hold immense potential for substantial reductions in energy consumption and the associated greenhouse gas emissions. To achieve this, NZEB design considerations encompass three primary categories: energy infrastructure connections, renewable energy sources, and energy-efficiency measures. Surprisingly, a comprehensive review of recent advancements in residential NZEBs is noticeably absent from the existing literature. Hence, this endeavor aims to furnish a comprehensive overview of each category, emphasizing the latest developments within the last decade. The primary objective is to provide valuable references and support for the widespread and efficacious implementation of residential NZEBs worldwide.

This study explores energy infrastructure connections, including electrical grids, district heating/cooling networks, and various energy storage options like vehicle-to-home and hydrogen storage. Moreover, a thorough examination of renewable energy sources is undertaken, encompassing solar photovoltaic and solar thermal technologies, wind power, and biomass solutions, including micro combined heat and power (CHP) systems. Additionally, the paper delves into the domain of energy-efficiency measures, which comprise enhanced building envelope designs, efficient HVAC systems, optimized domestic hot water systems, and the integration of phase change materials. Within each category, a plethora of technology options exist, rendering the selection of an ideal configuration more challenging. Nevertheless, this abundance of choices allows for design flexibility, facilitating adaptation to local climates and other pertinent factors such as building codes, energy resources, and costs.

In essence, this comprehensive examination aims to furnish a repository of references and emphasize various technological alternatives that pave the way for the successful realization of residential NZEBs across the globe. By shedding light on recent advancements and offering insights into the multifaceted considerations involved, this paper seeks to accelerate progress in the field and encourage the widespread adoption of sustainable and energy-efficient residential buildings.

Contents

List of Figures:

List of tables:

Chapter 1

1.1. Introduction

The building stakeholder sector is important in the environmental and energy scenario of any country and accumulates approximately a third of the final energy consumption. Consequently, the improvement of the energy efficiency in buildings has become an essential instrument in the energy policies to ensure the energy supply in the mid to long term (moreover is the most cost-effective strategy to deal with the use of CO2 emissions as climate change and global warming are the most critical issues discussed in the last decades.

Energy consumption in buildings significantly increases every year due to the increased human comfort needs and services. Much of the stress people impose on the earth is manifested in the way architects design, construct, and use in built environments; that means **buildings and cities** must play a vital role in shaping a sustainable future. **The net-zero energy approach can be taken to any scale and positively affect the way build and live-in communities and cities**. Net zero energy buildings are tools in shaping the future because it is noticed that buildings are aimed to consider social, environmental, and economic values besides a substantial focus on the automated technological attributes. (Attia, 2018).

In light of numerous commendable green building initiatives, there has been a noticeable surge of interest in integrating information technology and advanced control techniques into architectural design. This growing enthusiasm stems from the recognition of the imperative for sustainable development, considering the far-reaching consequences of climate change. As a result, a range of interconnected approaches to green building design has been implemented, all with the common goal of fostering the sustainable development of cities.

Designing a sustainable city (SC) with zero-energy buildings that cope with the reduction of CO2 has become one of the urgent tasks of the next 20 years. One promising approach to achieve SC is to combine appropriate land use (compact city with wit energy-efficient buildings and photovoltaic panels (PVs)). (O'Brien & Atheneites, 2015).

The primary objective of this research is to explore the noteworthy progress in building design as an integral component of city development, with a focus on establishing more sustainable and efficient built environments. This study is a theoretical study of different case studies existing around the world, by the method of comparison. Furthermore, through a comprehensive analysis, the findings validate the crucial role of the ZEB concept in driving net-zero energy districts.

1.2. Methodology

The research methodology employed in this study relies on qualitative data derived from various sources such as books, articles, case studies, and the interpretation of existing structures, buildings, and districts and is the theoretical study. In addition, certain quantitative data have been utilized to enhance comprehension and identification of the thesis problems. This approach facilitated the determination of designing requirements, issue identification, and the provision and implementation of solutions.

The approach to generating suitable recommendations for the districts in Turin encompasses three primary steps. Firstly, it entails recognizing the challenges associated with designing net zero energy buildings through the interpretation and analysis of existing articles. This step considers four main aspects: concept design, design development, net zero energy design tool model resolution, and design methods.

The second step involves reviewing the implementation strategies of Net Zero Energy Buildings (NZEB) in terms of passive and active strategies at the building scale. This is accomplished by examining various case studies.

Lastly, the third step focuses on implementing some of these appropriate technologies within the districts themselves. This methodology aids in a comprehensive analysis of the existing areas and facilitates the identification of suitable suggestions to address the main thesis questions.

1.3. Thesis structure

This thesis research starts with defining Zero energy buildings and about the scientifical background. The primary focus of this study was to establish a universally recognized understanding of Net Zero Energy Buildings (Net ZEBs) by employing a common methodology. This involved reviewing and analyzing existing definitions and data about Net ZEBs, as well as classifying them based on climate zones. Additionally, several case studies were conducted to examine approaches used in the construction of newly built buildings with similar characteristics. The study also emphasized the development and testing of innovative, comprehensive solutions for achieving net-zero energy consumption in cold, moderate, and hot climates. These solutions aimed to incorporate exemplary architecture and technologies and serve as the foundation for international collaboration and demonstration projects. To achieve this, the study documented and analyzed existing Net ZEB designs and technologies, benchmarked them against near Net ZEBs and other energy-efficient buildings, and considered sustainability, economic aspects, and prospects. This analysis was conducted using a project database, a literature review, and input from practitioners through workshops.

Chapter three of the study delved into the design of Net ZEBs, focusing on three steps: concept design, design development, and model resolution. The model resolution encompassed various factors such as the building's geometry, shape, HVAC systems, photovoltaics, lighting, and the impact of windows and solar shading. This step aimed to enhance the management of design complexities and elements at different stages.

Chapter Four examined the current global climate issues, particularly in the building sector. The study conducted an extensive review to explore the strategies implemented over the past decade to achieve Net ZEBs, considering both passive and active approaches. Part A of this analysis focused on passive strategies, aiming to reduce building energy demand through architectural design techniques during the early design stage. It further categorized passive strategies into sustainable design and energy-saving techniques. Part B centered on active strategies, which aimed to address the remaining energy demand after applying passive strategies. Active strategies included renewable energy (RE) solutions and backup systems for RE. The study also analyzed the costs and benefits of different techniques through a comparative approach utilizing various case studies.

Throughout the research, numerous design solutions were introduced and analyzed through case studies. Some of these solutions drew inspiration from net-zero energy house design and emphasized energy reduction and reuse. By combining bioclimatic architectural principles with modern technologies, significant reductions in energy requirements were achieved.

Subsequently, energy production solutions were implemented in districts based on building positioning and shape, highlighting each building's contribution to the overall energy dynamics of the district. The study also examined appropriate technologies for the district, as demonstrated by a case study in Lyon. This included energy reduction and production solutions, ultimately showcasing how districts function as energy-conscious systems by integrating individual building contributions.

In summary, this research utilized a comprehensive methodology to establish an internationally agreed understanding of Net ZEBs. It encompassed reviewing definitions, conducting case studies, developing innovative solutions, exploring passive and active strategies, analyzing costs and benefits, and examining appropriate technologies for districts.

In this study, we used some main references for each chapter that was so helpful for us in each step, as we mentioned before this study is theoretical, and data is derived from various sources such as books, articles, and case studies. For chapter one I get help from the book **NET ZERO ENERGY DESIGN A GUIDE FOR COMMERCIAL ARCHITECTURE by Tom Hootman**, in chapter one the main reference that es helped us was the book **Modeling, Design, and Optimization of Net-Zero Energy Buildings**, and Some Case studies such as Case Study of **a Nearly Zero Energy Building in Italian Climatic Conditions** by Hassan Saeed Khan, Muhammad Asif, and Mohammed Alhaji Mohammed some another case studies were situated in Rome, **the Leaf House** . important part is the chapter number 5 thank to **professor Bottero and professor Orlando that help me for the part of Turin by the case study: Decision making for sustainable urban energy planning: an integrated evaluation framework of alternative solutions for ana NZED (Net Zero-Energy District) in Turin and**

Design of District-level Photovoltaic Installations for Optimal Power Production and Economic Benefit.

And the part related to Lyon I get help from the Case Study: Smart Community Demonstration Project in Lyon, France, and the Article Smarter Together: Monitoring and Evaluation of Integrated Building Solutions for Low-Energy Districts of Lighthouse Cities Lyon, Munich, and Vienna.

1.4. research questions

In this research, we delve into the topic of net zero energy, exploring its key principles, challenges, and opportunities. By examining the latest advancements, successful case studies, and emerging trends in the field, we aim to gain insights into the feasibility, benefits, and potential strategies for achieving net zero energy in different contexts. Additionally, we will address the economic, social, and environmental implications of transitioning towards net zero energy, considering its impact on energy costs, occupant comfort, job creation, and overall sustainability.

With this backdrop, our research question is:

1. What is NZEB and why is it an important topic?
2. What are the important criteria for achieving net zero energy building?
3. How to build NZEB? What Are the main factors?
4. What is the main problem we will face during these processes?
5. Why net-zero energy district?
6. what advances in the light of empirical experiences?

1.5. Objective

This thesis is a comparative approach to identify and reflect on the current energy requirements of Buildings for reaching net zero energy and interpreted of e buildings when each building is coming together t make neighborhood districts for low energy demand.

- Determining some problems we will face during the design of net zero energy
- The demonstration of urban scale proposal for energy neighborhood
- The introduction of critical elements for achieving net zero energy buildings

Chapter 2

2.1.Net Zero Energy building design fundamentals

The realm of Net Zero Energy Buildings (NZEBs) presents an exciting frontier for innovation and competition within the global real estate market. Europe holds immense potential for rapid scalability in this domain. The Architectural, Engineering, and Construction (AEC) sector is witnessing a growing demand for robust, cost-effective ultra-low-energy buildings. To embrace energy efficiency in high-performance structures, a paradigm shift in the construction cycle becomes imperative, necessitating unanimous agreement on performance standards among all project stakeholders. NZEBs play a crucial role in global energy efficiency strategies, given that buildings contribute significantly to global final energy consumption. This study aims to equip AEC professionals and researchers with fundamental concepts and analytical frameworks, enabling them to make informed decisions within the realm of energy-efficient and healthy buildings. NZEBs, by definition, are ultra-low energy structures that annually fulfill their energy requirements through onsite or nearby renewable sources. While exemplary NZEB examples and models already exist worldwide, it is important to note that definitions and concepts surrounding NZEBs may vary across Europe. The potential of NZEBs for fostering Sustainable Cities is immense, as they empower building owners and occupants to strive for utmost energy efficiency while generating energy onsite. However, it is essential to acknowledge that NZEBs are intricate endeavors, demanding meticulous attention during the phases of planning, design, construction, and operation. Moreover, systematic performance metrics and monitoring mechanisms are indispensable. Homes are rapidly embracing standards about health, comfort, and energy performance, with NZEBs leading the way in utilizing local resources and skills. Both policymakers and the AEC industry face a host of challenges and opportunities in their collective pursuit of reducing energy consumption, enhancing indoor environmental quality, and augmenting the utilization of renewable energy sources. The profound impact of greenhouse gas emissions on the economy, society, and the environment cannot be understated, as carbon pollution resulting from human activities destabilizes the climate. (O'Brien & Atheneites, 2015).

2.2. The concept of net zero energy building

The convergence of the need for innovation and substantial reductions in energy consumption and greenhouse gas emissions within the construction industry presents a unique opportunity to revolutionize the way we conceive buildings and their energy systems. It is crucial to consider demand reduction through passive design, energy efficiency measures, and conservation strategies alongside the integration of solar systems and on-site generation of heat and power, all within a holistic approach to building energy design. The landscape of building energy design is undergoing transformative changes driven by three key factors and corresponding technological advancements:

1. The adoption of net-zero energy as a long-term objective for new buildings in many developed countries and influential professional associations like ASHRAE.

2. The imperative to mitigate peak electricity demand from buildings through optimal operations, thereby reducing the necessity to construct additional fossil fuel-powered central power plants.

3. The decreasing cost of energy-generating technologies, such as photovoltaics, makes building-integrated energy systems more affordable and competitive. This trend is further magnified by the escalating costs associated with conventional energy sources. (O'Brien & Atheneites, 2015).

A critical aspect of designing high-performance buildings lies in the comprehensive understanding of a building as an interconnected energy system, meticulously crafted and operated to deliver an optimal indoor environment that aligns with its intended purposes. Notable progress has been achieved in the realm of building envelope technologies. This encompasses cutting-edge innovations such as vacuum insulation panels and advanced fenestration systems, including "smart windows" with electrochromic coatings. Moreover, solar thermal technologies for heating and cooling, as well as solar electric or hybrid systems, have emerged as significant contributors to building performance. Combined heat and power (CHP) technologies have also witnessed substantial development over the past century. Furthermore, the field has seen the advent of a wide range of HVAC, lighting, and automation technologies, each offering its unique contributions to enhancing building performance. By skillfully integrating a combination of both traditional and emerging technologies, designers can create high-performance buildings tailored to their specific functions and environmental contexts. This approach allows for the optimization of energy efficiency and the delivery of superior indoor environments in line with desired outcomes. Effectively managing solar gain, and daylight, and maintaining thermal and visual comfort poses an ongoing challenge in building design and operation. Smart window systems offer a promising solution by enabling active control over solar radiation transmission. A combination of passive and active measures can be employed to reduce solar gains. Passive measures are implemented during the design phase, while active measures, such as motorized veVenetianlinds, are utilized during building operations. It is worth noting that solar gains exhibit delayed effects due to building thermal mass, underscoring the importance of predictive control and optimal operation of passive and active storage systems, leveraging real-time weather predictions. (O'Brien & Atheneites, 2015).

To achieve high-performance buildings that provide a comfortable indoor environment, a holistic approach as an integrated energy system is crucial. This entails incorporating a diverse range of technologies, both established and emerging, to meet the specific requirements of each building's purpose and environmental context (Atheneites, Stylianou, and Shou, 1990).

Emerging building technologies, including phase change materials (PCM), advanced daylighting devices integrated within active façades, and building-integrated solar systems, present new challenges, and opportunities for improving comfort while simultaneously reducing energy consumption and peak loads. These advancements must be considered when developing optimal control strategies. Furthermore, it is essential to recognize that commercial and residential buildings have distinct energy and control needs. Commercial buildings, for instance, rely heavily on cooling and lighting, while homes, particularly in colder climates, prioritize space heating and domestic hot water heating. Plug loads, encompassing appliances and office equipment, play a significant role in overall building energy consumption. As HVAC and lighting systems become more energy-efficient, the contribution of plug loads becomes increasingly prominent. Therefore, there is a growing interest in implementing demand response solutions, such as appliance scheduling, to effectively manage peak energy demand caused by plug loads. These solutions have gained popularity due to their potential to alleviate strain on energy resources during peak periods. (O'Brien & Atheneites, 2015).

2.3. Net zero energy building as a solution set

Based on the information presented above, countries must address the GHG emissions and sequestration opportunities linked with the construction industry. All main business sectors must operate with zero carbon emissions by 2050. The AEC industry is on the verge of fast transformation due to quick improvements in essential technologies like as solar power, battery storage, heat recovery systems, heat pumps, BAC, performance dashboards, LED lighting, and electric vehicles. The grid's flexibility and smart management, as well as the electrification revolution, are hastening structural transition and change (Attia, 2018).

In general, ZEBs entail two design strategies: First reduce the need for energy in buildings (particularly for heating and cooling) through more energy-efficient measures, and (ii) embrace renewable energy and other technologies to meet the lowest energy needs.

The Green Building Council advocates for a radical and ambitious shift to a carbon-free built environment, with the following dual goals:

• All new buildings must operate at net zero carbon from 2030.

• 100% of buildings must operate at net zero carbon by 2050.

As a result, high-performance buildings, such as NZEB and PEB, are an effective means of combating climate change. To promote health, accomplish comfort, and reduce energy consumption, the energy demands for space cooling, space heating, domestic hot water, and ventilation must be calculated and operated. One of the primary strategies for meeting carbon reduction targets is to construct energy-neutral buildings that create the energy they consume to meet the demands of their users. The rest of the energy mandate using renewable sources and managing energy systems must be satisfied by implementing high-energy efficiency measures to reduce energy demand as much as possible. NZEB also has a performance-based approach that ensures IEQ, energy efficiency, and energy generation all at the same time.

NZEB has proven to be a trustworthy and innovative solution. NZEB reduce their environmental effect while remaining robust enough to resist storms and other climate conditions. They are part of the healthy building movement, which aims to put people and health at the center of the design and operation of buildings. Scaling this concept to benefit from distributed energy resources (DERs) including roof-top solar, heat pumps, electric batteries, and smart mimicrogridsas already been proven to have a solid business case. Climate change impacts can be averted, and several societal and economic gains can be realized by concerted action by three key groups of actors—business, government, and nongovernmental organizations (Attia, 2018).

2.4. Net zero energy building design fundamentals

2.4.1. CLASSIFYING NET ZERO ENERGY BUILDINGS

Standardized criteria and procedures for evaluating net zero energy in a building are critical for providing the industry with a consistent approach to constructing these structures and then monitoring the results of their actual operation. A Classification System Based on Renewable Energy Supply Options," by Shanti Pless and Paul Tortellini. NREL's classification system has four classes, A through D, and prioritizes the application of renewable energy to place a greater value on high-priority renewable energy applications. The system also enables buildings that may struggle to achieve net zero energy to do it to some extent. The NREL system, which should be utilized in conjunction with the four standards, allows a building to achieve one or more of the four definitions at a certain classification level. In addition, the NREL classification system emphasizes demand-side reduction as a requirement, reflecting the critical requirement for a net-zero-energy building to be a very low-energy facility. After then, the system prioritizes the use of renewable energy based on its nature and proximity to the building. After then, the system prioritizes the use of renewable energy based on its nature and proximity to the building. The categories also provide a rough estimate of how difficult it will be to achieve net zero energy with the renewable energy application in question. Renewable energy applications span from installing all necessary renewable energy systems within the building footprint (Classification A, or NZEB: A) to supplementing on-site renewable energy with purchased renewable energy credits to meet the concept of a net zero energy building (Classification D or NZEB:D). NZEB stands for "net zero energy building," and the abbreviation "NZEB: classification" is used (Hootman, 2012).

Classification A

A low-energy structure that meets one or more of the four definitions of net zero energy by producing enough renewable energy from sources inside its footprint. Only individual buildings fall under this category. (Figure 1)

Example Scenarios

- Photovoltaic systems fixed to the façade or top of the building.
- Solar thermal systems affixed to the façade or top of the building.
- Wind turbines integrated into or installed on the structure (Desideria & Asdrubali, 2018g).

Classification B

"Summary: A low-energy structure that meets one or more of the four parameters of net zero energy by producing enough renewable energy on the project's site. Campus situations where the renewable energy systems are situated on jointly owned adjacent land are included in the definition of the site boundary. (Easements are permitted to separate commonly owned property). This description may be used for a single building or a group of structures.

Typical Scenarios

- Ground-mounted photovoltaic systems or systems installed over parking lots.
- Ground-mounted solar thermal systems at the location.
- Wind turbines erected on towers at the location.
- Energy is produced on-site from biomass that has been gathered nearby. (Desideria & Asdrubal, 2018g).

Classification C

A low-energy building that, to the greatest extent possible, first uses renewable energy sources within the building's footprint and on-site, and then imports enough renewable energy from elsewhere to produce energy on-site that meets one or more of the four categories for net zero energy. A single building or a group of buildings may fall under this category.

Scenario Examples

- Biomass is imported on-site and used to produce electricity.

- Biomass is imported on-site and used to produce thermal energy (Desideria & Asdrubali, 2018g).

Classification D

"A low-energy building that, to the extent practical, first uses renewable energy sources within the building's footprint and on-site, and, optionally, imports off-site renewable energy for use in on-site energy production. However, it purchases off-site renewable energy to meet the source or emission definition for net zero energy. A net zero energy definition for a site or cost cannot be met with this classification.

Typical Scenarios

Purchased certificates for renewable energy (RECs) (Desideria & Asdrubali, 2018g).

The most difficult classification is A, which requires a net zero energy building to manage all its required renewable energy inside its footprint. Earning this Classification, certification has inherent value because the renewable energy systems are incorporated into the building and will most likely serve the structure for the life of the renewable energy system. Renewable energy systems put on a site, on the other hand, may be removed or become shaded if new structures or expansions are built on the property. The project's renewable energy resources receive the highest categorization, which becomes the project's designation. Renewable energy resources from higher classifications, on the other hand, can be used to help meet the requirements of a lower classification. If the project does not have enough building-mounted photovoltaics to meet the net zero energy requirement for classification A, for example, a mix of site-mounted and building-mounted photovoltaics may be used to meet the net zero energy criterion for classification B and in Table 1 we can see the Summary of Common ZEB Definitions (Tortellini, 2010)

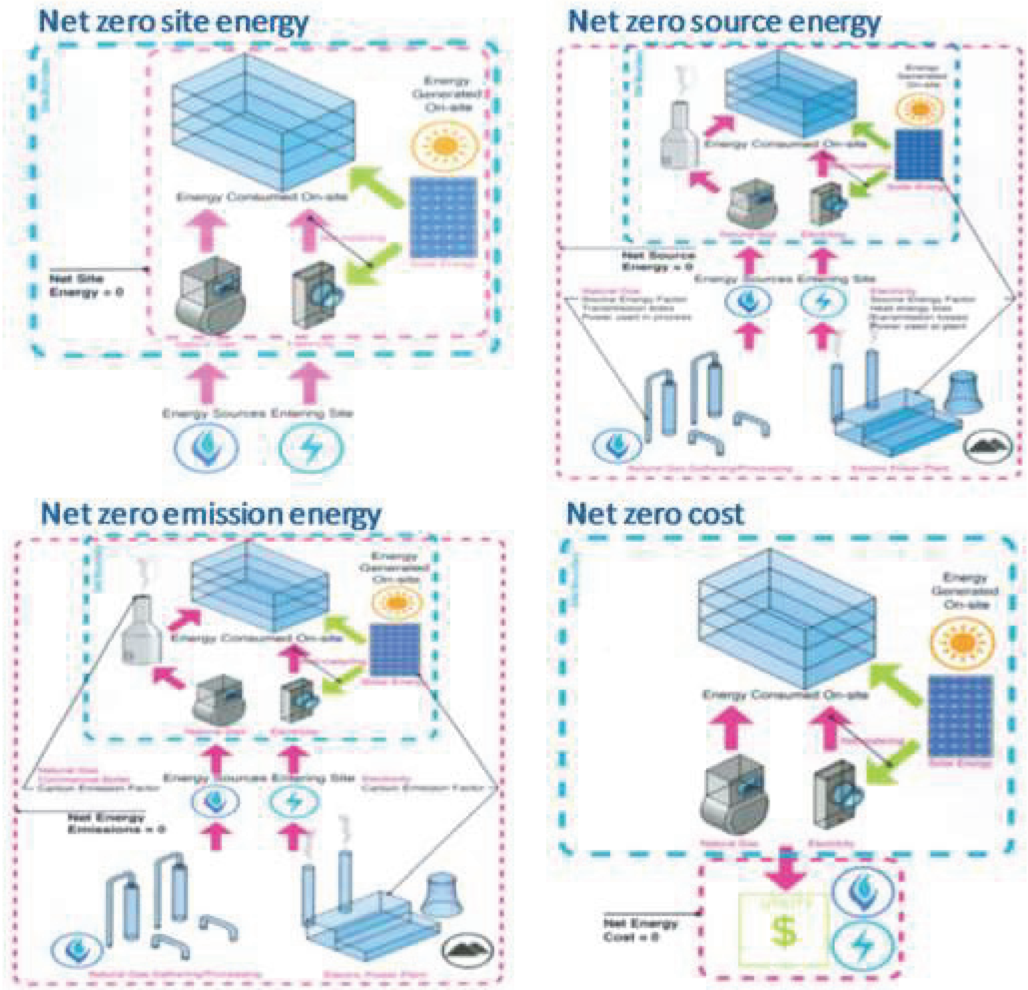


Figure 1: Representation of the different ZEB definitions proposed by (Torricelli, 2010)

	Advantages	disadvantages
Site ZEB	• Easy to implement • Verifiable through on-site measurements • No externalities affect pertormance • Easy to understand and communicate • Encourages energy-efficient building designs • Conservative approach to achieving ZEB	• Requires more PV export to offset natural gas • Does not consider all utility costs • Not able to equate fuel types • Does not account for nonenergy differences between fuel types
Source ZEB	• Able to equate energy value of fuel types used at the site • Better model for assessing the impacts on national energy systems • Easier ZEB to reach	• Does not account for nonenergy differences between fuel types • Source calculations too broad • Source energy use accounting and fuel switching can have a larger impact than efficiency technologies • Need to develop site-to-source conversion factors
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 to national grid for demand • Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges • Highly volatile energy rates make for difficult tracking over time

Table 1: definition of ZEBs, *(Tortellini, 2010)*

2.4.2. Definition and Evaluation of a Net Zero Energy Building

the methodology for analyzing the zero energy case study buildings is presented. The underlying principles of this methodology are presented in this introduction. The methodology can be used as a framework for contrasting Net ZEB buildings' energy efficiency in cold, moderate, and hot regions. The methodology is based on the following essential concepts for developing high-performance (energy) buildings:

1) Evaluation of primary energy delivered, net ZEB performance, and delivered energy (balance).

2) The choice and classification of buildings based on their intended function and local climate.

3) Determine overarching design principles for every building type and climate combination.

4) Based on the relevant three strategy categories, identify the passive, energy-efficient, and energy-supply measures used in the chosen buildings.

The definition and evaluation of a Net Zero Energy Building are explained here, along with the ideas of boundary and balance (Ayoub et al., 2017).

2.4.2.1. Physical boundary

A crucial aspect of accurately comparing different buildings lies in establishing a uniform specification for the building system boundary. A building typically draws energy from multiple sources, including on-site renewable energy generation and off-site grid electricity, whether renewable or not. The boundary delineates the separation between the on-site and off-site domains, serving as both a physical barrier and an energy balance boundary.

The physical boundary defines the extent of the project under consideration within the energy balance framework. It can encompass various definitions, such as a community-scale boundary, which includes a cluster of buildings like a settlement, neighborhood, or city district. In such cases, synergies can be achieved among individual buildings that, on their own, may not qualify as Net Zero Energy Buildings (Net ZEBs). By collectively balancing positive and negative energy balances, these communities can attain a Net Zero status. Buildings within the community can exhibit varying seasonal performances. For instance, a building may have excess photovoltaic (PV) capacity during the summer, enabling the sharing of electricity with neighboring buildings through the grid. Similarly, a building equipped with a combined heat and power (CHP) unit that produces surplus electricity but not heat can contribute to a district heating system, sharing excess heat energy. Consideration should also be given to retrofit options within a community-scale physical boundary. Introducing a new building with an energy surplus into an existing neighborhood can be a viable approach to help the entire community achieve Net Zero status. This approach presents opportunities for collaboration and mutual benefit.

The physical balancing boundary for each building is marked at the intersection of the building and the energy supply infrastructure, including the electricity grid, heating or cooling grid, gas grid, or fuel/biomass delivery chain. This boundary incorporates delivery points or meters to account for the connection between the building and the grids. Furthermore, renewable energy generation systems fall within the physical boundary and are referred to as "on-site generation" systems, positioned within the project's distribution grid after the meter.

By establishing clear and consistent building system boundaries, it becomes possible to accurately assess and categorize various renewable energy generation systems, ensuring reliable comparisons and evaluations. (Ayoub et al., 2017).

“Typical on-site generation systems are PV, micro-CHP plants and micro wind turbines, which allow energy to be generated on-site and exported beyond the physical boundary (see Figure 2) (Ayoub et al., 2017).”

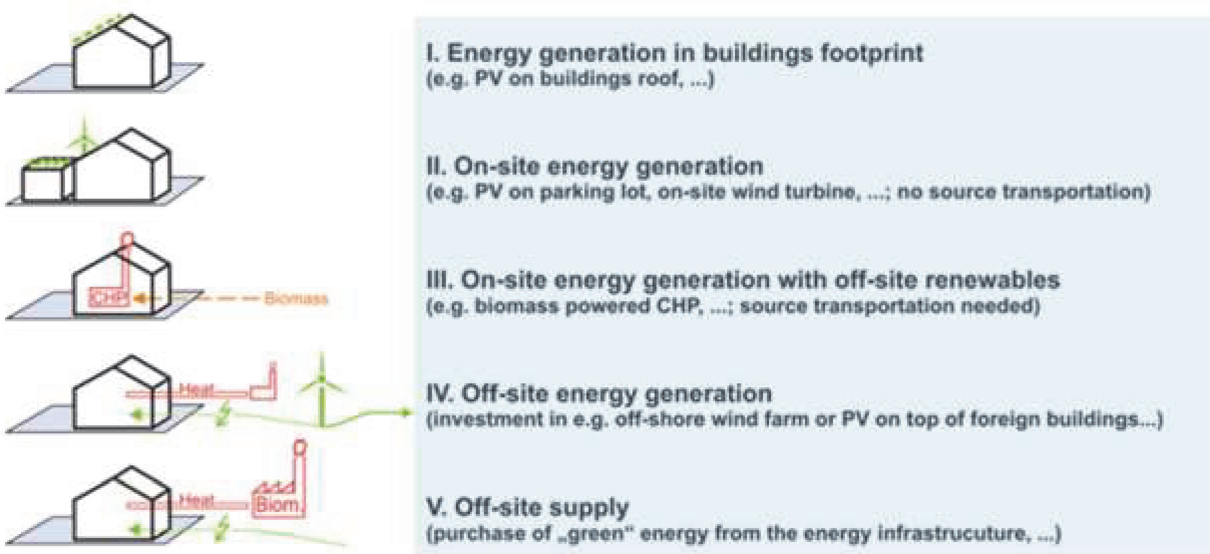


Figure 2: Overview of possible renewable supply options. (Ayoub et al., 2017).

At this juncture, it is crucial to highlight an important distinction. Solar thermal systems, due to technical limitations when connecting to district heating grids, typically consume their yield entirely on-site. Consequently, solar thermal systems are primarily regarded as demand-reduction technologies, falling along the efficiency path on the x-axis of Figure 3. Locating a construction site that is ideal for harnessing wind energy is a rare occurrence. Towns and villages are generally established in areas with less pronounced wind speeds. As a result, it is usually more resource-efficient to deploy wind turbines in nearby high-wind zones rather than on-site. Off-site generators, which cannot be directly connected to a building's energy requirements, can be easily replaced by procuring green electricity from alternative suppliers. Due to this factor and the focus of the Energy Performance of Buildings Directive (EPBD) on building design, the measurement of Net Zero Energy Building (Net ZEB) performance in Europe exclusively accounts for on-site or locally produced energy. By recognizing these distinctions, we can better understand the considerations surrounding solar thermal systems and wind energy deployment, considering technical limitations, resource efficiency, and the focus of relevant regulations. (Ayoub et al., 2017).

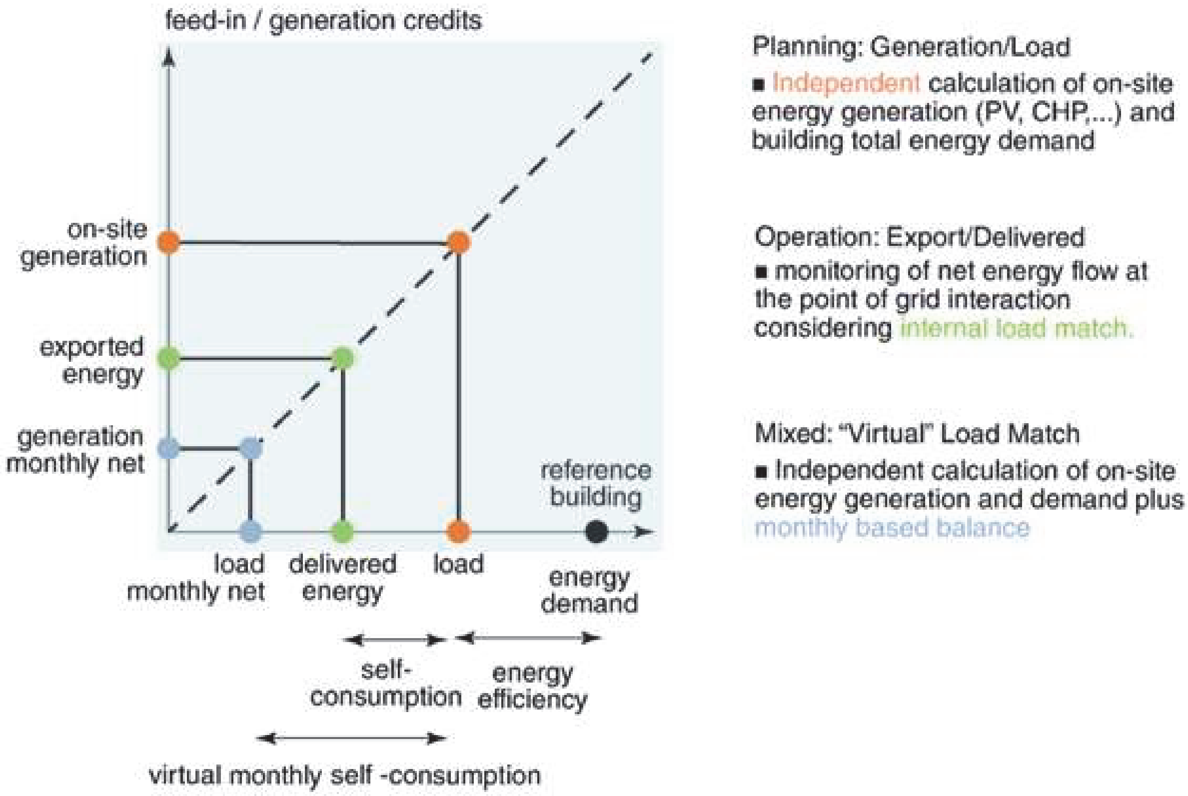


*Figure 3: Graphical representation of three types of balance: import/export balance between weighted exported and delivered energy, load/ generation balance between weighted generation and load, and monthly net balance between weighted monthly net values of generation and load. (*REHVA Journal Nearly-zero, Net Zero, and Energy Buildings – How Definitions & Regulations Affect the Solutions*, n.d.)*

2.4.2.2. Balance boundary

The determination of energy consumption considered in the calculation of the energy balance is known as the "balance border." While national building codes typically focus on technical services such as heating, cooling, ventilation, and lighting (in non-domestic buildings), alternative definitions of Net Zero Energy, often adopted by non-governmental entities, also include plug loads and central services, as they are commonly metered at the point of delivery. Some studies even incorporate electric vehicles, despite their indirect impact on a building's performance. The inclusion of electric car batteries is justified by their potential to enhance on-site electrical storage capacity. Net Zero Energy Buildings (Net ZEBs) may utilize additional materials, such as insulation, and advanced installations like photovoltaic (PV) systems, to achieve higher efficiency and energy production compared to conventional buildings. As a result, the embodied energy within a building's overall life cycle energy balance increases, while the demand for operational energy decreases. The life cycle energy balance must also account for the energy required for replacement and renovation projects throughout the building's lifespan. Studies examining the life cycle energy balance of low-energy and Net Zero Energy structures indicate that the embodied energy of a typical building represents no more than 20% of the total primary energy consumption. This percentage only slightly increases when transitioning towards virtual and Net Zero Energy structures, primarily due to the prominence of structural building components over energy-saving strategies and generation systems. These calculations are based on an assumed building lifespan of 80 years and can vary significantly depending on the construction style and factors such as the presence of an underground garage. Since building embodied energy cannot be directly measured and is not included in annual operational records, a common approach to incorporate it within the balance boundary is to divide the total building embodied energy by the building's lifetime and add the resulting value to the annual balance. In this context, embodied energy can be considered as an increase in annual energy usage of 30 kWh/m2. Beyond the environmental and sustainable benefits of expanding the definition of Net ZEBs, the inclusion of embodied energy in the equation is crucial. Embodied energy analysis emphasizes the advantages of renovating buildings to achieve Net ZEB status, as current construction credits can be reset to zero and should not be factored into the overall energy balance. (Ayoub et al., 2017).

2.4.2.3. Weighting system

Various energy sources, including solid fuels, biomass, natural gas, and electricity, need to be compared using a Net Zero Energy Buildings (Net ZEB) statistic. The energy balance metric can prioritize energy, emissions, or costs, depending on the chosen criteria. To ensure comparability, primary energy or CO2-equivalent factors are used to convert different forms of energy into a consistent metric, especially when evaluating the complete energy supply chain or utilizing multiple energy forms. This conversion considers natural energy sources, conversion processes, grid-based transmission, and distribution. The weighting variables involved in this conversion can vary due to regional and national grid conditions.

Different primary energy considerations also contribute to variations in conversion factors. For example, the total primary energy approach includes both renewable and non-renewable sources, while the first strategy focuses only on non-renewable primary energy (e.g., in Europe for EN 15603). This decision-making process may be influenced by political objectives or initiatives aimed at promoting specific markets. It is also possible for the availability of biomass and biofuels from sustainable forestry to be intentionally adjusted to align with regional limitations. Preferences for all-electric solutions, such as buildings equipped with heat pumps and photovoltaics (PV), or code requirements based on reduced primary energy components, may reflect national plans to transition towards a greener electricity sector. Asymmetric weighting factors can serve as another political tool in this context. Different primary energy conversion factors may be assigned to the energy supplied by the grid compared to energy fed into the system, to promote on-site generation. For instance, electricity exported to the grid might have a primary energy ratio of 2.8 kWh primary energy per kWh end energy, while power provided from the grid could have a primary energy factor of 2.4 kWh primary energy per kWh end energy. This approach aims to encourage consumer behavior that favors on-site generation. Moreover, weighting criteria can be adjusted over time to accommodate changes in renewable power generation availability and align with the energy requirements of the grid. For example, a lower weighting factor for solar power generation in the summer compared to winter could incentivize the development of energy-efficient buildings or increase demand coverage. These variations can be incorporated into monthly calculations. Time-dependent electricity pricing facilitated by "smart energy networks" can inform building owners about these different weighting variables, promoting awareness and facilitating informed decision-making. (Ayoub et al., 2017).

2.4.2.4. Further requirements

Buildings with energy generation on-site systems have a few options for meeting their energy needs and making use of Local area network infrastructure requirements, such as the electricity grid and, in some situations, the heating/cooling grid. There are differences in:

1) The temporal match between energy generation on-site and the building load (load match)

2) The temporal match between the energy transferred to a grid and the demands of a grid (grid interaction)

3) The temporal match between the types of energy imported and exported (fuel switching) (Ayoub et al., 2017).

Discussions about load matching and grid interaction are necessary considering the energy type and temporal resolution. Each sort of energy needs to be calculated independently. Seasonal building performance can be described and investigated using simple monthly net metering, but daily and hourly changes require high-resolution simulation or monitoring. In the context of a fuel-based energy supply, load matching and grid interaction are essentially unimportant, but they are crucial for electricity grid interaction. An intrinsically advantageous strategy for a grid-connected building is not to increase the load match. The utilization of on-site storage systems to enhance load matching can result in losses that may outweigh the value of the exported energy required to meet grid loads. In dynamic scenarios, the decision of whether to export data or store it locally depends on various factors. The concept of load match, whether high or low, does not inherently carry positive or negative connotations. However, calculating load matches based on monthly data, such as monthly net metering, can provide valuable insights into the utilization of grid services to address seasonal disparities between load and generation. To drive favorable and sustainable advancements, weighting variables that incorporate seasonal or monthly changes can be implemented within building energy code systems. These variables influence balance outcomes and facilitate strategic progress, aligning with national directives, plans, and constraints. Time-dependent electricity tariffs are commonly employed as a measure in "smart grids" to address such complexities at the financial level. As mentioned earlier, a Net Zero Energy Building can be characterized in various ways depending on specific objectives, which themselves are shaped by strategic priorities and limitations. In this essay, the term "balance" refers to the equilibrium between annual weighted energy consumption and generation, considering primary energy based on measured energy values. The consumption of heating and cooling energy, domestic hot water, lighting, air conditioning, and other end uses are all encompassed and linked to the net floor area. In the case of small villages, the boundary is established at the individual structure level, defining the physical boundary. (Ayoub et al., 2017).

2.5. Net ZEB case studies: building, climate, and measure classifications

Balancing energy consumption while considering the specific requirements of a structure is a complex process. The Net Zero Energy performance of buildings is subject to various site-specific and client-specific factors, making a comprehensive analysis challenging. The scope of this study does not encompass analyzing the buildings in the Task 40 database, considering these considerations. Instead, the proposed systematic approach aims to identify the similarities and differences among key strategic and technological solutions that contribute to the Net Zero Energy performance of buildings by database. This technique involves steps such as the classification of climate, classification of building type, and the classification of metrics used by the case study buildings, which will be discussed in the following pages.

The performance of Net Zero Energy buildings is significantly influenced by the climate and the type of structure. Climate conditions impact the availability of renewable energy resources as well as the demand for space heating and cooling. Meanwhile, the architectural characteristics of a building play a crucial role in determining the remaining energy requirements. Apart from these primary factors, other driving and limiting factors, as illustrated in Figure 4, can also influence the Net Zero Energy performance of a building. (Hoes, P, 2009)

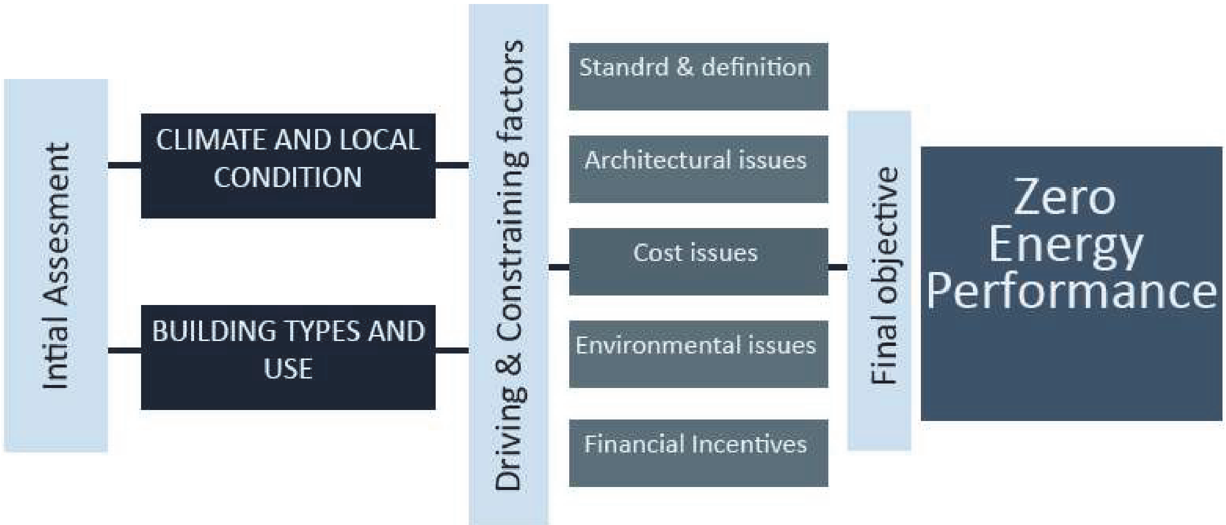


Figure 4: Net ZEB performance assessment. (Hoes, P, 2009)

2.5.1. CLIMATE ASSESSMENT

A net zero energy project's design must consider the climate. It affects a project's exterior thermal loads and serves as a free energy source. Any climate, in a variety of shapes and sizes, can access this free energy gift. A net zero energy project must, in other words, be climate responsive. It must be able to utilize all the climate's and location's free energy while passively reducing thermal burdens. Although the climate has a substantial impact on energy use, net zero energy is not always a result of the climate. The building program type and program frequently have a more significant impact on achieving this goal. In any climate, net zero energy buildings are feasible, but reaching net zero energy for all types of structures is a considerably bigger task. Definitions of Climate When he observed, "Climate is what we expect; weather is what we get," Mark Twain nailed the key difference between climate and weather. The prevailing weather patterns of a location as averaged over a long period are referred to as its climate. It is a significant contribution to the process of defining the qualities and characteristics of a place that go beyond the weather, in terms of the natural and human responses to climate, as demonstrated by the local ecosystem, city planning, and prevailing architecture (at least, vernacular architecture). Climate should be the primary determinant of the architectural form if it has such a significant role in defining an area's ecosystem and influencing the type of living there. Just as a place's personality is influenced by its climate, the place itself—or to be more precise, its geographic location—directly affects the climate. The climate is direThe climatefluenced by latitude and altitude (Hootman, 2012).

"As you move away from the equator in latitude, the solar altitude angle decreases, resulting in reduced solar radiation. When you move higher in elevation, air pressure decreases and, with it, air temperature. Geographic features, too, such as terrain, mountains, bodies of water, and in particular oceans, have a dynamic effect on climate. Globally, the interaction of atmospheric patterns and ocean currents plays a leading role in determining overall climate characteristics. (Hootman, 2012)."

The scheme is based on five primary climate classes (identified using the uppercase letters A through E), which are then subdivided into types and subtypes (using lowercase letters). The highland classification is also at times used as a type of E climate, designated as EH. The five primary classes are (Hootman, 2012):

A: Tropical

B: Arid

C: Temperate

D: Cold

E: Polar

Climate Classification A: Tropical

"Climate Characteristics Tropical climates are characterized by year-long hot and moist weather with significant rainfall and humidity. Tropical climates are located along the equator and experience limited to no seasonal variation (except seasonal precipitation levels, in some cases). Example Location: Miami, Florida, USA (Tropical-Monsoon; see Figure 5)

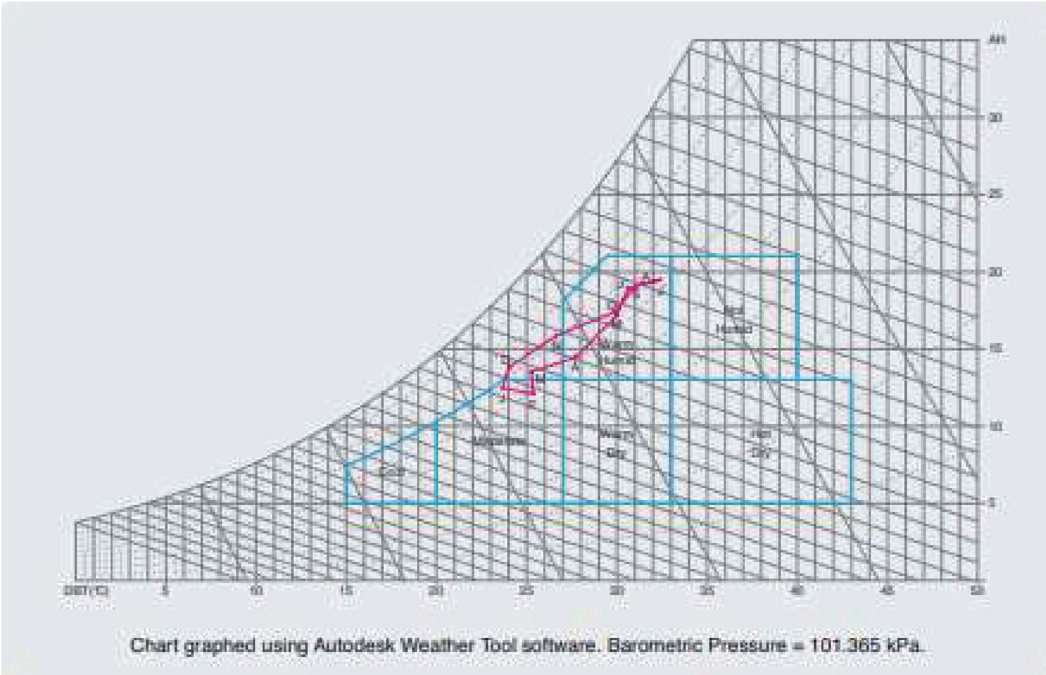


Figure 5: Psychrometric climate classification A, (Hootman, 2012).

Passive Design Responses

■ The primary concern is to reduce the cooling load with passive strategies, such as minimizing solar radiation through 100 percent solar shading Reduction of thermal conductivity through covering, and reduction of internal heat through reduction of lighting and equipment load. The locations are near the equator, so the high solar elevation makes roof shading a potentially good strategy.

■ Due to the abundance of water and year-long growing season, vegetated shading elements outside of or integrated within the building envelope can be an effective means of providing shading.

■ Light colors for exterior surfaces reflect rather than absorb solar radiation. This can be very beneficial for roofs, due to the high solar altitude all year long.

■ Natural ventilation can be useful in some tropical climates and at certain periods of the day or year, depending on the mechanical system selection.

■ Daylighting lowers lighting energy use and internal heat gain. Daylighting should be carefully coordinated with shading strategies.

■ Passive desiccant dehumidification can be used to control interior humidity levels and allow air to be cooled with nonconventional and refrigerant-free cooling, such as evaporative cooling.

Passive solar or waste heat desiccant drying or recharging should be considered (Hootman, 2012).”

Climate Classification B: Arid

“Climate Characteristics Arid climates are characterized by lack of precipitation. Arid and semiarid climates can be cold or hot. Example Location: Cairo, Egypt (Arid-Desert, Hot; see Figure 6)

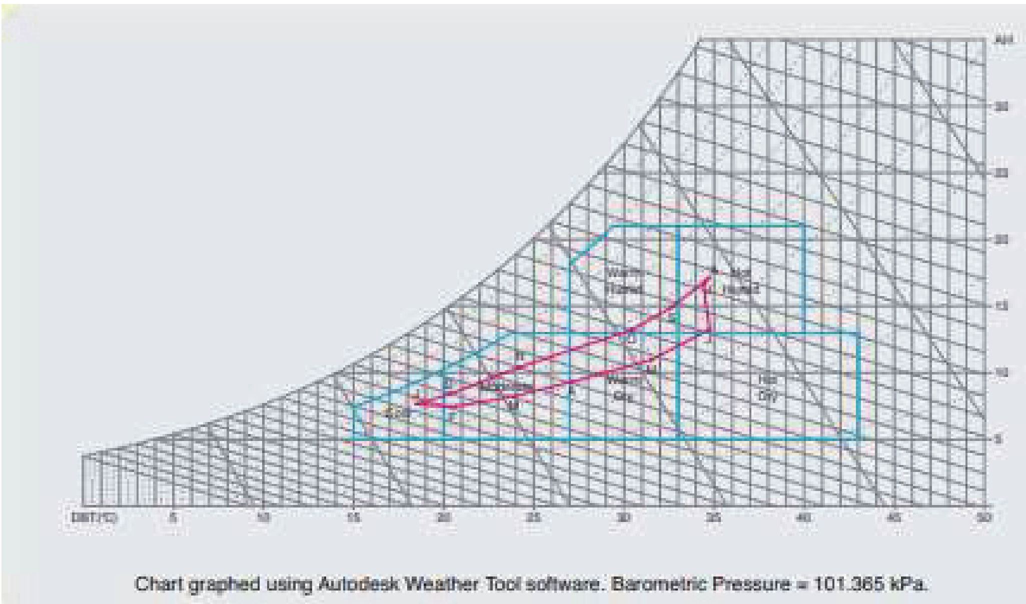


Figure 6: Psychrometric climate classification B, (Hootman, 2012).

Passive Design Responses

■ Hot arid climates will be cooling-dominated, whereas cold arid climates will be heating-dominated.

■ Wide diurnal swings allow for the effective use of thermal mass with night flushing.

■ Thermal mass without night flushing can also be effective for moderate cooling.

■ Provide solar shading during the cooling season.

■ Provide natural ventilation during the cooling season.

■ The generally low levels of humidity allow for nonconventional cooling, such as evaporative cooling.

■ Passive solar during heating season: Be careful not to overheat with solar gain during heating periods.

■ Daylighting lowers lighting energy use and internal heat gain.

■ Reduce heat transfer through conduction with a well-insulated building envelope (Hootman, 2012)."

Climate Classification C: Temperate

"Climate Characteristics Temperate climates are characterized by mild to very mild temperatures (compared to other classifications), including warm summers and cool winters. They can exhibit a considerable range of precipitation and humidity. Many locations in temperate climates are influenced by the climate-tempering impacts of the ocean. Example Location: San Francisco, California, USA (Temperate-Dry and Warm Summer; see Figure 7.

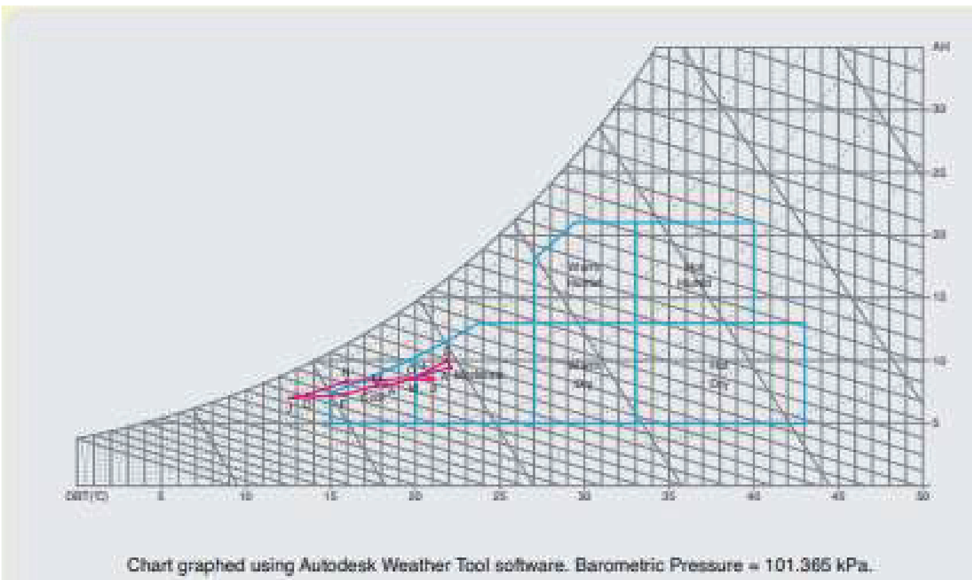


Figure 7: Psychrometric climate classification C, (Hootman, 2012).

Passive Design Responses

■ Temperate climates vary considerably. Although they do not have extreme hot or cold periods, they typically have both heating and cooling seasons. Humidity levels vary and can be high in climates with hot summers.

■ Wide diurnal swings allow for the effective use of thermal mass with night flushing.

■ Thermal mass without night flushing can also be effective for moderate cooling.

■ Provide solar shading during the cooling season.

■ Provide natural ventilation during the cooling season.

■ Passive solar during heating season: Be careful not to overheat with solar gain during heating periods.

■ Daylighting lowers lighting energy use and internal heat gain.

■ Reduce heat transfer through conduction with a well-insulated building envelope (Hootman, 2012)."

Climate Classification D: Cold

"Climate Characteristics Cold climates exhibit a wide range of seasonal temperatures but are characterized by cold winters with snow. Locations in cold climates are often interior to continental landmasses. Example Location: Anchorage, Alaska, USA (Cold-Cold Summer Without Dry Season; see Figure 8)

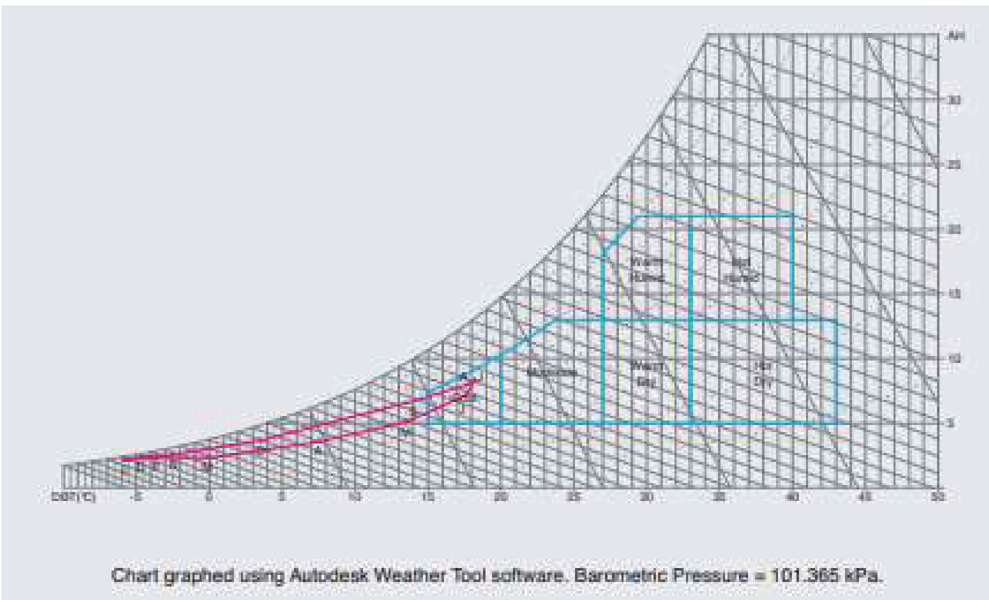


Figure 8: Psychrometric climate classification D (Hootman, 2012).

Passive Design Responses

■ Cold climates with cold summers are very heating dominant.

■ Humidity levels vary but can be high in climates with hot summers.

■ Reduce heat transfer through conduction with a well-insulated building envelope.

■ Wide diurnal swings allow for the effective use of thermal mass with night flushing

for cooling during warm or hot summers.

■ Provide solar shading during the cooling season if summers are hot.

■ Provide natural ventilation during the cooling season.

■ Passive solar during heating season: Thermal mass can be used to store passive

heat gain. Be careful not to overheat with solar gain.

■ Daylighting lowers lighting energy use and internal heat gain. Northern locations have

drastically reduced daylit hours, annually (Hootman, 2012)."

Climate Classification E: Polar

"Climate Characteristics Polar climates are characterized by extremely cold temperatures, often with no summer season, and are typically treeless. Example Location: Arctic (Nanisivik Airport) (Polar-Tundra; see Figure 9)

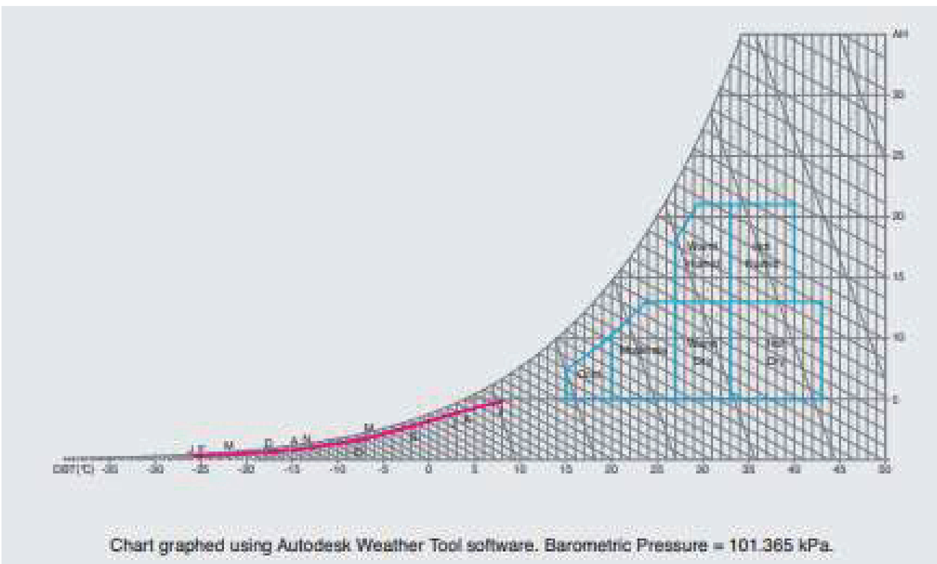


Figure 9: Psychrometric climate classification E (Hootman, 2012).

Weather Tools and Data Links

■ Climate Consultant: www.energy-design-tools.aud.ucla.edu

■ Autodesk Ecotec Weather Tool: http://usa.autodesk.com

■ METEONORM: www.meteonorm.com

■ Energy Plus Weather Files: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm (Hootman, 2012)."

2.5.2. Net ZEB measure classification

Drawing upon two fundamental aspects, namely the correlation between building energy efficiency and climate/building type, as well as the relationship between various building requirements and these aspects, this analysis presents the classification and analysis of the case study buildings. It is essential to consider the building requirements, which include domestic hot water (DHW), lighting, and heating. The classification of the case study buildings is determined by the distribution of measures implemented to achieve these objectives, encompassing energy efficiency and energy supply choices. The case study buildings are grouped into three categories of Net Zero Energy Measures: Passive (PA), Energy Efficiency (EE), and Renewable Energy Systems (RE). These categories are depicted as concentric rings in Figure 10. The innermost circle of Figure 10 represents the first principle of the Net Zero Energy Building (Net ZEB) design, which focuses on reducing energy demand through passive methods. The middle circle represents the second principle, which involves implementing energy-efficient strategies that consider the specific requirements for artificial lighting, heating, and cooling. The outermost circle in the diagram symbolizes the utilization of renewable energy systems to meet the energy demands for lighting, heating, and cooling. Figure 10 also provides examples of measures from each category that address the three building requirement groups. In Figure 10, three building requirements are displayed: heating, cooling, and electricity. For presentation, the third requirement is combined. However, in all other building regulations, electricity, lighting, and plug loads are treated and presented as separate building needs, except for this specific diagram. (Thollander, Palm, Rohdin,.2010)

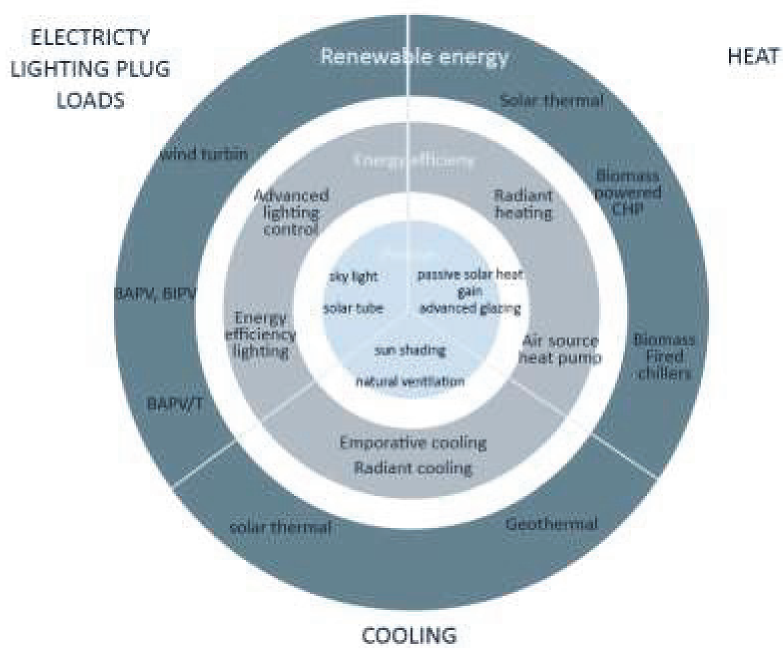


Figure 10: Net ZEB Design: outward progression and measure example (Thollander, Palm, Rohdin,.2010)

2.5.3. Net-zero energy strategies and measures

This section presents an overview of the policies implemented by the buildings in Task 40/Annex 52 database. The description is organized within a framework that begins with outlining the construction requirements, followed by an exploration of the general methods and actions employed to meet these requirements (as depicted in Figure 11).

Subsequent sections in this chapter are structured according to the Categories Measure outlined in the left-most column of Figure 11. These sections delve into the methods and actions utilized to fulfill construction standards, focusing on measures related to Passive techniques, and Renewable Energy, Energy Efficiency. (Yan & Yang, 2021b)

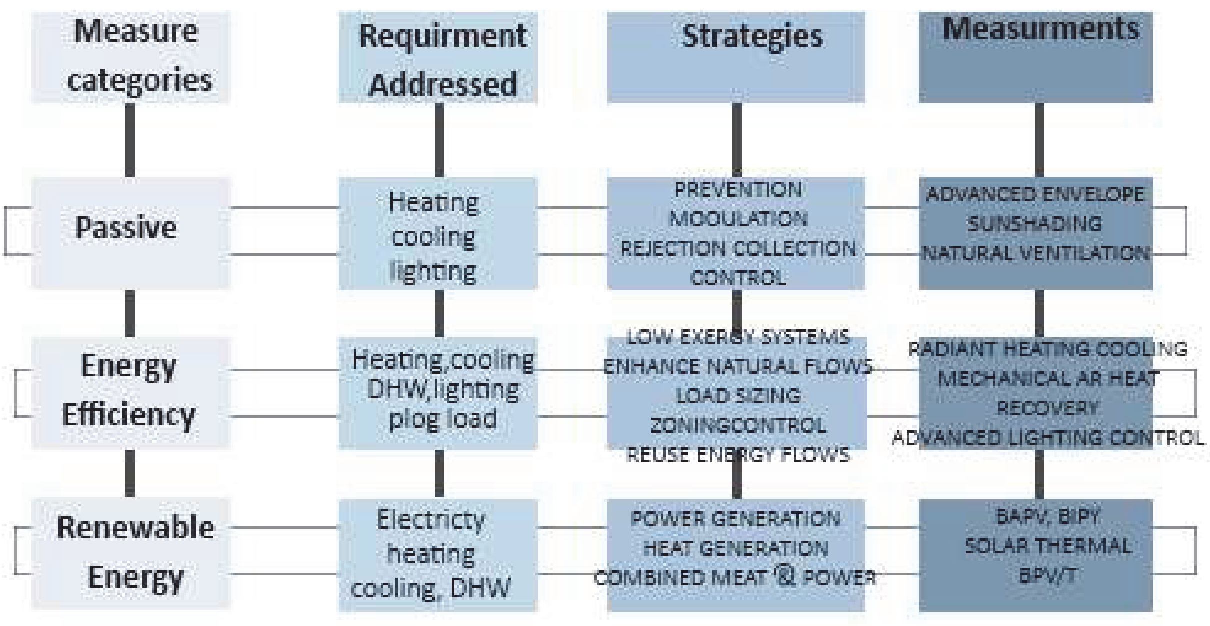


Figure 11: Building Requirements, Strategies, and Measure Examples shown for the Measure Categories (Yan & Yang, 2021b).

Chapter 3

3. Integrating modeling tools in the Net ZEB design process

In the absence of specific energy or environmental goals, the design process for conventional buildings tends to follow a linear approach. The architect focuses on aspects like building siting, orientation, form, and envelope, while the structural and electrical engineers handle their respective systems. The mechanical engineer selects and sizes the HVAC system, and the building owner determines their priorities and requirements. However, this design process often overlooks the efficiency of the structure in terms of energy use, leading to suboptimal decisions regarding form and orientation. When aiming to construct a Net Zero Energy Building (Net ZEB), energy usage, environmental impact, and comfort become crucial considerations. Early design decisions that directly impact building energy consumption and the potential for renewable energy technology integration must be carefully evaluated. Therefore, it is important to involve stakeholders early in the design process and gather input on the economic, environmental, comfort, and energy usage aspects of the building. Building performance simulation technologies can be employed to provide valuable feedback during this stage, aiding in informed decision-making. (Atheneites et al., 2010); also, stakeholders1 with various areas of knowledge can be included early in the design process to aid in decision-making. An integrated design process is what is used in this approach. (IDP) (AIA, 2008; Lehnert, Dalkowski, and Sutter, 2003) or integrative process (ANSI, 2012).

In contrast to the conventional approach of working in isolation, collaboration among all team members is essential at every stage of the design process to achieve the project's overarching objectives. This section provides a comprehensive overview of the numerous steps involved in designing a Net ZEB (Net Zero Energy Building). It explores the tools available to support designers in their work and discusses the design decisions that are commonly encountered throughout these stages. Additionally, the section delves into project delivery techniques and their influence on successfully attaining the net-zero energy goal, culminating towards the end.

3.1. Overview of phases in Net ZEB realization

In contrast to the conventional approach of working in isolation, effective collaboration among all team members is crucial at every stage of the design process to successfully meet the overall project objectives. This section provides a comprehensive overview of the numerous steps that can be undertaken to design a Net ZEB (Net Zero Energy Building). It also explores the various tools available to assist designers in their work and discusses design decisions that are commonly encountered throughout these stages. Towards the end, a thorough review of project delivery techniques is conducted, analyzing their impact on the achieving of the net-zero energy goal.

1. Preparation, or programming

2. Concept design, or schematic design
3. Design development
4. Technical design, or construction documentation
5. Construction
6. Commissioning, operation, and monitoring.

To achieve optimal design outcomes, the allocation of resources by the design team needs to be strategically planned, allowing for potential overlaps, shortenings, or extensions of project phases in alternative project delivery methods like construction management at risk and design-build. During the planning stage, the building owner plays a crucial role by providing essential elements such as the construction budget, site information, functional specifications, occupancy level, and desired economic, energy, and environmental outcomes. Incorporating specific energy-saving strategies right from the conceptual design phase is essential to ensure thermal and visual comfort while considering the environmental impact. These strategies encompass load control, daylighting, natural ventilation, a high-performance envelope building, and passive solar architecture.

Enhancing the feasibility of achieving a net-zero energy goal is greatly influenced by considering the integration of specific elements and their control mechanisms during the early design stage. Decisions made at this crucial point carry significant implications. For instance, the window opening-to-wall ratio plays a vital role in natural ventilation, lighting opportunities, cooling load, and the size and cost of cooling equipment and renewable energy technologies (RETs). During the concept design stage, the building designer provides a broad overview of the building, although the exact composition of opaque and glazing elements may not be finalized. Overall heat transfer coefficients (U-values) are used for envelope components. HVAC control strategies and system concepts are established, albeit with some details and components yet to be determined.

The design development phase, as the third step, focuses on integrating efficient HVAC systems and optimizing RETs for heating, cooling, and power. In the fourth stage, building details are finalized, and construction commences in the fifth stage. Throughout the commissioning, operation, and monitoring phase, continuous assessment of the building's operation and performance ensures the attainment of economic, energy, and environmental goals, as well as occupant comfort. This section primarily emphasizes the concept design, design development, and technical design stages of building design. Table 2 provides an overview of the overall process, illustrating the progression of building design through each step. It is important to acknowledge that the building design process involves multiple iterations within each stage, even though the chart depicts a linear and well-defined sequence. Similarly, while the systems may appear independent, they are interconnected and must be treated as such. Tasks can overlap or transition between stages, and the stage names themselves may vary depending on regional variances or specific project requirements, such as delivery method or contractual obligations. Approaching the design of a net-zero energy building (Net ZEB) can be done in various ways, as elaborated below. (AIA, 2008).

Column1	CONCEPT DESIGN	DESIGN DEVELOPMENT	TECHNICAL DESIGN
DAYLIGHT	window-to-wadll ratio Window visible transmittance Dasiichit Factor Day lucht autonomy Useful daylight illuminance	Window location and detailed composition Electric lighting design to complemete daylighting Daylight factor Daylight autonomy Useful day light illuminance	Detailed eviduation of daylighting level with intenor finishing details and shading devices
PASSIVE SOLAR	Window-to-wall ratio and glazing properties Type of solar sheding devices and their controls Thermal mass level	Shading devices location, size and control strategies Thermal miss composition type and location	Window specifications Interior finishing details Cecilint. Noor, HVAC tenminals and stivatics)
NATURAL VENTILATION	Opening dimensions, positions, and controls for cach zone	Opening dimensions and position for each zone coordinated wath control strategies and thermal ness (passive design)	Thermal mass accessitilit
BUILDING ENVELOPE	U-values for opaque and glazing elensents	Building cavclope detailed composition	
ELECTRIC LIGHTING AND PLUG LOADS	typical power densists	Plug loads and clectrie lighting requirements Equipment type and concrol (dimming) strategies Asociated internal gains	Integration with day lighting design and possible shading controls Occupant comfort studies
HVAC	System concept for heating and cooling generation and distribution	System sizing in accordance with boiling envelope. plug loads and coupling with RET Control strategies	Optimal HVAC control HVAC network dimensionine
RET	System concept for RET and building integration	RET sizing in accontinee with HVAC system und economical and environmental concerns	RET dimenscoing Optimal RET control

Table 2: design stage flow of information, (AIA, 2008).

3.2. Concept design

When designing a Net ZEB, the goal is to first reduce the building's energy consumption. In the conceptual design phase, the goal is to approach this goal by prioritizing the following construction aspects:

1. Daylight

2. Solar protection

3. Building thermal inertia (thermal mass)

4. Natural ventilation

5. Building envelope insulation

6. Building-integrated solar energy technologies.

These factors play a crucial role as they are difficult to modify once the design is finalized and help shape key aspects of the architectural concept, such as building form, surface orientation, and fenestration. To achieve the goal of net-zero energy, careful consideration of these factors during the early design phase is essential, considering the building's functionality. These elements interact with each other and are vital for a building to be prepared for solar energy collection. For example, compact buildings with a low volume-to-envelope area ratio minimize thermal energy losses but may have limited opportunities for natural lighting and ventilation. The concept design phase should be an iterative process to achieve the most logical design that fulfills the for mentioned criteria for net-zero energy. Neglecting certain details early on, such as a very low window-to-wall ratio, can result in higher energy costs for lighting and cooling, as well as increased design and redesign expenses later in the design process.

Internal gains from plug loads and electric lighting significantly influence the energy required for room heating and cooling. Depending on the building type, typical power densities for lighting and electrical equipment should be incorporated into the model during the concept design phase.

Building-integrated solar energy technologies should be included in the early-stage design of a Net ZEB. These solar energy systems have a profound impact on various aspects of the building, including its form, program, envelope composition, and structural considerations, in addition to the overall net energy balance. For instance, the desired size of photovoltaic modules heavily influenced the roof design of the ÉcoTerra house.

Even if specific HVAC work may not have been done yet, the design phase must allow for the integration of HVAC systems in the future. There's a chance that the planning phase included a discussion of the core HVAC concepts.

It's critical to consider operational strategies and a few comfort levels currently. If radiant floor heating is to be used, the thermal mass incorporated into the floor should be considered for passive gain storage as well as extra heat generation. Additionally, a proper control method should be developed. Operating plans must consider the building's anticipated occupancy profile. For example, using cool outdoor air for night cooling is preferable in commercial buildings where occupants are more likely to leave than in homes where it could be uncomfortable. The zone temperature setpoints and their allowable variability must be determined as a result.

3.2.1. Daylight

In the context of energy-efficient buildings, it is essential to address the balance between insulation and natural lighting. While a well-insulated building is beneficial for energy conservation, office buildings can still consume significant amounts of energy if the architectural design limits the entry of natural light. The potential for natural lighting is often influenced by the building's geometry rather than technical considerations. Long, narrow buildings tend to have greater opportunities for natural lighting compared to compact and deep structures.

To mitigate the limitations of natural light in a compact building, architects can incorporate design elements such as an atrium. An atrium serves as a central feature that allows natural light to penetrate the building. Figure 12 illustrates a commercial building with an atrium positioned in the center. The rooms surrounding the atrium do not have windows or exterior walls. By incorporating an atrium, the reliance on electric illumination in these areas can be reduced. During the concept design phase, architects must prioritize sufficient natural lighting within the building. They should assess the overall building design or specific zones using simulation tools or general guidelines. These techniques enable the calculation of daylight levels or determine the necessary amount of glazing area required to achieve a specific daylight factor. The daylight factor represents the ratio of internal light level to external light level and helps inform the design decisions related to natural lighting. Precision geometry information for the zone, visible glazing transmittance, and interior surface reflectance are often needed for detailed modeling approaches for daylight. Additional information on permanent shading apparatus is required. It is necessary to make assumptions about these optical features to determine the daylighting potential because internal surfaces' optical attributes are typically unknown at the concept design stage.

The usual light reflection rates for floors, walls, and ceilings are 10–30%, 40–60%, and 70–80%, respectively. If fixed shading devices are used to include them in daylight evaluation, it is desirable to have simple dimensioning for the overhangs and fins. (Johnsen and Watkins, 2010).

Figure 12: Atrium providing natural lighting to internal zones (Polytechnic Di Torino - Sede Lingotto, n.d.)

3.2.2. Solar protection

A building should efficiently manage solar gains to reach the net-zero energy target. Solar gains can cause overheating, but it can be prevented by load control employing thermal mass and solar shading devices.

Well-designed solar shading mechanisms in non-tropical areas should shield the space from the sun in the summer and shoulder seasons while allowing solar radiation transfer to space during the winter. Additionally, they should ensure that the area receives a significant amount of daylight while reducing glare. When weather and financial circumstances permit, solar shading devices are preferable to be external because solar radiation is reflected before being transmitted by the glazing. By varying the height of the blinds or the angle at which the slats are tilted, moveable shading devices strive to both limit solar gains and let in a sufficient amount of light. However, because they need to be controlled (either manually or automatically), moveable shade devices may be rendered ineffective if they react slowly to changes in the position of the sun. To create a feedback loop, one alternative is to have the shade devices automatically controlled and integrated with electric lighting, heating, and cooling control systems. The integration of control techniques into the initial design phase requires special consideration.

Fixed shading structures, such as overhangs, wing walls, or fins, present a design challenge since they must effectively regulate both solar gains and daylight. Due to the low sun altitude angles on the east and west façades, designing solar shading devices is particularly challenging. Additionally, the difference between solar altitude and annual temperature fluctuations can lead to overheating when temperatures are mild, but the sun can penetrate deeply during shoulder seasons. Fixed shade systems have the advantage of being able to reduce solar gains or daylight glare without the requirement for occupant controls. Sun path diagrams for the location of the building or well-known formulas that enable dimensioning of the overhang depth and fin width as a function of the starting day when solar protection becomes necessary can be used for the design of fixed solar protection. Since solar shading devices can affect how much daylight can enter the structure, the management and sizing of electric lighting should be done concurrently with the size of fixed sun protection equipment. (Atheneites & O'Brien, 2015f)

3.2.3 Building thermal inertia.

Thermal mass reduces indoor temperature variations, which has an impact on a building's dynamic thermal behavior. By storing or releasing heat, thermal mass components delay and alter how interior air temperature responds to load change. For example, the thermal mass of the structure can, to a certain extent, absorb internal loads and solar gains during the summer, delaying the need for cooling until later, unoccupied hours of the day when there is less demand. In addition to actively charged mass (such as vented concrete slabs (VCS)), floor heating, and phase change materials, the building may have a range of thermal mass components, including heavy floors, ceilings, and façades. (PCMs).

Thermal mass is a critical design element that must be considered at least briefly during the early stages of the design process, depending on the predicted internal stresses. A well-designed building should ideally store the solar and internal benefits during the day and release them at night. One way to choose the right thickness of thermal mass for moderate climates in summer conditions is to make sure that the thermal mass temperature rises by no more than 5 °C during the day. This is assuming that the thermal mass is replenished during a night shift and operation between 21 and 26 °C is allowed. The admittance approach covered in Chapter 2 can be used to determine the mass thickness early in the design process. Because the structure must be able to sustain the thermal mass safely, the amount of mass has a significant impact on the structural design.

The design of exposed thermal mass in sophisticated modeling tools necessitates connectivity of the thermal and airflow networks. Due to the dearth of relevant inputs (such as the optical characteristics and thermal capacitance of building materials and furnishings, as well as the precise location of windows), this type of simulation is not feasible in the early design phase. Building designers should therefore consider the possibility of including thermal mass in their concept designs (such as exposed concrete, phase-change materials, or other materials). Figure 13 shows an illustration of thermal mass integration in a commercial structure with exposed concrete slabs and columns. When using thermal mass, structural factors need to be considered.

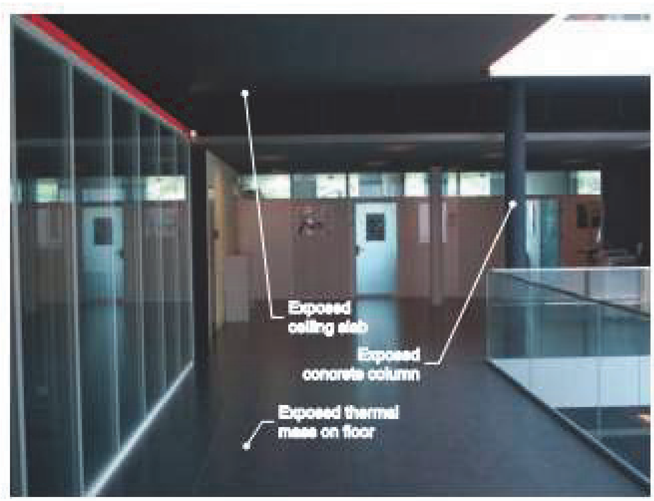


Figure 13: Example of thermal mass integration in a commercial building (BC-EPFL Lausanne Switzerland, Architect: R. Luscher Lausanne, Energy Concept: Sarane S.A, Ecublens)

3.2.4 Natural and hybrid ventilation

When the environment permits it, natural ventilation is an essential part of the design of low- or net-energy buildings because it provides free air exchange and free cooling, reducing the need for mechanical ventilation and air conditioning. It provides consumers with a way to change their environment and is one of the main components of adaptive comfort models. The comfort temperature range of the occupants in these models is predicated on the surrounding environment. The ability of a structure to employ natural ventilation is determined by several elements. Operable windows provide a degree of personal control that can boost both real and perceived control, both of which are essential for occupant contentment in general. However, when the outer climate has a suitable wind pattern and a temperature range of at least 16 to 28 °C from day to night, natural ventilation can be utilized in many applications. Openings in the building envelope and the creation of a building geometry that promotes air circulation by better utilizing the stack effect and wind pressure are two methods for enhancing natural ventilation. Low evening temperatures could potentially serve as a pre-cooling source for the structure the following day. Evenings are cooler. A natural ventilation system operating at night can have a greater cooling effect and reduce the need for cooling during the day in buildings with a lot of thermal mass. High heat inertia and adequate solar protection are required for natural ventilation to be successful. If not, natural ventilation could not be sufficient to reduce the requirement for active cooling by eradicating internal and solar gains. The shoulder months (April, May, September, and October), which make up 30 to 40% of the year in Montreal, Canada, are the optimum times for natural ventilation because the city's summers are typically humid. COMIS and Allard and Santamouris (1998) offer more information on natural ventilation design suggestions. (LBNL, 1999). Utilizing fans to aid natural ventilation is also a part of hybrid ventilation. Look at a study by Karava et al. It serves as an example of the benefits of including very thermally efficient motorized sunshade devices in an atrium setting with hybrid ventilation.

Figure 14 exemplifies the potential achievement of natural ventilation in a commercial building featuring an atrium. The atrium and most office spaces within the building are naturally ventilated through operable openings present on the office façades, at the top and bottom of the atrium, and in other locations. These openings are equipped with rain protection barriers, enabling ventilation even during rainy periods. While mechanical ventilation is necessary in certain laboratories for health reasons, the design of this building demonstrates that other areas can still benefit from natural ventilation. Assessing the effectiveness of natural ventilation, like evaluating thermal inertia, relies on the integration of thermal and airflow networks. Cutting-edge building simulation tools such as TRNSYS, TRNFLOW (University of Wisconsin, 2012), and Energy Plus (DOE, 2012) facilitate this linkage. However, creating a comprehensive model during the initial concept design stage is challenging due to the substantial effort and numerous assumptions required, including exterior and interior details, fenestration, shading devices, and more. Consequently, for early-stage natural ventilation modeling, simpler systems like COMIS are more suitable. These basic tools can assess air exchange rates and the effectiveness of natural ventilation with minimal inputs such as wind pressure coefficients, opening heights, and discharge coefficients (considering both contraction and friction losses). By utilizing this approach, a reasonable estimate of the necessary opening area can be obtained, although temperature assumptions within the zone are necessary. The design development stage will be completed following the enhancement of this construction function.

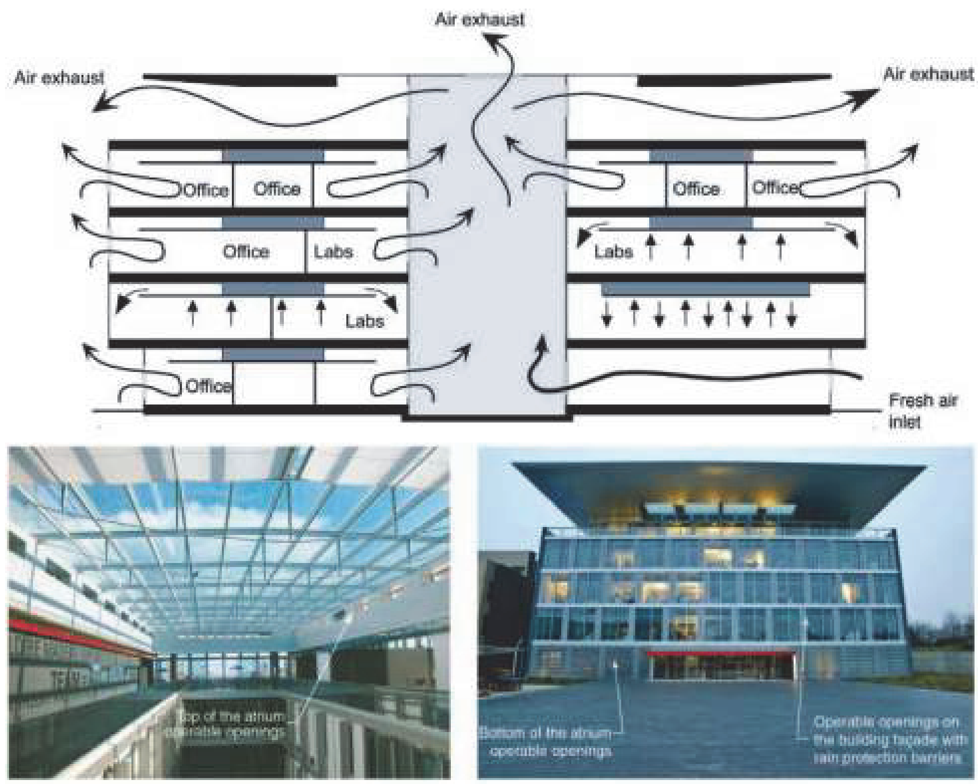


Figure 14: Natural ventilation in an atrium (BC-EPFL Lausanne Switzerland, Architect: R. Luscher Lausanne, Energy Concept: Sarane S.A, Ecublens)

3.2.5 Building envelope thermal resistance

The energy usage associated with heating and cooling rooms is influenced by various factors such as the building's geometry (orientation, aspect ratio) and the thermal resistance of its envelope. During the initial concept design phase, the building's overall shape is known, but the specific composition of the walls is yet to be determined. Therefore, it becomes challenging to accurately predict the characteristics of the walls and windows since the final building envelope composition relies on energy calculations and functional considerations.

When the details of the building envelope components are unknown, estimating the overall heat transfer coefficient (U-value) only requires information about the insulation's thickness and type. Adhering to the pre-determined insulation level should ensure that the subsequent specification of the wall composition, which occurs later in the design process, has minimal impact on the U-value. The anticipated heat transfer coefficients for walls, roofs, floors, and windows can be used, along with meteorological data and other inputs, to calculate the energy consumption of the structure for a given shape. Subsequently, adjustments can be made to the shape and aspect ratio based on the desired energy usage.

With a few key figures as inputs, such as the U-value of walls, floors, and roofs, as well as the U-value and solar heat gain coefficient (SHGC) of glazing elements, simple techniques can be employed to assess a building's energy consumption for heating. The specifications for the U-values, SHGC, and insulation of windows and opaque surfaces are then determined. However, it is important to note that these specifications alone do not guarantee the proper functioning of the construction; they serve as performance metrics that are useful but not sufficient to achieve a net-zero objective. The additional factors described earlier in the design phase must be considered to complement and enhance the overall design.

3.2.6 Solar energy technologies integration

The integration of solar energy technologies plays a crucial role in achieving Net Zero Energy Building (Net ZEB) designs. Therefore, it is essential to assess the availability of solar energy resources as early as possible during the concept design phase. Conducting preliminary studies on solar energy availability and the expected energy production from solar technologies can offer valuable insights guiding decisions regarding technology selection, building form, envelope design, and architectural concepts. Additionally, these studies provide crucial information on the potential energy contribution from solar sources, helping designers establish the target energy consumption level for a specific building. During this stage, simple tools such as RET Screen and rules-of-thumb can be employed to facilitate the assessment.

3.3. Design development

The improvement of RET solutions and architectural concepts, as well as the design of HVAC systems, are the two main objectives of the design development of a Net ZEB. As a result, during the design development phase, the concepts for HVAC systems as well as daylighting, solar protection, load management, building thermal mass, natural ventilation, envelope thermal performance, and RETs are further developed. The following elements are taken into account:

1. **Envelope and thermal mass**
2. **Daylight**
3. **Plug loads and electric lighting.**
4. **RETs and HVAC.**

The design development phase is an iterative process, just like concept design. This implies that each component of the structure is considered separately and then revisited as the solutions are improved. Additionally, just like with all previous design phases, there should be back-and-forth communication between the engineers and architects. To allow for the most efficient design, the engineer typically develops recommendations for the architect, who may then include these ideas in the design. The building will go through this iterative process until it is optimized. The engineer will next suggest HVAC solutions fit the calculated load using thirty calculations, taking into consideration RETs. The design of the RETs and HVAC systems should be completely integrated into an ineffective ZEB.

3.4.Net ZEB design tools, model resolution, and design methods

Introduction

Building Performance Simulation (BPS) has been available since the 1960s as a method to predict the performance of a structure before construction. However, when aiming for ambitious performance targets like net-zero energy, the demands on the usability and accuracy of BPS tools increase significantly. Presently, BPS tools are primarily utilized for equipment sizing and assessing how a proposed building performs in comparison to a reference scenario, such as ASHRAE Standard 90.1. Conversely, a key objective of this chapter is to provide more precise performance data and emphasize the importance of BPS in the entire design process, from conceptualization to detailed design (ASHRAE, 2010a).

According to widely recognized Net Zero Energy Building (Net ZEB) guidelines (Marszal et al., 2011), a comprehensive modeling approach should predict both the annual energy demand and on-site energy generation. To address grid interaction variables, there are additional requirements: (a) the model must incorporate a high temporal resolution of electrical power consumption and supply to and from the grid, and (b) information on occupant comfort should be considered to ensure that achieving energy targets does not compromise comfort levels. Therefore, the following three fundamental characteristics must be met by Net ZEB modeling tools:

1. The BPS tools used in the design process should be able to integrate the model system. An unintegrated model (for instance, evaluating a house and its solar thermal system separately) could result in low modeling accuracy depending on the planned construction systems. All building systems interact to some extent, and this interaction should be taken into consideration.
2. By utilizing precise inputs and accounting for the uncertainty associated with weather, tenant behavior, and construction quality, one should be able to estimate the absolute performance of the structure and all its subsystems. This represents a substantial departure from the majority of modeling approaches and building energy regulations, which place a focus on typical building conditions (such as occupancy patterns) and accept relative anticipated performance.
3. For Net ZEB design, BPS tools need specific outputs. This entails flexibility regarding output reporting frequency (for example, sub-hourly) and output detail (for example, zonal air and surface temperatures).

Given these limitations, there is an increasing demand for simpler, lower-resolution tools, particularly when aiming to create affordable Net Zero Energy Buildings (Net ZEBs) that incorporate integrated design principles from the outset. Simplified procedures are essential to efficiently explore a wide range of design variations during the early stages when the building's design is still flexible and more amenable to changes. This section addresses the selection of an appropriate model resolution, simulation-supported design methods, and various applications of

Building Performance Simulation (BPS) in Net ZEB design, and provides recommendations for future BPS tools.

3.4.1. Model resolution

Designers of Net ZEBS (and other sophisticated structures) should make an effort to select the proper level of model resolution. The likelihood that quantitative analysis—specifically, the use of BPS—will have an impact on the design as it progresses quickly decreases. Changing a design now costs more money because decisions have already been made and documented in architectural drawings and specifications. The challenge of adopting BPS in early design lies not just in the accuracy and usability of the tools themselves, but also in BPS itself.

Since the design timetable is often very short in the early planning stages, it is impractical to establish a fully detailed model for conventional building design procedures. It can take weeks or months longer than the architects expect to include all consultant input before creating a single comprehensive BPS model. Therefore, without providing designers a chance to provide feedback, using a detailed BPS model would at best confirm preliminary performance predictions. Therefore, it is vital to use simple tools that enable quick model development so that results can influence design and that also enable quick result interpretation. The simplest of these tools ought to produce results rapidly enough to be used in design charrettes or right before them. 2) These devices are intended to answer order of magnitude-type questions, such as:

- “What passive strategies are best for this particular climate?”
- “How much solar energy can be collected and stored on the building site?”
- “Approximately how much can space heating energy be reduced by upgrading windows or walls?”

Although the answers to these questions don't give an exact sense of performance (or at least they shouldn't be taken at face value), they do give information on how effectively different design strategies and technological advancements approach net-zero energy (O'Brien & Athienitis, 2015).

The following elements also lend encouragement to the early use of simplified tools: Simple models can nonetheless yield significant accuracy due to (a) the declining returns on model accuracy with increasing model resolution and (b) the simplicity of simple tools, which increases confidence via knowledge. However, the mathematical models that underlie the BPS tools ought to be very explicit so that users are aware of their assumptions and limitations. Designers may prefer complicated tools to simpler ones because they think detailed models are risk-free as all construction-related elements are ostensibly depicted in an integrated way. Evidence suggests, however, that using sophisticated tools beyond a certain point may lead to a decline in model accuracy. This is partially because larger models require many more inputs, such as architectural details, which novices may find difficult to understand or enter incorrectly. Furthermore, it could be more difficult to uncover flaws in complex models, and they might even go undetected.

The following are recommended easy techniques and resources for early Net ZEB design:

•Case studies and database searches are good places to start when looking for additional high-performance structures in a comparable setting. These might help you spot good and bad design elements. Examples of Net ZEB databases are The Zero Energy Buildings Database and the Net-zero energy buildings map of international projects.

• The most effective passive strategies can be found by evaluating the normal local climate for conditions. A portfolio of appropriate design techniques that specifically take advantage of or have superior tolerance for steady state or dynamic sequences of weather conditions can be built without specific building design skills (e.g., solar, wind, temperature, relative humidity). Climate Consultant and Ecotect are two examples of tools for visualizing climate data. Later in the chapter, there is a lengthy discussion of the use of such tools in the design process.

• Applying preexisting concepts to a specific design can be accomplished using tools based on look-up tables, design charts, or straightforward rules of thumb. These methods usually rely on numerical or experimental results that would take a lot of time or money to get for early design. Their disadvantage is that they are dependent on the presumptions of the software developer and could not be appropriate in different design scenarios. CMHC's Tap the Sun from 1998, the Daylighting Pattern Guide from the Advanced Buildings Institute from 2013, and Sander and Barakat's passive solar design charts from 1985 are a few examples.

• Designers can concentrate on one feature of a building at a time with the use of single-component or single-aspect tools. This can result in the dangers of ignoring system interactions, as discussed in Section 4.3.2. However, employing single-feature tools can be a valuable design strategy in weak coupling situations since they let the designer concentrate on a single system. LBNL Window for window thermal and optical property study, RET Screen for RETS, DAYSIM for daylighting analysis, and MOIST for combined heat and moisture transfer via wall constructions are some examples of single component tools. Radiance for the NREL RSF construction is an illustration of how a single-aspect tool is used. Later, other techniques for evaluating overall energy use incorporated the Radiance results.

• tools with fewer inputs that are based on dynamic sub-hourly timestep simulations. Although these programs may feature simulation engines or complicated models at their core, the tool developer typically limits the inputs to sensible values, partially mitigating the dangers associated with complex models. The variety of predetermined designs and building systems that are readily available is this category of tools' main drawback. HOT3000 (ESP-r), DAYSIM (RADIANCE), Example File Generator (Energy Plus), eQUEST (DOE2.2), COMFEN (RADIANCE and Energy Plus), and SPOT are a few examples of streamlined tools (and their underlying simulation engine) (RADIANCE).

The following are two tested methods for including escalating model resolution in the design process:

Enhancing model resolution throughout the design process can be achieved effectively by utilizing multiple models or interfaces with varying degrees of complexity within a single simulation engine. Different component models within specific tools offer varying levels of detail. For example, Energy Plus provides three solar models: simple, comparable one-diode, and Sandia models (Department of Energy, 2013b). In practice, a simulation can begin with the simplest photovoltaic (PV) model, which yields faster results with acceptable accuracy. As more data becomes available, such as precise product specifications, and the need for precision increases (e.g., when conducting the energy balance analysis), the simulation can progress to more complex models. As the model resolution increases, additional building attributes like daylighting, HVAC, and envelopes can also be incorporated effectively.

2. Tool interoperability allows for the same model to be saved and opened in different design programs, ideally with varying model resolutions. Recent advancements in industry standards, such as Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML), have contributed to breaking down barriers between different software products. However, managing the conflicting demands of multiple technologies and their intended users remains a challenge. Building Information Modeling (BIM) systems, for example, excel in providing detailed geometry but may have limited information on building materials. Conversely, building energy modeling tools require extensive data on building materials, such as thermo-optical properties, but may require less detailed geometry information, such as trim and intricate detailing. In practice, including excessive data can lead to overly complex models that do not significantly enhance accuracy (refer to Figure 10) and may result in longer simulation times and increased error detection. While BIM has transformed the building design industry, energy modeling is yet to gain widespread recognition. (O'Brien & Athienitis, 2015).

3.4.2. Model resolution for specific building systems and aspects

The following sections elaborate on specific aspects of net ZEB modeling. The intent is to discuss some of the major challenges and issues concerning selecting an appropriate model resolution.

3.4.2.1. Geometry and thermal zoning and Shape of Building

Building Performance Simulation (BPS) heavily relies on building geometry or a simplified representation thereof. While certain tools, such as ESP-r, allow for the use of "fake" or "fictitious" surfaces to represent apertures like windows, walls, and doors, building models typically consist of one or more thermal zones bounded by surfaces. Although more advanced models may incorporate multidimensional Computational Fluid Dynamics (CFD) or account for vertical stratification by including vertically stacked air masses, most BPS tools assume well-mixed air within the zones.

For each region of a structure to have its features, such as heat gains, sun exposure, operating conditions (such as temperature), and occupancy patterns, the thermal zones should be discretized. Additionally, the zonal arrangement must consider the HVAC control zones. (especially for detailed design). O'Brien, Athienitis, and Kesik (2011b) illustrated how predicting energy use and thermal comfort during the early stages of design for structures with few zones can result in inaccurate and excessive forecasts. A two-story house model with 1, 2, 3, and 5 zones was made by them. Figure 15 shows the heating and cooling energy usage for windows with south exposures of varying sizes. (O'Brien & Athienitis, 2015).

The results of Figure 15 clearly show how modeling the home as a single zone reduces predicted energy use while increasing the appropriate window-to-wall ratio. This ensures that, as the single zone arrangement anticipates, all solar benefits in the southern part of the house are immediately transferred to the entire structure. (Perfectly blended air assumption. In reality, only the southern part of the house would likely be heated by solar gains, making simultaneous heating and cooling of the northern part of the building necessary. (Zone for direct gain).

One of the most consuming time, tasks in building modeling is geometry input. Bazjanac estimates that roughly 80% of the resources utilized for simulation input time are devoted to tasks involving geometry. (Fig. 16)

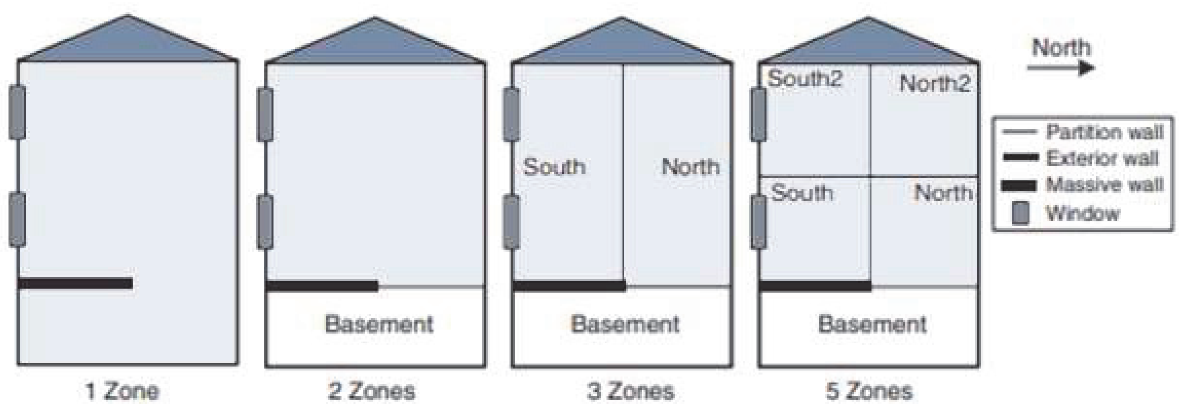


Figure 15: Four different thermal zone configurations for a passive solar house (O'Brien, Athienitis, and Kesik, 2011b)

Several approaches that can shorten the process of geometry input include:

• **import data from a 3D modeling program**. In several BPS tools, such as ESP-r and eQUEST, direct import from 2D or 3D architectural sketching and modeling software is possible, or at the very least, importing and tracing a drawing is possible. A seamless transfer from 3D models to energy models is not yet attainable. The translation of geometry is challenging, but it's also tough to understand why rooms should be divided into thermal/HVAC zones and other recommended geometrical simplifications for energy modeling.

• **Simplify the building's overall geometry.** Another strategy is to design geometry that is condensed and eliminates unnecessary elements (such as bay windows and dormers). Zone grouping reduces model creation work as well as model debugging and simulation time.

• **Examine a single zone at a time.** One can learn a lot about structures with a high degree of repetition (such as multiple similar offices, homes, or stories) by focusing on one feature of the building at a time. As a result, the vast amount of data that BPS technologies produce can be reduced by designers. Some tools (like Energy Plus) make it simpler to simplify the geometry when zones or floors are repetitive by allowing zones to be multiplied by an integer so that only one zone or group of zones needs to be depicted. (O'Brien & Athienitis, 2015).

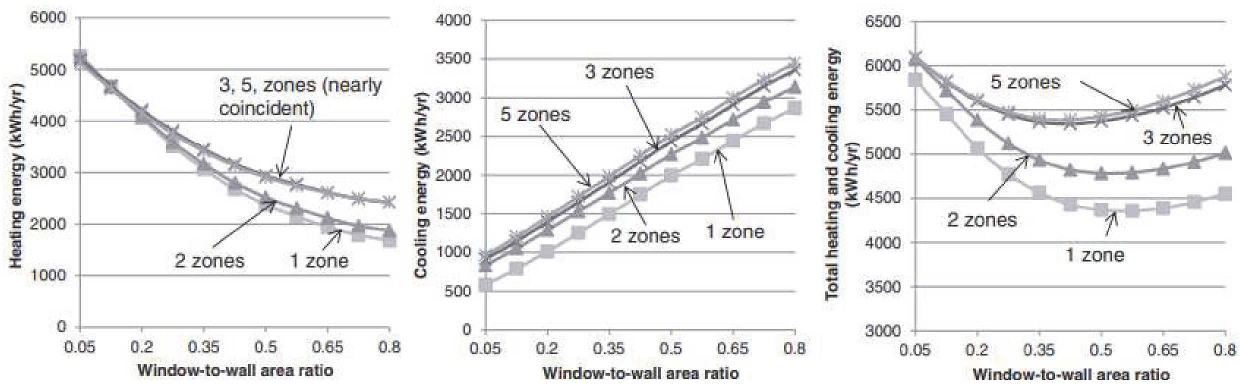


Figure 16: Total heating and cooling energy for four thermal zoning configurations of the same house model (O'Brien, Athienitis, and Kesik, 2011b)

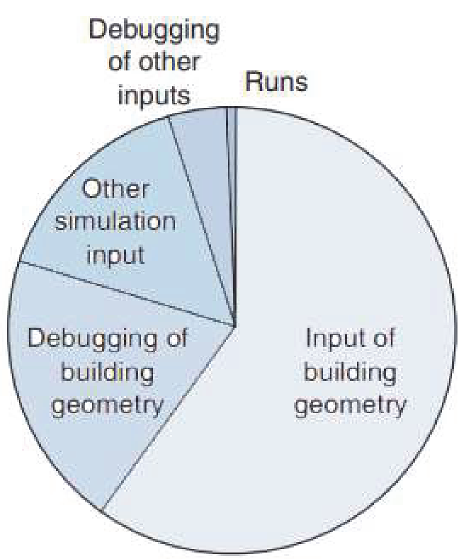


Figure 17: Proportion of time devoted to different tasks for building energy modeling (reproduced from data from (Bazjanac, 2001))

The phenomenon being examined determines the resolution of the model geometry, as shown in Figure 18. A straightforward model might be sufficient to calculate the thermal loads brought on by heat transfer through the building envelope. Zone sizes in thorough HVAC simulation models should correspond to the HVAC control zones for the actual building. This guarantees that the planned HVAC system can handle various space loads, both sensible and latent, under the anticipated thermal loads (e.g., solar, occupants, equipment, and heat loss).

Because most BPS tools often require zone boundaries to represent interior surfaces, detailed lighting, and acoustic analysis are among the zonal configuration's most difficult tasks. Because fewer walls between spaces improve daylight penetration, combining rooms into a single zone is likely to overestimate daylight illumination. As opposed to thermal domain modeling, where it is typically allowed to combine multiple zones with similar air temperatures into one.

In the end, the most complex requirement may be the limiting element for zonal arrangement (as per Figure 18). For energy analysis, it is best to avoid modeling every room as a zone (particularly for large buildings) because it is computationally expensive, takes a lot of time to model, and can result in excessive output data quantities and make model debugging difficult (O'Brien & Athienitis, 2015).

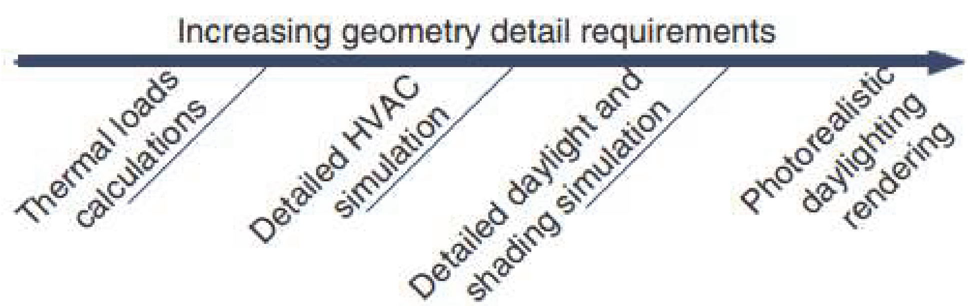


Figure 18: Model geometry resolution by building aspect *(O'Brien & Athienitis, 2015).*

3.4.2.2. shape

The owner and design team select where a new building will be located and how it will be positioned early in the design phase, according to an adage in architecture. The owner and design team select where a new building will be located and how it will be positioned early in the design phase, according to an adage in architecture. Buildings with the highest levels of energy efficiency are those where shape and configuration are considered early in the design process. The National Renewable Energy Laboratory (NREL), which completed its initial project in 2010 near Golden, Colorado, chose to build a new Research Support Facility there, they wanted the new building to set an example for stainability and energy efficiency (see the examples in the appendix).

According to Michael Holtz of the Architectural Energy Corporation, the design team decided on a series of slim three- and four-story structures extending in an east-west orientation after conducting several studies.5 Every person in the building is no more than 30 feet from a window and the advantages of natural ventilation and daylighting because the buildings are only 60 feet deep from north to south. The buildings are connected by walkways that offer services and points of entrance, and they are spaced apart by about 100 feet to prevent shading one another. Each building's fundamental design and layout allow it to include daylighting, natural ventilation, and other energy-saving features. The building form also permitted conventional construction techniques and materials at typical construction costs for the area. The Iowa Utility Board building in Des Moines was designed by Bob Berkebile's company, BNIM, using a similar idea.

The IUB building is much smaller, with just under 45,000 square feet and only two stories, but once again, as with the NREL facility, the design team was able to give most of the occupants daylight and natural ventilation by stretching the building in an east-west direction and limiting the building depth from north to south. Building orientation and configuration was one of the fundamental techniques and a guiding principle for keeping the project straightforward and replicable, according to Carey Nagle, the project architect. Another illustration of how shape and arrangement are used to maximize natural ventilation and lighting is the RMI Innovation Center in Basalt, Colorado. However, the shape and layout of the structure should be considered first when opportunities arise. Depending on these early choices, future chances for energy efficiency, particularly those connected to daylighting and natural ventilation, will either be possible or not. For these buildings, the east-west narrow building profile worked well, but many alternative options would be more suited for other locations and climates. The key is for the design team to invest some time in exploring the best possibilities early in the design process. It is necessary for energy efficiency now and in the future as the building is renovated and modified for new tenants. (Eley, 2016)

The case study is located in Roma It, is an apartment building, a typical architectural style in densely populated places. The choice of a fixed variable, namely the volume of the building itself, addresses the need to investigate scenarios that are as realistic and similar as possible. The Typology Approach for Building Stock Energy Assessment (TABULA) of the European scientific project, which provides information about the national residential building stock with a high level of detail, serves as the starting point for the building dimensions. According to TABULA, the average volume of different apartment building types is roughly 9000 m3, and the number of floors ranges from 4 to 8. Based on the previously mentioned fixed dimensions, eight possible forms are taken into consideration for the first geometry optimization. To have a broad range of options, the most typical shapes in the residential sector are considered, such as linear shape (I), L-shaped (L), court (O), and C-shaped (C) buildings. However, some uncommon shapes are also included, such as T-shaped (T), H-shaped (H), cross (X), and Y-shaped (Y) buildings. These extra geometries were chosen based on the observation of existing instances in the urban region of

Rome (and other urban areas) and the knowledge that such shapes can be created beginning with a linear building. Additionally, four structures of each form are simulated while keeping the volume constant (about 10%) and varying the shape's proportion, which we refer to as the "shape proportion" (SP) gene. In this phase, each building is assumed to be one thermal zone. Figureure 19. To define the thermal loads, an Ideal Load Air System is considered, and the thermostat is set at 20 ◦C during the heating season and 26 ◦C during the cooling season.

This section of the study focuses on modeling and simulation during the early conceptual stage of design when detailed information about the building and HVAC system is not yet available. Therefore, it is essential to keep the building model as simple as possible, and a single thermal zone is chosen to eliminate potential confounding factors. In addition to the previously mentioned factors of shape and proportion, two additional considerations in this phase are the Window-to-Wall Ratio (WWR) on each façade and the orientation of the structure concerning the cardinal points. For this case study, the optimal solution, referred to as X.3, is the SP.3 building—a six-story, cross-shaped structure with a Solar Coefficient (SC) of 0.32 m^-1. The WWR values are 0.40 for the south façade, 0.45 for the north façade, and the minimum values are assigned to the east and west façades (0.05). The building is oriented at 355° with concern. Table 6 provides a summary of the geometry configuration for the selected optimal solution. It demonstrates that the optimal solution yields energy savings of up to 60.6% compared to the performance predictions of the worst solution on the Pareto frontier depicted in Figure 20. The table also includes information about the standard floor, a 3D view of the building, and an exploded view of the thermal zones to provide a comprehensive understanding of the geometry.

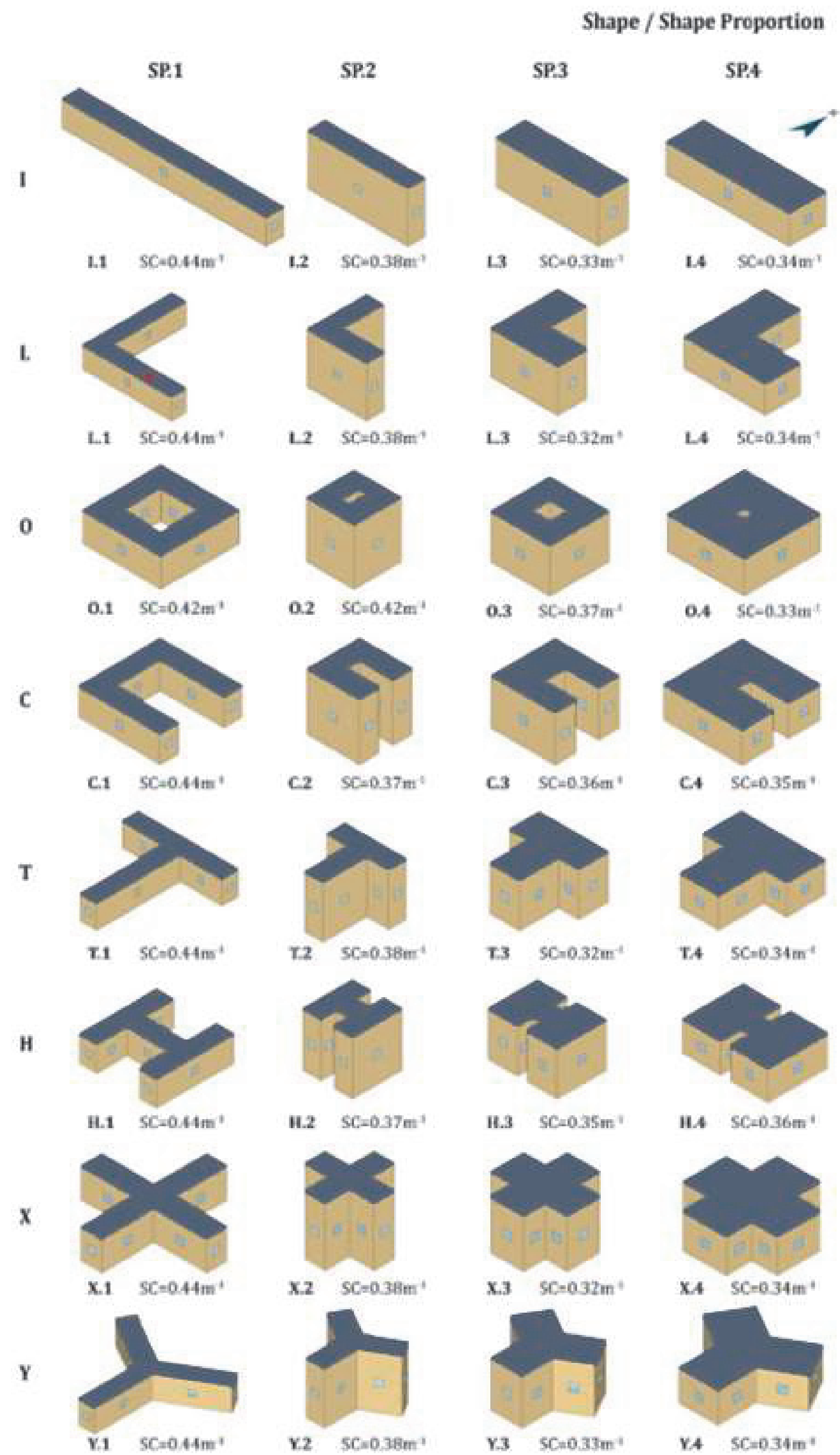


Figure 19: investigated shapes, shape proportion, and corresponding shape coefficients. (Applied Energy | Journal | ScienceDirect.com by Elsevier, n.d.)

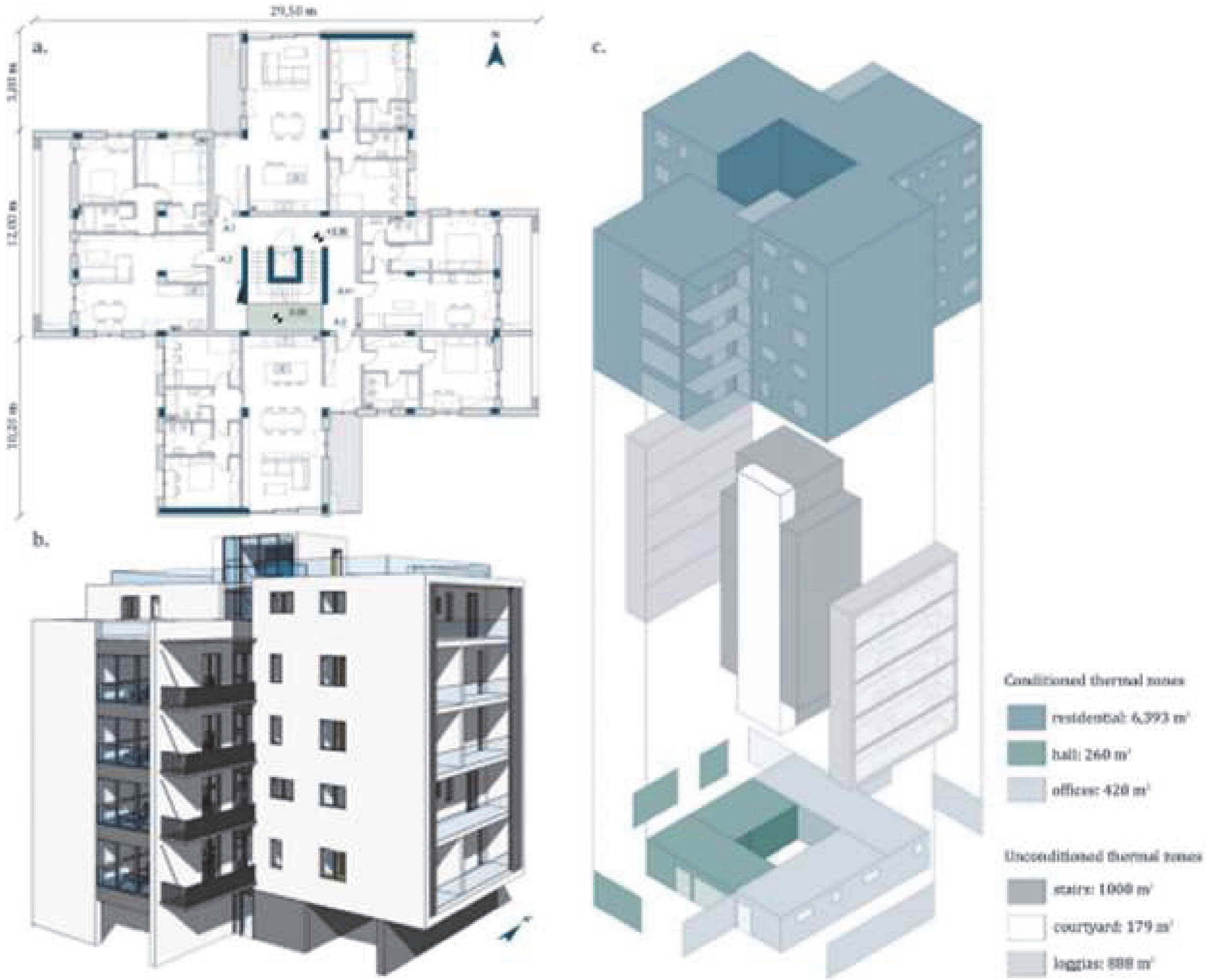


Figure 20: Case study buildings a. plan of the typical floor; b. 3d view of the building; c. exploded view of the building and thermal zones.

The solutions are depicted in Figure 21, where the Pareto frontier is represented by the red dots. The space is defined by four axes: IC (investment cost) on the x-axis, CO2 (carbon dioxide emissions) on the y-axis, EDtot (total energy demand) on the z-axis, and EC (energy cost) represented by the color axis. Each dot on the plot represents a solution, and the x-axis always represents the cost of implementing the techniques in the reference structure. The values of the optimal solutions and the reference building are also shown in Figure 21. In contrast, Figure 22. focuses on the y-axis, which is expressed per unit of surface area. This allows for the representation of both the overall energy consumption of the structure (Figure 21) and the energy consumed per square meter (Figure 22 .a), providing a benchmark for comparison with similar structures. The solutions in Figure 22. a are distributed almost horizontally, indicating that the improvement in energy demand remains relatively constant above a certain investment level (around 50,000 euros). All Pareto solutions fall within the range of 57 and 63 kWh/m2. Figure 22. b illustrates a more pronounced relationship between the investment cost and energy cost, with values ranging from 7,200 to 9,200 euros, as depicted by the dots on the plot.

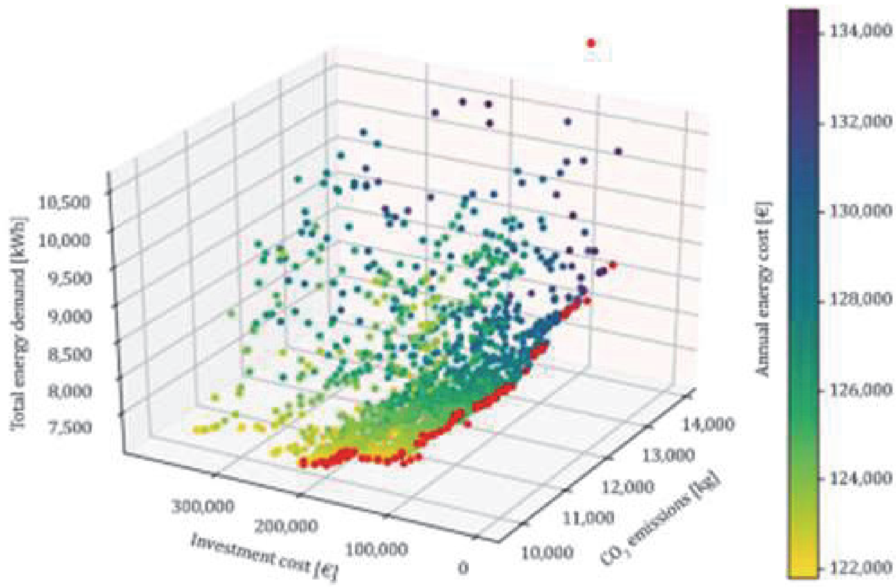


Figure 21: space of solution of multi-objective optimization of phase II. (Applied Energy | Journal | ScienceDirect.com by Elsevier, n.d.)

According to the analysis of the Pareto solutions, it is observed that shapes O, T, H, X, and Y comprise 75% of the solutions, while shape "I" accounts for 25% of the solutions. We put forth the proposition that there exists a relationship between the minimization of self-shading potential and shape coefficient in these top-performing shapes (O, T, H, X, Y). The aim is to effectively mitigate solar heat gains during the hot season, particularly in the early morning and late afternoon when the apartments are occupied. To achieve this, most of the proposed solutions incorporate low Window-to-Wall Ratios (WWR) in the eastern and western orientations. By employing this approach, exposure to direct sunlight during critical hours can be significantly reduced. (*Applied Energy | Journal | ScienceDirect.com by Elsevier*, n.d.)

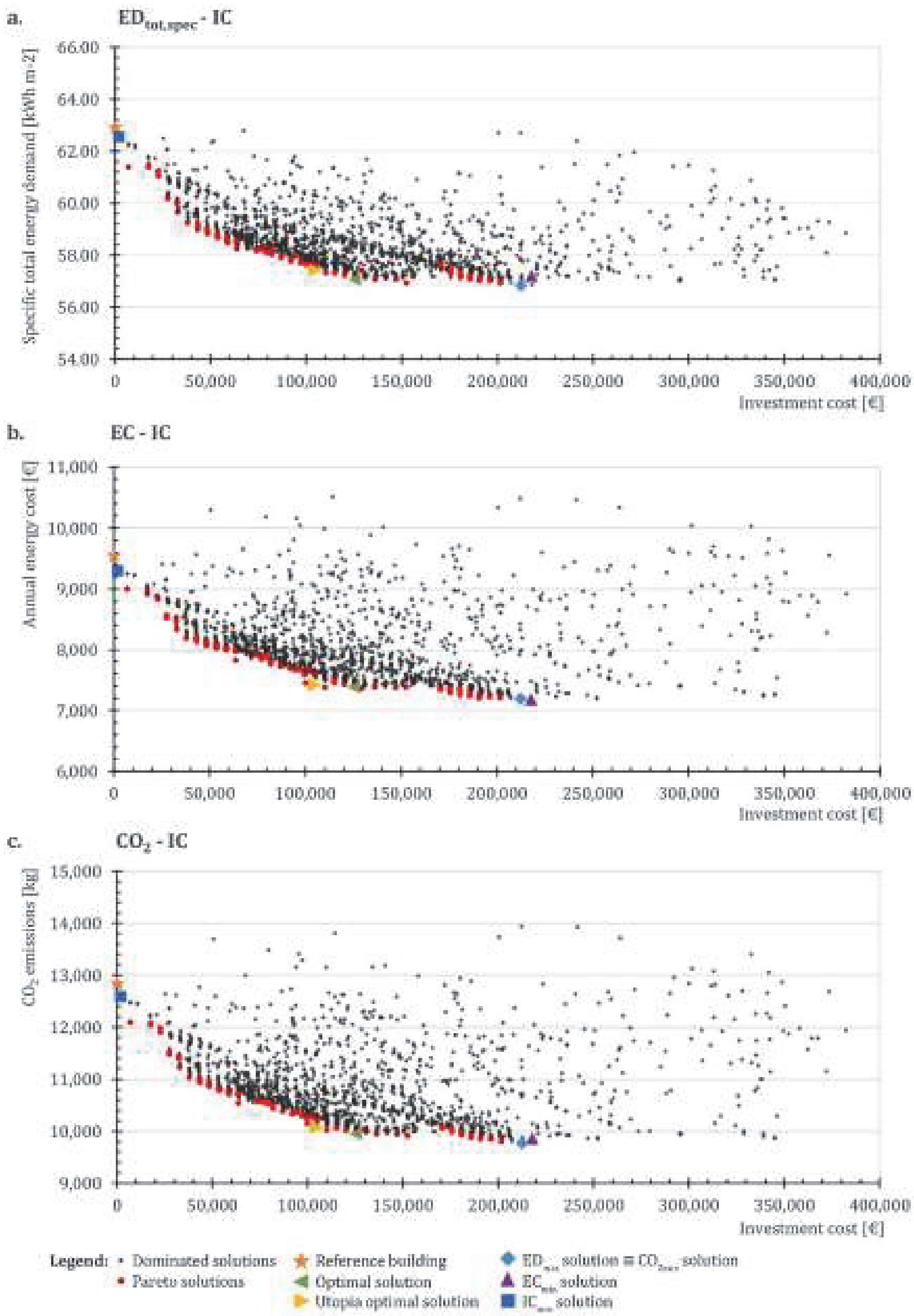


Figure 22: section of the R4 space for ED, b, EC, c, CO2, and IC axes. (Applied Energy | Journal | ScienceDirect.com by Elsevier, n.d.)

3.4.2.3. HVAC and active renewable energy systems

Heating, ventilation, and air conditioning (HVAC) systems are responsible for a significant portion of energy consumption in buildings, particularly in sealed structures located in extreme climates that lack natural ventilation. During the initial design stages, when passive techniques like building shape, insulation, window properties, and thermal mass are considered, simplified HVAC systems are typically sufficient. These idealized systems aim to provide heating and cooling as needed to maintain comfortable indoor conditions based on factors such as ambient temperature and humidity. However, as the design progresses and specific details such as HVAC capacity, energy distribution (fans, pumps), and controls are specified, the accuracy of these idealized approaches diminishes. Net Zero Energy Buildings (Net ZEBs) often require careful consideration of HVAC components, as distribution energy requirements (fans, pumps) can be substantial, and advanced control systems are typically employed. Replicating the wide variety of HVAC setups and components accurately poses a challenge. To address this issue, various Building Performance Simulation (BPS) tools and interfaces such as Request, EnergyPlus, and Example File Generator have incorporated templates that offer users access to common HVAC systems. In cases where a desired HVAC configuration is not represented by the available templates, a typical workflow involves starting with a suitable template and modifying it to match the specific configuration of interest. Therefore, a comprehensive coupled model is necessary to accurately simulate these interconnected HVAC systems. During the design of the ÉcoTerra home, which includes a groundbreaking Building-Integrated Photovoltaic/Thermal (BIPV/T) collector connected to an actively charged vented concrete slab, publicly available models for such a system were not accessible. The interdependence of the collector's thermal energy output (representing the storage capacity of the vented slab) and the heating demand within 12 hours made it evident that a connected model was required. Additionally, the ability of the collector to offset purchased heating energy significantly relied on factors such as the temperature of the slab and the air output from the collector. To account for energy consumption by the fan and duct losses, the collector outlet temperature needed to be at least 5 °C higher than that of the vented slab. It is common practice to represent renewable energy sources integrated into the HVAC system as a connected system to accurately quantify the usefulness of the obtained energy. For simulating specialized mechanical systems, the most effective and versatile tool is TRNSYS.

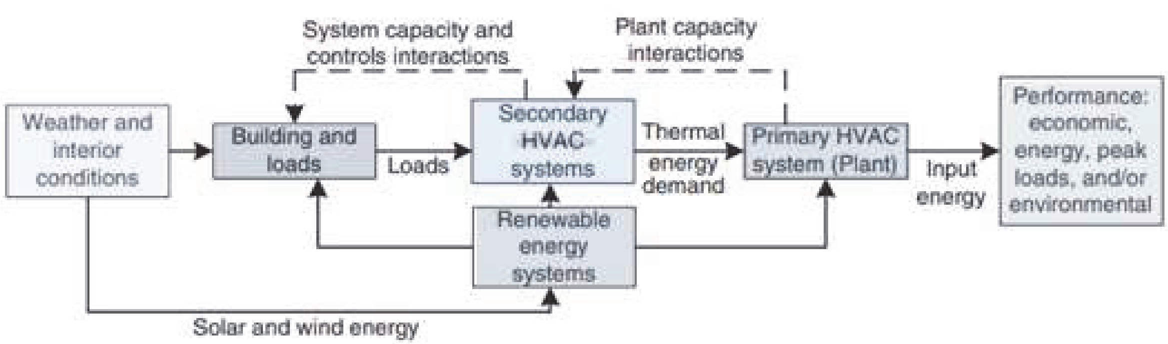


Figure 23: Data flow in decoupled (——————) and coupled (———) building-HVAC modeling approaches for Net ZEBs

Modern advanced Building Performance Simulation (BPS) engines have adopted a different approach by integrating HVAC and building models to simultaneously analyze their performance at each time step. Figure 23 illustrates the flow of data between buildings and HVAC equipment, showcasing both traditional and contemporary techniques. In decoupled models, the "loads-systems-plant sequence" depicted in the diagram progresses from left to right for each time step, without incorporating feedback loops. For instance, the heat load information required to maintain a specified temperature in space is provided to secondary or terminal HVAC equipment, such as a hydronic radiant heating panel. Based on this information, the plant's thermal energy requirements are calculated, determining the amount of fuel or electricity needed for energy production. Each step in this process represents a transfer function that assesses the efficiency of energy conversion. However, it is important to note that the underlying principle assumes that any system to the right of the preceding one can precisely supply the required amount of energy at a specific time step. The intricate interconnections between the plant, distribution system, and various locations may become overly complex to represent effectively. This complexity can pose a significant challenge for Net Zero Energy Buildings (Net ZEBs) that emphasize passive approaches to minimize both energy demand and plant capacity.

Decoupled HVAC models exhibit limitations when applied to HVAC systems with a significant thermal mass component (Chen, Galal, and Athienitis, 2010a; Chen, Galal, and Athienitis, 2010b). While the HVAC system itself does not directly consume energy, the building envelope plays a crucial role in determining the energy required for lighting, heating, cooling, and ventilation. An optimal building envelope effectively regulates the ingress and egress of heat, air, and light from the structure. It can "breathe" by allowing the entry of light and air when external conditions are favorable while creating a barrier against heat flow, wind, and excessive sunlight during unfavorable weather conditions. Visualize a wildflower that opens its petals to the sun during the day but closes them at night to shield itself from cold winds. In the case of most commercial buildings, their envelopes tend to effectively create a barrier but cannot often "open up." They cannot release internal heat or allow fresh air circulation when appropriate, despite conventional design guidelines and building regulations emphasizing insulation and air sealing of the building envelope. Consequently, this responsibility is often shifted to the HVAC system, which fulfills the task but at a high energy cost and reduced resilience during emergencies. A building that solely relies on electric lighting and HVAC systems can become virtually unusable during extended power outages.

However, there are examples of buildings designed to "breathe" and leverage natural ventilation. The Y2E2 Building at Stanford University (Figure 24) demonstrates this concept differently. Openings at the top of a central atrium automatically open when the outside temperature drops below 82°F (humidity and wind are not significant concerns in Palo Alto), and occupants are notified via email to open their windows. Conversely, the atrium windows close when the temperature exceeds 82°F, and residents are advised to do the same. Another strategy implemented in the Stanford project is utilizing cool nighttime temperatures to naturally cool the building's thermal mass. The atrium's roof windows provide nighttime ventilation, along with actuator-controlled windows in public spaces. Cole Roberts of Arup North American Ltd., the engineer for the building, refers to the atrium as "the lungs of the building." Similarly, the Bullitt Center in Seattle employs comprehensive automation (see appendix). Exterior shades open and close based on an astronomical time clock, while windows automatically open and close to facilitate natural ventilation and nighttime cooling. (see appendix). (Eley, 2016b)

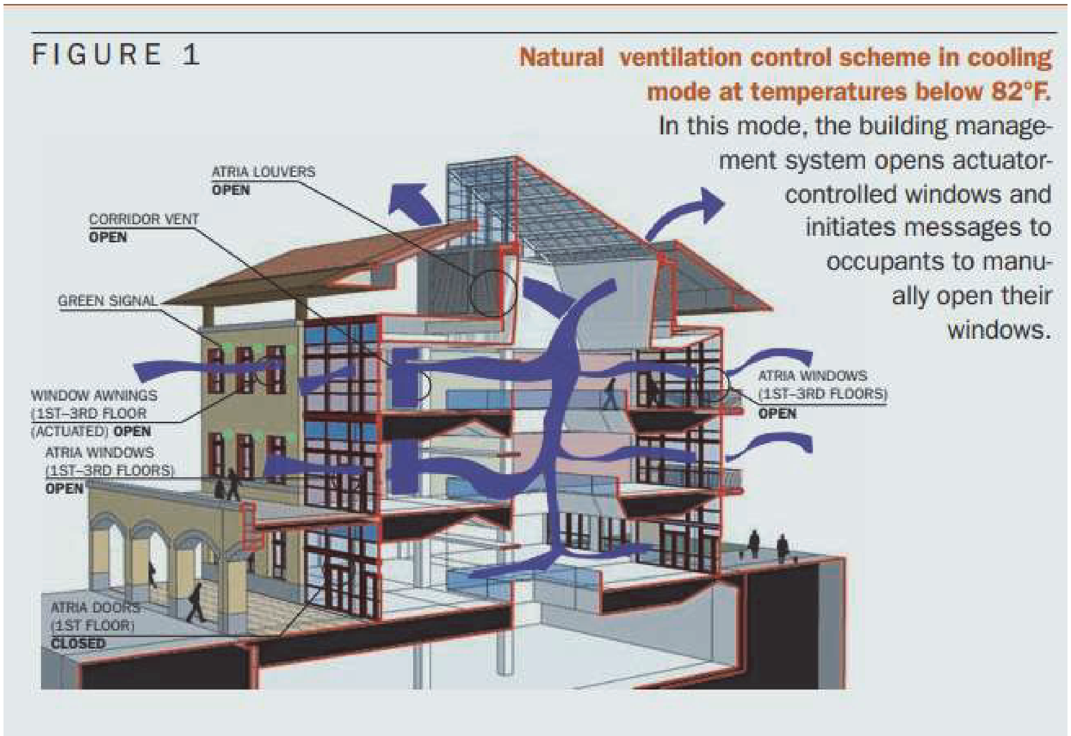


Figure 24: Ventilation Strategies at the Y2E2 Building on the Stanford Campus This diagram shows natural airflows when the outdoor temperature is below 82°F. Similar airflows occur at night to lower the temperature of the building and remove heat from thermal mass. (Imbabi et al., 2004)

3.4.2.4. Photovoltaics and building-integrated photovoltaics

BIPVs, or building-integrated photovoltaics, are photovoltaic materials that are used to replace traditional building materials in building envelope components like roofs, skylights, and facades. BIPV modules may also be retrofitted into existing structures, although they are increasingly being used as a primary or auxiliary source of electrical power in the construction of new buildings. Integrated photovoltaics have an advantage over more prevalent non-integrated systems in that the initial cost can be covered by lowering the costs of building materials and labor for the areas of the building where BIPV modules are used instead of traditional ones. These benefits make BIPV one of the photovoltaic industry's fastest-growing sectors.

BIPV systems must consider several variables, including the temperature of the photovoltaic modules, shading, installation angle, and orientation, to achieve multifunctional tasks. The irradiance and photovoltaic module temperature should be regarded as the most crucial elements among them since they have an impact on both the BIPV system's electrical efficiency and the energy efficiency of the buildings where BIPV systems are installed. Some researchers have presented the findings of fundamental studies on the irradiance and energy production of photovoltaic systems, while others have studied the temperature and generation performance of solar modules.

What are BIPV and BAPV?

BIPVs are regarded as an essential component of the building's framework. Designs in this category swap out common roofing materials like shingles, tiles, slate, and metal roofing. These goods may be difficult to tell apart from their non-photovoltaic counterparts. If there is a wish to preserve architectural continuity and not draw attention to the array, this may be appealing. BIPV modules can also be used as decorative architectural features to improve a building's aesthetic and produce eye-catching visual effects. These kinds of arrays can be utilized for curtain walls, awnings, windows, and skylights and feature custom-made module sizes and shapes with opaque or transparent intervals between the cells.BIPVsV are so solar items with multiple uses that both produce electricity and serve as building materials.

BAPVs are seen as an addition to the structure and are not directly connected to its functioning components. They are supported by a superstructure that also holdstypicallyl framed modules. BAPV systems can be divided into two subcategories: standoff arrays and rack-mounted arrays. A pitched roof has standoff arrays positioned above the roof surface and perpendicular to the slope. The modules in rack-mounted arrays are designed to be at the best orientation and tilt for the application, and they are commonly positioned on flat rooftops. Typically, a series of brackets or "feet" that are mechanically fastened to a part of the roof system are used to attach the superstructure to the roof. Without any mechanical connection to the original roof, BAPV arrays can also "float" above it.

Figure 25: An example of BIPV in which photovoltaic arrays are combined with a roof another example is attached to the rooftop. (Ata, 2018)

The cost of solar panels is the main problem.

Despite solar cells costing 286 USD/W and having efficiencies of 4.5–6% in the early 1950s, the cost of silicon, which is used in most panels, is presently rising rapidly due to a significant increase in demand. To reduce costs, this has led developers to start using thinner silicon and other materials. As more people use and purchase solar panels, their price decreases because of economies of scale; this trend is anticipated to continue in the years to come as manufacturers increase output. Early in 2006, the typical installation cost per watt, including panels, inverters, mounts, and electrical components, was around USD 6.50–7.50. By 2050, the cost of electricity generated by photovoltaic cells will be close to that of conventional power generation. (Boemi et al., 2015c)

The system's spatial requirements, optimal location, and angle of inclination must be considered in the design.

• Facing south is ideal for both systems.

• collectors' Hot water should be positioned at an angle of around 40° when used primarily for heating space. For collectors used for both, the ideal angle is halfway between the two, or about 50° (for mid-Europe).

• For mid-Europe, a PV installation should be angled at about 40°.

• Variation is possible, but it lowers the output per square meter of a PV panel or collector. Shade caused by surrounding structures, roofs, dormers, flues, and plants, for example, must be avoided because PV systems are extremely sensitive to this.

Much like windows are placed in façades to allow sunshine to enter inside for passive solar energy generation the arrangement of walls is crucial. For this sunlight to effectively assist in energy generation, the direction need not be south. It is possible to adjust placement by around 20°. Undated (Andy van den Dobbelsteen and others)

According to the calculations, a south home facing receives the most sunlight. It has been demonstrated that solar windows lose their efficiency by the equivalent of 10m3 of natural gas per home annually with deviations of about 20° to the east or west.

When the variance is even bigger, energy use increases rather quickly. This depends on various elements, such as the amount of glass on the façade, its direction, and how well-insulated are the buildings. The following employs a hypothetical semi-detached house:

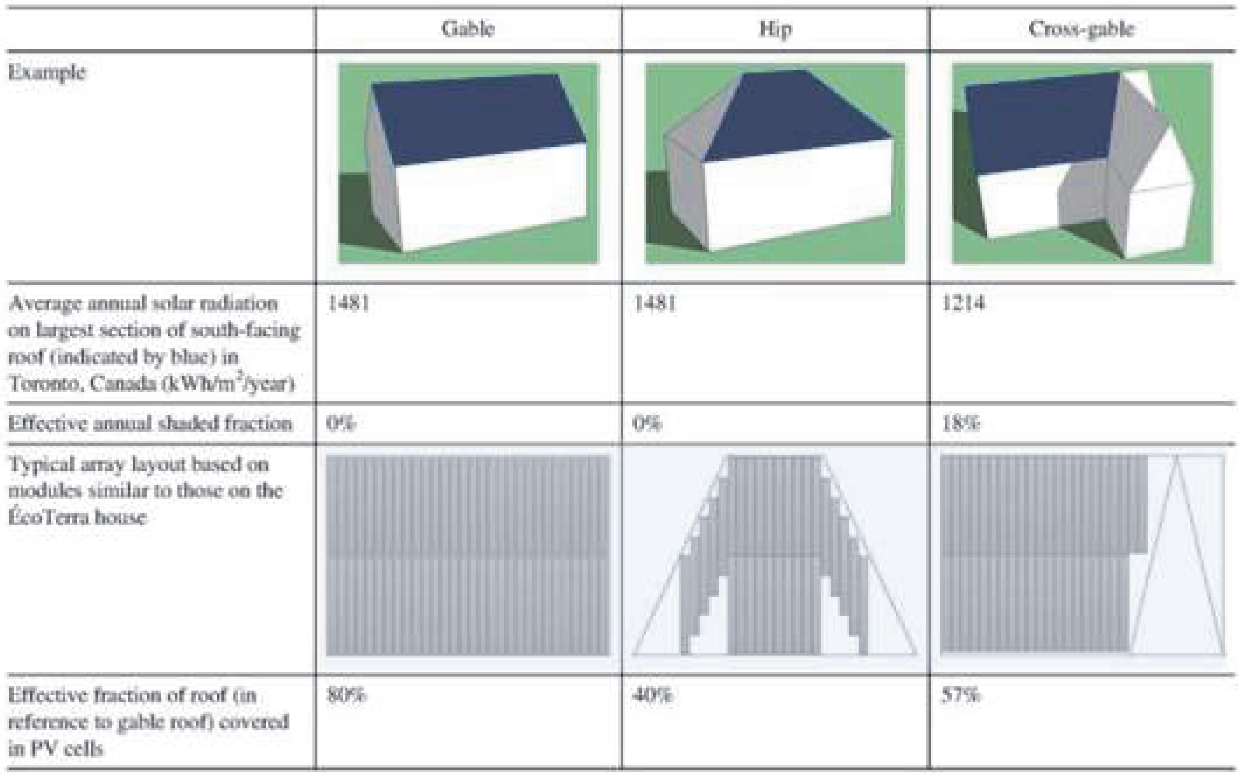
- The glass partition in the sample home is evenly distributed (50 percent on the north façade and 50 percent on the south façade). Moving 25% of the glass from north to south (i.e., 75% south, 25% north) can result in a savings of approximately 50m3 of natural gas per year.

- If the property were rotated 180 degrees, the distribution would be 25% south and 75% north, and the quantity of natural gas used would increase by roughly 95m3 per year. When the variance is even bigger, energy use increases rather quickly. This depends on various elements, such as the amount of glass on the façade, its direction, and how well-insulated the buildings are. The following employs a hypothetical semi-detached house:
- The annual energy usage changes as follows if the house's distribution of 50/50 south and north is rotated by a quarter to become 50/50 east and west:

Due to the front façade's window, natural gas usage increased by over 50 m3 for the front façade that faces north and by almost 10 m3 for the front façade that faces south. (Andy van den Dobbelsteen et al., n.d.)

Due to their consistent production of electricity during the day, low maintenance requirements, flexibility in capacity and surface area, lack of angular dependence, and ability to be installed on flat or near-south facing roofs, photovoltaic systems are among the most popular renewable energy systems in Net ZEBs. Although there are several technologies for predicting the performance of standalone PV systems, specifically modeling PV modules into the main building model has considerable benefits. PV self-shading, or the shading of BIPV modules by the construction of a building, is preventable and needs to be eliminated if possible. PV modules can be harmed if they are improperly wired using a bypass diode, which can result in performance for shaded modules that are significantly lower than the percentage of the shaded area. (GSES, 2004). Since each module is controlled separately and has no impact on the operation of the others, microinverters can help to somewhat ease this issue. Roof geometries Complex, such as a cross-gable, can considerably lower PV performance, as seen in Figure 26.

Numerous BPS tools perceive BIPVs as continuous surfaces and ignore the individual module geometry. Therefore, self-shading and other geometric compatibility concerns must be avoided during design. (O’Brien & Athienitis, 2015).



	Gable	Hip	Cross-gable
Example			
Average annual solar radiation on largest section of south-facing roof (indicated by blue) in Toronto, Canada (kWh/m²/year)	1481	1481	1214
Effective annual shaded fraction	0%	0%	18%
Typical array layout based on modules similar to those on the ÉcoTerra house			
Effective fraction of roof (in reference to gable roof) covered in PV cells	80%	40%	57%

Figure 26: Three different BIPV roof configurations showing geometrical implications of complex roof geometries. (O'Brien & Athienitis, 2015).

3.4.2.5. Lighting and Daylighting

Electric lighting constitutes a significant portion of energy demand in commercial buildings, typically ranging from 15 to 25 percent (DOE EERE, 2010; NRCan, 2008; Pérez-Lombard, Ortiz, and Pout, 2008). This percentage tends to be higher in moderate climates. Furthermore, daylighting is a key objective in various building standards for new constructions, not only due to energy savings but also the psychological benefits of natural views and dynamic illumination (Veitch, 2001). However, the lack of detailed information on interior finishes and geometry, along with the limited realistic modeling capabilities of commonly used BPS tooposespose challenges to accurate daylight modeling (O'Brien & Athienitis, 2015).

To assist in daylighting design decisions, such as window type, size, position, room depth, surface optical characteristics, and shading devices, the rule of thumb and pattern guides continue to be effective approaches (O'Connor et al., 1997). Nonetheless, dynamic daylight simulation becomes valuable, particularly when assessing energy savings for innovative lighting techniques, advanced equipment, or unconventional geometries. The primary algorithms employed in daylight modeling are the split flux method, radiosity, and ray tracing, with increasing levels of model resolution (Hensen and Lamberts, 2012).

The split flux method calculates illumination on the work plane by considering surface-reflected light and direct views of interior points to external light sources like the sky. However, this method may underestimate daylight due to disregarding certain light reflections. It is prone to inaccuracies in spaces with high aspect ratios, specular surfaces, or interior obstructions (Department of Energy, 2013b). Radiosity, originally developed for calculating non-visible radiative heat transfer between surfaces, has been adapted for daylighting applications. It simultaneously accounts for lighting on all interior surfaces using surface reflectance and luminance exitance. However, a limitation of radiosity is its treatment of all surfaces as fully diffuse reflectors, which may be inappropriate for specular surfaces such as metals, glass, and highly polished materials. This drawback is especially relevant for glare-prone areas and equipment requiring specular solar shading, such as light louvers (O'Brien & Athienitis, 2015). A daylighting analysis technique known as ray tracing is employed to track the path of light from a source to interior surfaces (forward ray tracing) or in the opposite direction (reverse ray tracing). Unlike the previously mentioned techniques, ray tracing is capable of accurately handling complex geometry and specular surfaces. However, for Net ZEB design, the implementation of such intricate technology may not be necessary. According to Hensen and Lamberts (2012), forward ray tracing involves tracing light rays from all light sources to a surface, with the user specifying the number of bounces the rays should follow based on the complexity of the geometry and desired precision. On the other hand, backward ray tracing starts from a final surface and traces the path of light until it reaches a source if it ever does. Ray tracing is generally considered highly effective for complex geometries with small and/or specular surfaces (refer to Figure 27). Several comparative studies on daylight simulation methods and tools are available in the literature (Carrol, 1999; Ramos and Ghisi, 2010; Reinhart and Fitz, 2006; Reinhart and Herkel, 2000; Yun and Kim, 2013). (O'Brien & Athienitis, 2015).

Figure 27: shading fixture (Ata, 2018)

The choice of daylight simulation algorithm for simulating different building phenomena depends on the specific design objectives and characteristics of the building. Simple daylight models are easier to create and simulate, but they may lack accuracy when dealing with complex geometries and fail to account for factors like glare and discomfort (Hensen and Lamberts, 2012). On the other hand, complex daylighting models are typically handled by computer software, and the choice of the algorithm should be based on processing speed and efficiency rather than modeling time. However, the full potential of modern daylighting analysis algorithms can only be realized when the user provides accurate geometrical information and optical attributes. Unlike daylight analysis, simulating electric lighting is relatively straightforward due to the static nature of artificial lights (Hensen and Lamberts, 2012). Luminance output from lighting fixtures can be obtained from manufacturers in the format specified by the Illuminating Engineering Society (IES), which offers more clarity compared to the variability of sky conditions. When using software tools for luminaire selection and layout, a light loss factor (LLF) is commonly used to account for various factors that can reduce the actual lumen output of a luminaire from its rated values.

A one-way data flow method is typically appropriate for the connection of lighting and daylighting models. Depending on the BPS tool, either the manual or automatic execution of the following steps occurs:

1. A simulation of daylighting is run, and the amount of additional electric illumination required is determined and forwarded to Step.
2. In the main building model, electric lights are turned on as needed to augment daylighting using the electric lighting schedule profile. The simulation includes the heat gains and electricity usage that ensue.

The cumulative and flexible nature of electric and natural light illuminance allows for their stacking on any surface, making it possible to incorporate thorough daylight analysis techniques into the design process. However, a drawback of the sequential approach is that it may not be well-suited for dynamic shading devices that can be adjusted for both visual and thermal comfort, such as roller shades or electrochromic windows, particularly when considering stochastic occupant modeling. Moveable window shading systems play a crucial role in reducing solar gains and minimizing eye strain, enabling buildings to adapt to changing climatic conditions. Ideally, these shading devices should be located on the exterior of the building and have a light-colored surface to minimize solar heat gain. However, indoor moveable shades are more commonly used in colder regions, particularly in North America, where concerns about cost and the accumulation of ice and snow come into play. The combined optical and thermal properties of complex fenestration systems, including windows and moveable shade systems, significantly impact a building's performance. Nonetheless, research on these topics remains relatively limited (Newsham, 1994; Tzempelikos and Athienitis, 2007). The WINDOW software developed by Lawrence Berkeley National Laboratory offers an efficient means of analyzing the thermal and optical characteristics of intricate fenestration systems. (O’Brien & Athienitis, 2015).

3.4.2.5. *Effect of Window Size on Cooling Capacity and Energy in Climates*

The characteristics of the building envelope and the energy effectiveness of the chosen HVAC system determine how much energy is used by a structure. In contemporary offices with energy-efficient light fixtures and laptop computers, the features of the windows are the most important factor in cooling demand. The need for cooling can be considerably decreased with effective solar shading. The range of HVAC systems that can be employed in buildings is increased by the decrease in cooling loads. In such buildings, efficient solar shading is created, making the introduction of low-temperature heating and high-temperature cooling air-water systems easier [3When air-water systems are taken into consideration during the design process, it's crucial to distinguish between sensible cooling and total cooling loads. Only practical cooling loads are covered by room units in air-water room air conditioning systems. To prevent condensation in the room space, the latent load is adjusted in AHU by dehumidifying the supply airflow to the necessary amount. As a result, the cooling capacity is substantially smaller than it would be when utilizing, for instance, condensing fan-coil units, where much of the dehumidification takes place in the fan-coil unit in the room areas. The necessary sensible and total cooling capacity as well as the energy consumption of a chilled beam system were examined in a case study. The investigation was conducted in a variety of climate zones throughout Asia and Europe, including cold, temperate, subtropical, and tropical regions. Under typical design circumstances, the breakdowns of the necessary sensible and latent cooling capacities are shown. The needed cooling capacity and energy utilization of an office room were calculated using the IDA-ICE energy simulation software.

The office space was replicated in six different climate zones: Helsinki, Paris, and Rome were in Europe, while Singapore, Seoul, and Tokyo were in Asia. The area of the mock office room was 10.8 m2 (4.0 m, 2.7 m, and 3 m, L, W, and H). In all cases, the window's width was 2.5 m, and four different window heights—1.2, 1.6, 2.0, and 2.8 m—were examined. In Fig. 28, the window sizes are displayed. The window had three panes and a solar factor (also known as the solar heat gain coefficient, or SHGC) of 0.4. The external wall's total thermal transmittance (U-value) was 0.3 W/m2 K while the window's overall U-value was 1.1 W/m2 K. The inner walls were plasterboard constructions, while the outer wall was a concrete wall (heavy). There was no thought of heat transfer between inside walls. The infiltration rate during the cooling season was 0.15 l/h. The cooling requirements were greater in European locations with south-facing facades than in Asian locations (Fig. 28). The vertical incident angle of solar radiation is greater at northern latitudes, and as a result, the solar load is higher. European cities experienced a greater impact from window height than Asian megacities. As a general rule, it can be said that a full-width window that is 40 cm taller enhances cooling capacity by 15 W/floor-m2. In the south rooms, the maximum cooling capacity was between 80 and 120 W/floor-m2. It is possible to use the cooling power of 80 W/floor-m2 to maintain the set room air temperature by lowering the window height to 1.6 m. The maximum cooling capacity in the east- and west-facing office spaces was 120 W/floor-m2. The needed cooling capacity decreased to 90 and 80 W/m2 when the window height was 1.6 and 1.2 m, respectively. The office space with the north façade had a cooling capability of 70–90 W/m2.

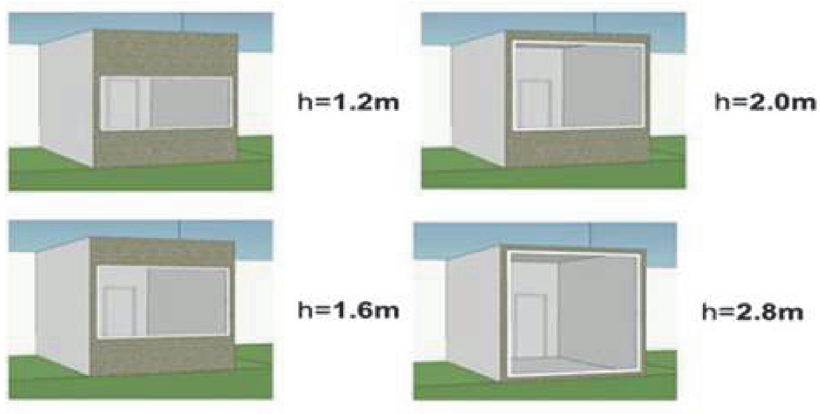


Figure 28: Office building module division with longitudinal installation. (Attia, 2018).

It's crucial to determine the real cooling demand when sizing an air conditioning system utilizing a dynamic energy simulation program. The entire system is larger if the impact of the thermal mass is not considered. Window characteristics are important in the cooling demand. The necessary cooling capacity might easily be 1.4–1.6 times more than with state-of-the-art windows if there is no sun shading or a window with a good solar heat gain coefficient (SHGC).

The latent load is larger in southern European towns where the solar load is lower than in the northern region. It is significant to note that the chiller's sizing is based on the overall heat load, whereas room air conditioning systems that use chilled beams or other dry cooling principles must always be scaled based on the sensible load of the room space. On the other hand, the latent load is taken into consideration when sizing, for example, a split system or fan-coil room system, where the dehumidification happens partially or entirely in the room area (Attia, 2018).

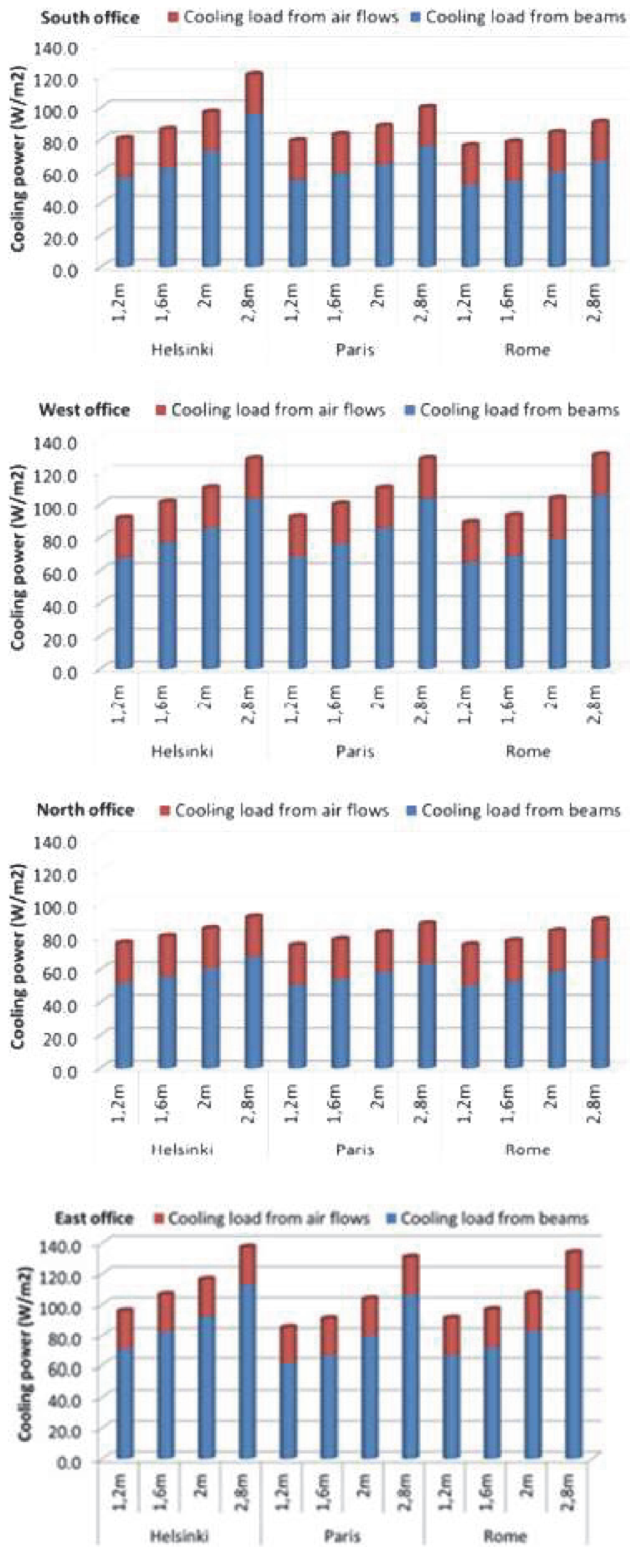


Figure 29: Sensible cooling capacity in European cities using different window heights. (Attia, 2018).

3.4.2.6. Solar Shading and Examples of Facade Solutions

Solar shading is used to ensure as much diffuse sunshine as possible while simultaneously obstructing direct sunlight. To prevent glare and use less energy for cooling during the spring and summer months, the amount of direct solar radiation that enters the room should be kept to a minimum. It is false to assume that daylight spaces and huge glass surfaces go hand in hand. If the problem of solar shadowing is not resolved, these structures demonstrate that window coverings are always drawn and spaces are lit artificially, as seen in Fig. 30, (Attia, 2018).

Figure 30: Solar shading of the façade is not resolved. Most of the curtains are constantly closed. Durthe ing daytime, spaces are lit with artificial lighting instead of daylight. (Attia, 2018).

Studies have demonstrated peoples' "laziness" in controlling curtains appropriately. Typically, the curtains are always open in areas with no direct solar radiation and closed in areas with direct solar radiation. Office workers have been seen to initially adjust the curtains for the view and sunshine by the effect of direct solar radiation, but later give up and leave the curtains closed all the time. Effective solar shading helps avoid closed curtains. The following options can be used to achieve effective solar shading (Attia, 2018):

- Double-skin facades with blinds or other shadings in between.
- External blinds (lamellae).
- External overhangs.

• Self-shading facades.

• Combinations of earlier methods Internal and external blinds are two distinct solutions.

Installing blinds on the exterior effectively blocks direct sun radiation. In Western Europe, external blinds are commonly used for this purpose. Blinds placed between windowpanes also contribute significantly to reducing the cooling load. On the other hand, internal rib curtains, roller blinds, and similar types of curtains that allow solar radiation inside the space and often result in increased room temperature should be considered emergency solutions for solar shading. External rib curtains or lamellae feature broader ribs (around 5-8 cm), offering the advantage of automatic regulation based on the amount of direct sun radiation present (Attia, 2018).

It is important to note that with the lamellae system, when the solar altitude angle is below 30°, the lamellae are fully closed, preventing the view to the outside. The most widely used passive architectural shading method is provided by external overhangs, which effectively block direct sun radiation. The main types of exterior shading solutions are illustrated in Figure 31. Generally, horizontal overhangs are more suitable for southern facades, while vertical overhangs are better for eastern and western facades. Combining horizontal and vertical overhangs is also a viable option. The size of the overhang is determined by the building's geographic position or latitude. According to Table 2, on June 21 at noon, at a latitude of approximately 60°, the solar angle of incidence towards the vertical plane is around 54°. On December 21, the same angle is only 7°. To block direct solar radiation on the southern facade from April to September, the maximum solar angle of incidence is approximately 42° during the day. Since the sun angle is lower at 10 a.m. and 2 p.m., around 39°, the length of the external shading should exceed the width of the window. For instance, if a building has three-meter-high floor-to-ceiling windows, the length of the overhang should also be around three meters (Attia, 2018).

In countries such as Germany, Austria, Finland, Sweden, and Denmark, double-skin facades have become increasingly popular. Rib curtains or lamellae are well-suited for these facades as they provide effective protection between the double-skin layers. Self-shading facades can be achieved by incorporating inclinations, gradations, and other architectural shapes. For example, a southern facade can be designed with a specific inclination. In the case of small two-story office buildings, an external overhang extending over the roof can be considered. Combining the first two options mentioned above is another common approach, as illustrated in Figure 32 (Attia, 2018).

Table 2 External overhang options for blocking direct solar radiation on the southern side at 12 p.m. according to the length of the overhang in latitude 59°

12 p.m., noon	Solar angle of incidence (°)	Length of an overhang				
		40 cm	50 cm	60 cm	70 cm	100 cm
21 June	54.5	56	70	84	98	140
21 May/July	51	49	60	73	86	123
21 April/August	43	37	47	55	65	93
21 March/September	32	25	31	37	44	62
21 February/October	20	15	18	22	25	36
21 January/November	12	8	11	13	15	21
21 December	8	5	7	8	10	14

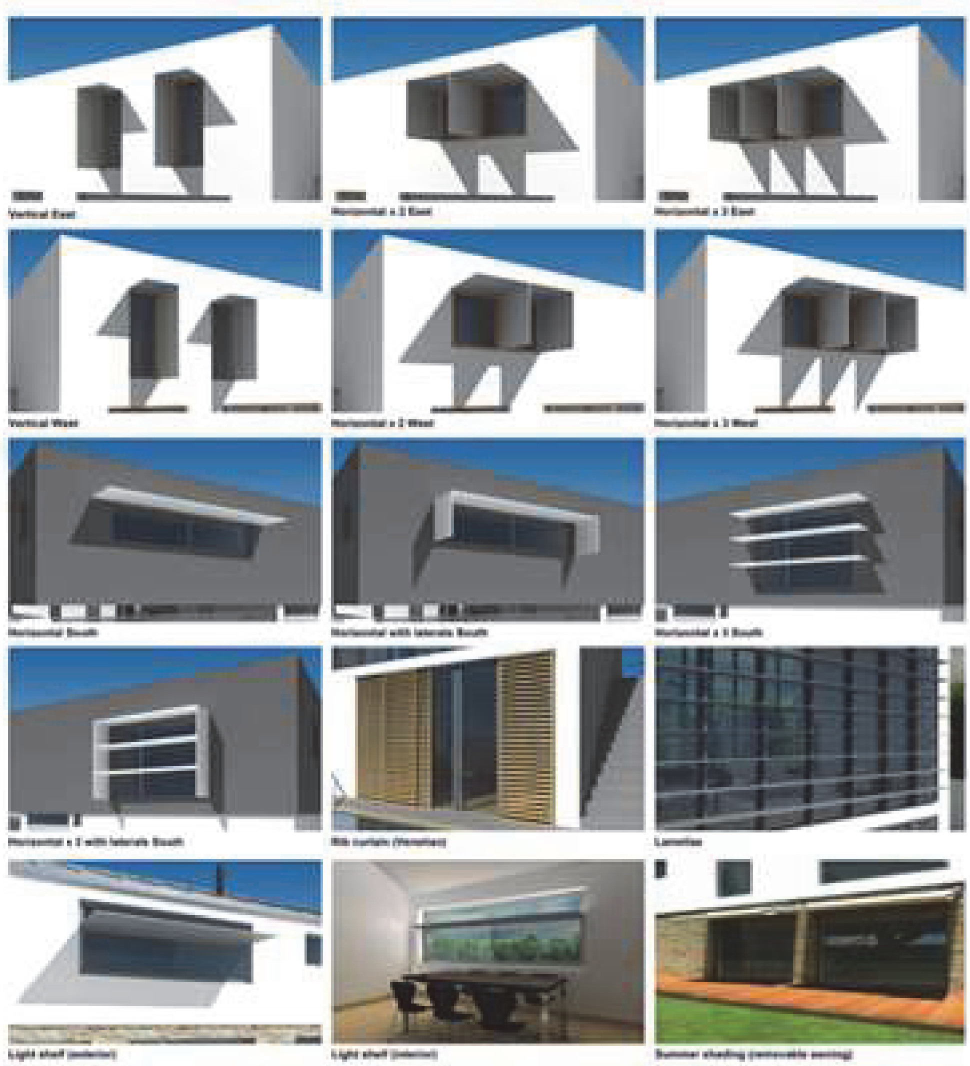


Figure 31: some examples of external over hangers and shadings. (Attia, 2018).

Figure 32: A combination of a self-shading façade with inclination and external overhang. (Attia, 2018).

3.4.2.7. Building thermal inertia

The dynamic thermal behavior of a building is influenced by thermal mass, which helps to reduce indoor temperature fluctuations. By storing or releasing heat, thermal mass components delay and modify the response of interior air temperature to load fluctuations. For instance, during the summer, internal loads and solar gains can be partially absorbed by the building's thermal mass, thereby postponing the need for cooling until later hours when there is less demand. Various components contribute to the thermal mass of a building, including heavy floors, ceilings, and facades, as well as actively charged mass such as vented concrete slabs (VCS), floor heating systems, and phase change materials (PCMs). Considering the anticipated internal loads, thermal mass plays a crucial role in the design and should be carefully considered early in the design process. The goal is to store the solar and internal benefits during the day and release them at night in a well-designed building. In moderate climates during summer conditions, a method to determine the appropriate thickness of thermal mass is to ensure that the temperature increase of the thermal mass does not exceed 5°C during the day, assuming that the thermal mass is replenished during the night shift when the operating range is between 21 and 26°C. The determination of mass thickness can be achieved early in the design process using the admittance approach as explained (O'Brien & Athienitis, 2015).

To ensure optimal conditions, it is essential that the thermal envelope completely encloses the areas requiring temperature control. A loose-fitting thermal envelope compromises the effectiveness of weather protection. To minimize heat transmission loss, the thermal envelope should be as compact as possible, as the surface area of the envelope directly affects the amount of heat loss. The "fabric first" approach, known as the passive house method, focuses on maximizing the energy efficiency of a building by prioritizing the construction of a strong and well-designed thermal envelope, as these components cannot be easily upgraded later. Therefore, when aiming to meet the Passive House standard as a step towards creating a Positive Energy Home, it is crucial to prioritize the proper construction of the thermal envelope. The boundary between controlled and uncontrolled areas should have three distinct functional layers. In hot environments, an airtightness layer (depicted in green) should be internal to an insulating layer (depicted in yellow). The wind and weather tightness layer (depicted in blue) should be the most isolated layer from the outside. Optimal performance requires all three functional layers to be intact, with potential perforations most likely to occur in the airtightness and wind/weather-tightness layers (Brimblecombe, Rosemeier, and CSIRO, 2017).

It is important to identify the specific thermal envelope layer present on each surface. In the previous diagram (Figure 33), the wind- and weather-tightness layer consists of a vapor-open membrane with taped joints, while the airtightness layer is comprised of engineered wood boards with taped joints. Insulation in the form of a mineral wool blanket is installed between the studs. The materials used for each functional layer may vary from one site to another, such as using a taped, engineered timber board as the airtightness layer for a lightweight wall, or a concrete floor as the lower boundary of the thermal envelope, as shown in the diagram. However, it is important to note that when the layers are misaligned, ensuring continuity through proper detailing becomes significantly challenging. Achieving successful joints with misaligned layers requires meticulous attention and skill comparable to watchmaking, which is often difficult to find among construction workers without appropriate compensation for their time. (Eley, 2016c)

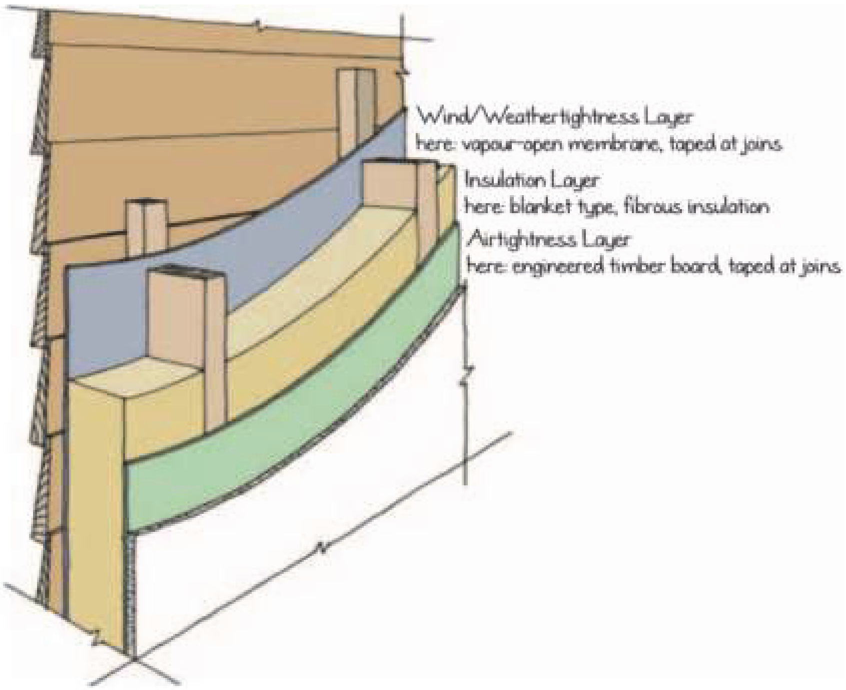


Figure 33: The layers of the thermal envelope in the passive house. (Brimblecombe, Rosemeier, and CSIRO (Australia) 2017)

Moisture migration is another factor that designers need to consider. Water flows from wet to dry conditions. In cold regions, the inside of a building will typically be more humid than the outside, and moisture will try to move from the inside to the outside. The opposite is true for air-conditioned buildings in humid climates: moisture will try to move from the moist exterior to the air-conditioned interior. A moisture barrier is necessary to stop condensation from happening in the center of a wall or roof cavity because when moist air is cooled, the water condenses. This can harm the structure, deteriorate the insulation, and in certain cases lead to mold growth and problems with the quality of the air. (Eley, 2016c)

The design of exposed thermal mass in sophisticated modeling tools necessitates connectivity of the thermal and airflow networks. Due to the limited inputs accessible during the early design process, this type of simulation is not feasible (e.g., optical properties and thermal capacitance of building material and furniture, and specific location of windows). Building designers should therefore consider the possibility of including thermal mass in their concept designs (such as exposed concrete, phase-change materials, or other materials) (O'Brien & Athienitis, 2015).

3.5. Future needs and conclusion

This section looked at various Net ZEB building design and simulation approaches to highlight the significance of selecting the right model resolution at various design stages. Accuracy and effort required for modeling are typically trade-offs. High-resolution models are typically not helpful at the beginning of the design process since designers need quick performance feedback. If the limits are recognized, using one or more basic tools is therefore suggested. As already mentioned, there are a variety of approaches to scale up to more intricate models. Tools necessary for traditional buildings must have two key characteristics that are not present in Net ZEB tools:

1. A need for tools with greater degrees of assurance and accuracy. In contrast to most building types, the Net ZEB definition requires an exact level of confidence in energy performance. As a result, tools must be able to accurately and definitively anticipate whether a building will be able to attain net-zero energy. For practically every aspect of buildings (materials, construction quality), occupant-building interactions, and present and projected climate scenarios, more precise and realistic mathematical models are needed.

2. The requirement for modern technology models. To achieve the lofty goal of net-zero energy, it is frequently necessary to combine tried-and-true design principles and technology with cutting-edge controls. Building system development and the accompanying BPS models are currently separated in time. Building designers who want to confidently demonstrate that a building with sophisticated technologies can reach expected performance have a challenge because of this.

The literature contains several in-depth reviews of the requirements of upcoming tools and features (Attia et al., 2009; Augenbroe, 2002; Ellis and Mathews, 2002). The experts of IEA SHC Task 40/EBC Annex 52 were also polled regarding the benefits and drawbacks of current simulation tools in the context of Net ZEBs. Here are some highlights of the for mentioned research findings:

– Ease of use: Net ZEB tools must be simple to use to appeal to a larger pool of designers. This calls for user interfaces that are simple to use, transparent (i.e., no hidden features or assumptions), standard (i.e., undo and auto-save), with few redundant inputs, effective input techniques, and understandable outputs.

– Accuracy: For designers to be able to forecast NetZero energy with a high degree of certainty, Net ZEB design tools must be precise. Tools used for thorough design must be accurate, whereas early-stage design tools can tolerate some inaccuracy because they offer quick feedback and concentrate on relative performance. Beyond the numerical techniques used to describe heat transport and other physical phenomena, accuracy includes having reasonable

– Availability of building features and technologies: To meet this ambitious energy goal, Net ZEBs frequently use technologically advanced building technologies. Numerous case studies, as previously mentioned, use specialized software to simulate specific architectural features. It is essential to have some modeling tools for these technologies. A tool's flexibility in integrating models for new technologies is at least as significant (for instance, TRNSYS permits the creation of custom models, and Energy Plus provides the Energy Management System, which has the option to incorporate custom code).

– Interoperability: Expecting a single tool to offer all the functionality needed for architectural design would be ridiculous. Move a model across programs, however, may involve partial or full input of data because many modern tools are standalone and employ proprietary or unusual file formats. Future tools ought to support easier switching between them.

– Rapid feedback: Wherever possible, quick feedback of simulation results is crucial to enable the exploration of more design options. Additionally, it gives the modeler more assurance that the simulation will succeed before expending excessive modeling effort. Faster input and faster simulation are two ways that rapid feedback can be achieved. The former will become more crucial as computer processing power rises. Design templates, tool compatibility, "smart" defaults, and effective input techniques can all help with this.

– Detailed documentation: BPS tools should offer comprehensive documentation on the modeling approaches and presumptions utilized, in addition to instructions on how to use the tools themselves. Users should be made aware of the restrictions placed on various tool features (such as simplifications) so they may weigh those risks against the benefits of using the tool. It is well known that two users of the same tool may obtain noticeably different outcomes. Therefore, the full disclosure of all underlying assumptions and modeling techniques is required.

– Built-in design guidance and rules of thumb: Many current BPS tools just provide anticipated performance metrics based on user inputs, not advice on how to create better designs. Future tools ought to have a function that offers general guidelines as a starting point.

– Parametric analysis and optimization: Even though parametric analysis is frequently utilized in design practice, very few tools now support it. Because several simulations, input data, and results must be kept, performing parametric analysis manually can take a lot of time. Similar to this, hardly many tools come with built-in optimization features. The BPS engine is currently driven by an external optimization engine for most optimization investigations. This calls for expertise in file management, programming, and optimization. Future Net ZEB technologies could ideally offer more assistance with optimization and result interpretation.

– Knowledgebase and database: A minimum of one building code or standard, such as LEED, ASHRAE Standard, and local building energy codes, must typically be followed by building modelers. The best tools would allow the insertion of code-minimum building specs and contain the compliance information for these standards.

– Useful graphical feedback: BPS solutions frequently offer enormous amounts of data (such as huge spreadsheets or automated reports), which can be too much for designers to handle. The Net ZEB design process would be aided by continued advancement in this area that would offer practical visual input on design performance. Sankey diagrams and multidimensional parametric analysis are two techniques for graphical feedback that have previously been proposed.

3.6. Conclusion

This chapter has covered two aspects of incorporating building performance simulation and other technology into the design process in great detail. The initial discussion focused on the Net ZEB design approach and the best design phases for incorporating different design features and tools. The main conclusions from that section are that, even when basic tools are used, attention should be paid to making important decisions that have an impact on energy performance early in the design process. A few of these include important geometry (for daylighting, passive solar heating, natural ventilation, and renewable energy collection), thermal mass (for passive solar design, and night cooling), and efficient envelope features (like insulation value and window-to-wall area ratio). Final tweaks and adjustments are typically made at later design stages. However, given the scope of Net ZEBs, numerous iterations may be required to reach all of the objectives. This is because the design stages are not well defined. Finally, a description of the IDP and three innovative project delivery methods—design-build (DB), construction management at risk, and IPD—was provided. The second main section of this chapter focused on modeling certain building phenomena and went into further depth regarding the appropriate model resolution for different building systems and design stages. The advantages and disadvantages of connecting various building system models were carefully considered. Even though an integrated model that includes all significant energy-related systems is strongly advised to ensure that net-zero energy (and/or other energy and comfort-related targets) is attained, this section recommends cautiously using simpler, standalone tools during the early design stages. Although it may be tempting for designers to use robust and detailed simulation tools to jump to complex models, such an approach is frequently so time-consuming that only a small number of design choices can be considered, and the majority of the tools' output comes too late to significantly affect design. Among other techniques, multidimensional parametric analysis and solar design days are suggested for using BPS tools and interpreting results.

Chapter 4

3. Review of the energy implications of passive and active strategies in nZEB

Countries have set targets to reduce their emissions below levels associated with business as usual by 2030 to meet their GHG emission reduction objectives. Implementing net-zero energy building (nZEB) in the building sector, which accounts for more than 25% of national GHG emissions and has the potential to considerably cut, is essential if we are to accomplish these goals. The most recent approaches to nZEB deployment are examined in this paper, including energy-saving techniques, passive sustainable design, able energy (RE), and backup systems for RE. The study also offers sophisticated recommendations for nZEB implementation based on the life cycle of a building, including the integration and optimization of passive and active techniques in the early stages of a building's life cycle and real-time monitoring of energy performance during the consumption period. The study intends to facilitate Indian rstastandingcomprehensive implementation options for nZEB by researchers, practitioners, and policymakers.

4.1. Outline

The review is carried out from two perspectives: Part A, which is centered on passive strategies, and Part B, which focuses on active strategies, as shown in Figure 34.

1. Passive strategies, aim to attain NZEB by reducing the building's energy consumption, particularly the heating and cooling loads, using architectural design strategies used in the early design phase, which is classified under Part A. Part A-1, which is passive sustainable design, and Part A-2, which includes energy-saving methods (EST), are the two subcategories of passive strategies.

2. Active strategies, belong to Part B, on the other hand, and are used after passive measures have been taken to lower the energy demand of the building. Active measures, such as the use of renewable energy (RE), can reduce the remaining load. Active strategies are divided into two parts: Part B-1, which is RE, and Part B-2, which is an alternative method for RE. (Smaoui et al., 2018)

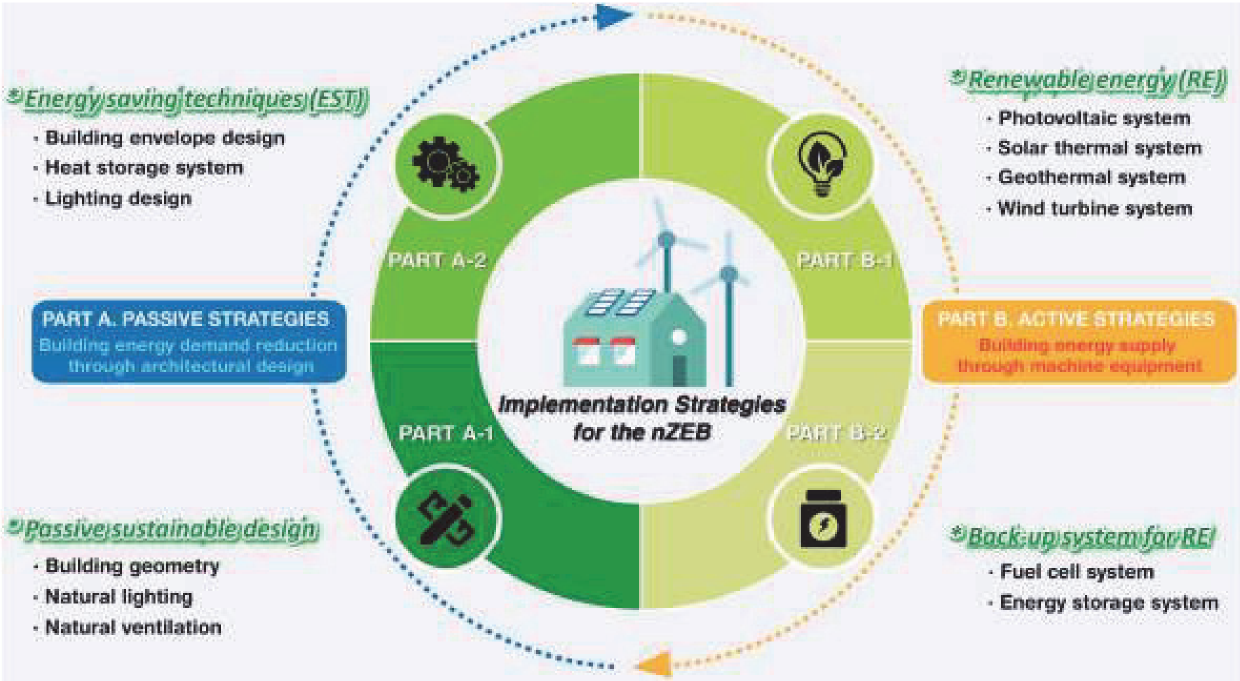


Figure 34: Passive and active strategies for implementing net-zero energy building. (Cellura et al., 2015)

4.2.A Holistic Review of the Implementation Strategies of NZEB

belong to Part B, on the other hand, and are utilized following the implementation of passive measures aimed at reducing the energy requirement of the building. The remaining load can be decreased through proactive efforts such as the usage of renewable energy (RE). Part B-1, which is RE, and Part B-2, which is an alternative to RE, make up the two categories of active strategies.

4.2.1. passive strategy

Prior studies on passive techniques for NZEB implementation have mostly been divided into two groups using the two components of passive sustainable design and EST. First, by considering the environment (such as latitude, longitude, and altitude) and weather (such as temperature, humidity, sunshine duration, and wind speed), passive sustainable design lowers the energy required for construction. Second, EST in the context of passive methods includes reducing the energy demand for buildings by enhancing insulation and sealing capabilities using better construction materials (e.g., thermal insulation, shading, etc.). (Cellura et al., 2015).

Part A-1: Passive Sustainable Design

There are various methods for passive sustainable design (e.g., site planning, layout planning site plan, natural lighting, natural ventilation, etc.), which can reduce energy consumption by considering the building's geographical and meteorological factors. In this study, the past studies on such various methods for passive sustainable design were analyzed by dividing them into three categories considering the progression of studies: (i) building geometry; (ii) natural lighting; and (iii) natural ventilation. In this study, the existing studies on these three factors are summarized in Tables 1–3.

4.2.1.1. Building geometry:

Building composition and shape have a significant impact on energy demand. As a result, many earlier studies on building geometry evaluated the energy efficiency of buildings by concentrating on the surroundings (namely, site slope) and plan form (see Table 3). (Cellura et al., 2015)

Another example pertains to a case study conducted in Calolziocorte, a town located in the Lecco region of Italy, situated in the northern part of the country. Calolziocorte is positioned at an altitude of 241 meters and has the following coordinates: 45°48'04.00" North, 9°25'05.700" East. The average elevation of Calolziocorte is approximately 100 meters above sea level. Considering its latitude and longitude, the local climate falls within the humid subtropical climate zone. The summers in this region are typically hot and wet, while winters are moderately cold. Average temperatures during winter range from around 1°C to 3°C, while in summer, temperatures can exceed 26°C. The hills experience mild summers, whereas the plains can become quite hot. The warmest month is July, with maximum temperatures reaching 28°C, while the coldest month is December, with a minimum temperature of -1.5°C. Cooling is typically required from May to September, while heating is needed from mid-October to March. Therefore, when calculating the heating and cooling loads for the studied building, the data should consider the effect of working hours, material properties, and ventilation systems. Rainfall is common and abundant throughout the year, with higher precipitation levels in spring and autumn. May is the wettest month. An analysis of incident solar radiation, including direct and diffuse radiation, reveals a significant potential for daylight utilization. The length of daylight varies from 9 hours in winter to 16 hours in summer. However, it is important to exercise caution and thoughtful planning to strike a balance between daylighting and cooling loads, as excessive radiation during summer months can lead to overheating in buildings. Despite its proximity to the lake, the city experiences challenging winter conditions. From November to March, temperatures consistently drop below freezing, particularly in December and January, accompanied by heavy and constant snowfall. The relative humidity in Calolziocorte ranges from 45% to 93%, with higher humidity levels in October and drier conditions in June. The average wind speed peaks in April, while December has the lowest average wind speed. Additionally, the average wind speed varies from 0 to 4 m/s. These factors should be taken into account to ensure proper air tightness and minimize the impact of wind on the heating and cooling loads of the building. (Khan et al., 2017)

For instance, in their study, De Castro and Gadi (2017) analyzed the annual energy savings based on the site slope ranging from 0 to 50 to determine the optimal design considering topography. Utilizing the 'EnergyPlus software tool, they demonstrated that a building with a 30-site slope and a box-type design exhibited the highest potential for energy savings. Choi et al. (2012) conducted a comprehensive investigation using questionnaires and field studies to examine energy consumption patterns in different living types and high-rise apartment layouts. The study assessed electricity, gas, and CO2 emissions to evaluate the energy performance of the buildings. The findings indicated that tower-type buildings consumed more gas but had lower electricity usage compared to plate-type buildings. Additionally, mixed-use buildings showed higher CO2 emissions in terms of living type compared to regular residential buildings.

In another research effort, various building shapes (L, U, T, H, triangle, rectangle, rectangle min-corner) and design variables (such as orientation, insulation, occupant schedule, etc.) were considered. Energy consumption was evaluated using multilinear regression analysis and Monte Carlo simulation. The analysis of annual energy consumption revealed that the H-shaped building in the Texas climate zone had the highest energy consumption among all the shapes studied. Consequently, it is essential to incorporate higher levels of insulation in the building envelope for our project to reduce the overall energy demand, considering that Milan is situated in the Lombardy region. In the Lombardy region, the reported heating load for sports facilities is approximately 268 kWh/(m2yr), indicating a total primary energy demand of around 300 kWh/(m2yr). This further underscores the need for improved insulation measures in our project to minimize energy requirements effectively. (Cellura et al., 2015)

4.2.1.2. Natural lighting:

Numerous researchers have conducted extensive studies on determining the optimal orientation of buildings and designing efficient atriums to incorporate natural light systems for achieving Net Zero Energy Building (NZEB) implementation. A thorough analysis of factors such as the sun's altitude and daylight levels has been undertaken (see Table 3) to guide these investigations.
Abanda and Byer (2016) utilized building information modeling techniques and advanced software tools, including Revit and Green Building Studio, to evaluate the impact of building orientation on energy consumption. Their study involved designing the building, converting it into numerical data using energy simulation tools, and analyzing the annual energy consumption based on different orientations. The findings revealed that a south orientation (+180 degrees from the north) yielded the highest reduction in electricity and gas consumption. Moreover, the study highlighted a significant energy cost savings difference of £878 over 30 years between the best and worst orientations (+45 degrees from the north).
To enhance energy efficiency beyond individual homes, researchers also investigated optimal building orientations at a community level. Furthermore, extensive research has focused on effective atrium design, considering that the atrium's shape significantly influences natural

lighting. Nasrollashi et al. (2015) examined the impact of the atrium-to-total building area ratio on energy efficiency and indoor environmental conditions using the Design Builder software. Their study demonstrated that a 1/4 atrium-to-total building area ratio provided the optimal balance of thermal comfort, daylighting, and energy efficiency.

In a similar vein, Mohsenin and Hu (2015) evaluated daylighting in an office building based on different atrium styles (central, attached, and semi-enclosed), atrium proportions (Well Index), and roof aperture designs using the climate-based daylighting modeling tool DIVA. Their analysis considered various elements, including monitor roofs and horizontal skylights, to assess the impact on daylight availability. Overall, these studies emphasize the importance of strategic building orientation and well-designed atriums to maximize energy efficiency, reduce energy costs, and optimize indoor environmental conditions in the pursuit of NZEB goals. (Khan et al., 2017)

To provide an example, let's examine The Leaf House (LH) located in Angeli di Rosora, Ancona, Italy. The LH serves as a case study, showcasing a south-oriented design that aligns with the country's prevailing energy regulations. It embraces a range of sustainable energy sources, adhering to current Italian energy laws. The environmental and energy performance of each of the six apartments within the LH is meticulously monitored and recorded.

Following the principles of Net Zero Energy Building (NZEB), the LH incorporates various elements and solutions rooted in bioclimatic and passive design strategies. Specifically, the windows are strategically sized to optimize passive solar gains during the winter. The southern façade features larger windows with approximately 20% wall porosity, while the eastern, northern, and western façades have smaller windows with wall porosity ranging between 6 and 10%. This deliberate design choice allows for the efficient utilization of solar energy. Additionally, the windows on the southern façade are equipped with coverings, such as solar thermal panels, and horizontally extended balconies measuring approximately 1 meter in length. In cases where additional coverage is required, rolling mechanisms can be employed to shield any window.

The Leaf House exemplifies the integration of sustainable practices and passive design techniques to create an environmentally conscious and energy-efficient living space that aligns with the NZEB concept. (Salom et al., 2011)

4.2.1.3. Natural ventilation:

When designing for the implementation of nearly Zero Energy Buildings (nZEB), it is crucial to consider an architectural strategy that effectively incorporates outdoor air circulation, commonly known as natural ventilation, during the early stages of the design process. Natural ventilation typically falls into two main categories: wind-driven ventilation, which relies on pressure differences between the front and back of the structure, and buoyancy-driven ventilation, which relies on temperature disparities between vertical and horizontal planes (refer to Table 4). Several

previous studies have investigated buoyancy-driven airflow. Li and Liu (2014) focused on the thermal efficiency of a solar chimney utilizing phase-change material (PCM) under different heat fluxes (500, 600, and 700 W/m2). Their research demonstrated that PCM-based solar chimneys, which enable the time-shifting of solar energy, are more effective for natural ventilation compared to traditional solar chimneys (Acred et al., 2014). This improved performance can be attributed to the significant thermal energy storage capability of PCM. Acred and Gary (2014) proposed a design approach for stack effect ventilation in a multi-story atrium building, utilizing a concise mathematical model. They developed dimensionless charts that serve as guidelines for achieving natural ventilation in building design. Additionally, numerous studies have explored wind-driven ventilation. For instance, computational fluid dynamics (CFD) tools and wind tunnel testing were employed to compare a novel wind-catcher-integrated wing wall design with a traditional wind catcher. The results indicated that the wind-catcher with a 30-degree wing wall angle exhibited superior ventilation performance compared to designs with 45-degree and 60-degree angles. The new design demonstrated a 50% improvement in ventilation efficiency over the conventional wind catcher. Furthermore, another study employed CFD software to evaluate ventilation efficacy in an urban residential neighborhood based on building density levels. This research provided a technique for selecting the most effective neighborhood building layout design in terms of ventilation and pollutant levels.
By considering these studies and incorporating appropriate architectural strategies for natural ventilation, designers can enhance the energy efficiency and overall performance of nZEB projects. (Mei et al. (2017).

4.2.1.4. Discussion:

This study has focused on the analysis of passive sustainable design, specifically examining building geometry, natural lighting, and natural ventilation. Building geometry has been a key area of research, exploring the energy-saving potential based on different shapes and densities. Similarly, previous studies have emphasized the importance of natural lighting in reducing the energy burden associated with lighting, cooling, and heating, considering factors such as the size, shape, and orientation of the atrium. Additionally, the study has examined the energy-saving potential and ventilation performance of buoyancy-driven and wind-driven ventilation. By considering building geometry, natural lighting, and natural ventilation from the initial stages of the planning process, significant outcomes can be achieved. These include a 25% reduction in heating requirements, a 20% improvement in energy efficiency, and a decrease in cooling burden ranging from 10% to 30%. However, to fully embrace the concept of Nearly Zero Energy Buildings (NZEB), passive sustainable design alone is insufficient. Future research in the field of NZEB should incorporate energy-saving techniques (EST) and active strategies in addition to passive sustainable design, ensuring a comprehensive approach to achieving energy efficiency.

Classification	Authurs	Design variable	Analysis target	simulation tools or methoods	Country	Main Finding
Orientation	Fallahtafti and Mahdavinejad	Orientation, building geometry, window-to-wall ratio (WWR)	Heating gain/loss	Mathematical model	Iran	The optimal orientation of a building rely on its compactness, additionally WWR has the most correlation in decision for orientation
	Abanda and Byer	U.K electricity price, gas price, orientation (interval: 45◦)	Annual CO2 emissions	Revit, BIM, Green Building Studio	uk	Appropriate orientated building can save up to £878 worth of energy over a lifetime
	de Vasconcelos et al	Orientation, discount rate	Global energy cost, energy consumption	Life cycle cost analysis	Portugal	Considering both building orientation and Portuguese discount rate can help making a decision on a cost-optimal solution for energy efficiency
	Hemsath	Orientation, climate factors	Annual energy costs, optimal orientation	BEopt, EnergyPlus	USA	Community orientation has more impact on the energy savings in comparison to individual household's orientation
Atrium	Taleghani et al.	Wind speed	Energy demand	EnergyPlus	The Netherland	From May to August, the energy efficiency of atrium is maximized during the whole year
	Nasrollashi et al	Atrium ratio, internal heat load	Annual energy consumption, comfort indices	Mathematical model	Iran	Lessening the atrium ratio reduces the annual amount of energy consumption and daylight amounts
	Mohsenin and Hu	Well index (i.e., atrium proportion), atrium types (e.g., semi-enclosed), aperture types (e.g., horizontal skylight)	Useful daylight illuminance	DIVA	USA	Atrium Well Index is an important indicator to decide atrium proportion and to comparing daylight illuminance in atrium.

Table 3: A literature review of natural lighting in terms of passive sustainable design (Oh et al., 2017)

Classification	Authurs	Design variable	Analysis target	simulation tools or methoods	Country	Main Finding
Buoyancy-driven ventilation	Li and Liu	Solar intensity (i.e., 500–700 W/m2), phase change material (PCM) thermos-physical properties	Air flow rate	Mathematical method	UK	It was confirmed that PCM-based solar chimney can achieve the time-shifting of solar energy, which can induce more effective natural ventilation compared to the general solar chimney, based on the capacity of PCM
	Jing et al	Solar intensity (i.e., heat flux), gap to height ratio (i.e., 0.2~0.6)	Air flow rate	Expriment	China	Optimal gap-to-height ratio (i.e., the area of the aperture to the height of the chimney) for promoting natural ventilation in solar chimney is about 0.5
	Tong et al	Weather (e.g., temperature, wind), season	Natural ventilation potential	Atmospheric boundary layer, meteorology model	USA	Among studied cities (i.e., New York, Los Angeles, Chicago, and Minneapolis), Los Angeles provides the most ideal climate for utilizing natural ventilation (i.e., 7258 natural ventilation hours or 83% of the year at ground level)
Wind-driven ventilation	Afshin et al	Wind angle, inlet wind speed	Air flow rate	Mock up experiment	Iran	The two-sided wind-catcher with the highest ventilation rate occurs at the angle of 90◦
	Mei et al	Building densities (i.e., medium (0.25) and compact (0.44) urban development)	Wind flow	CFD simulation	China	When low level of building density is maintained, the ventilation rate increases • Depending on the neighborhood composition characteristics (e.g., building block array), the breathability of city is greatly affected

Table 4: A literature review on natural ventilation in terms of passive sustainable design. (Oh et al., 2017)

4.3. Part A-2: Energy-Saving Techniques (EST)

The building envelope design, heat storage systems, and lighting design were the three categories in which the existing research on EST for passive strategies was investigated in this study. Additionally, Tables 5-7 methodically summarized earlier research on EST.

4.3.1. Building envelope design:

The role of the building envelope in energy consumption, particularly in terms of heating and cooling demand, has been extensively studied. These studies can be categorized into three main areas: heat insulation, opening design, and shading devices (refer to Table 5). Research focusing on heat insulation has yielded significant findings. For instance, Pomponi et al. (2015) compared different façade strategies and assessed their impact on CO2 emissions and energy consumption throughout the building lifecycle. The study concluded that a double-skin façade had the greatest potential for reducing carbon emissions. Another study by Tam et al. (2016) evaluated the technical performance and economic viability of green roofs as a heat insulation solution in Hong Kong, demonstrating that green roofs can lower interior temperatures by 3.4°C. Window design, given its vulnerability to heat gain and loss, has been a key area of investigation. Researchers, such as Wen et al. (2017), utilized software tools like Energy Plus to determine the optimal window-to-wall ratio (WWR) for different cities. Their findings revealed that energy efficiency was optimized between 30% and 45% of WWR for cities like Oslo, Frankfurt, Rome, and Athens. Additionally, Wen et al. aimed to provide guidelines for assessing the suitability of WWR during the early stages of the design process, considering window characteristics and meteorological variables. The effectiveness of shading devices in reducing building energy demand has also been extensively studied. Kim et al. (2012) examined various types of external shading devices, such as overhangs and blinds, using the IES_VE software. The research concluded that external shading devices outperformed internal shading devices in terms of technical performance and energy savings for heating and cooling. These studies collectively emphasize the importance of envelope design in reducing building energy demand. Through effective heat insulation, optimal window design, and appropriate shading devices, significant energy savings can be achieved. (Cellura et al., 2015)

The case study of SDE 2012 houses focuses on the envelope system, highlighting common features such as high levels of insulation, high-performance glass, and airtight construction. Figure 33 demonstrates that the thermal transmittances of the home envelopes were lower than the specified requirements of the Spanish Building Code (CTE) for Madrid city. It is worth noting that the roof U-value of H06 did not meet the minimum code requirement of 0.38 W/m2 K (refer to Figure 33). However, it is important to mention that thirteen homes (72%) had wall thermal transmittance values below 0.20 W/m2 K, surpassing the maximum allowed value of 0.66 W/m2 K according to the code (see Figure 35). Therefore, the majority of the SDE 2012 participant homes exhibited superior thermal performance, exceeding the prescribed standards of the Spanish Building Code. (Rodriguez-Ubinas et al., 2014)

4.3.2. Heat storage system:

The heat storage system has been extensively researched due to its significance in achieving NZEB goals, as a building's heat capacity plays a vital role. This study reviewed previous research that focused on thermal mass and Trombe walls, examining their impact on energy reduction and building thermal performance (refer to Table 6). Firstly, several earlier studies have explored the use of a building's thermal mass to reduce heating and cooling demands by analyzing its heat storage capabilities. Ma and Wang (2012) conducted a numerical study on the dynamic heat transfer performance of interior planer thermal mass, considering different thicknesses (ranging from 0.025 to 0.70 m) and materials (such as wood, concrete, and steel). The research found that achieving optimal heat storage capacity depends on the thickness of the thermal mass. Chernounsov and Chan (2016) utilized Energy Plus software to investigate the thermal performance of phase change materials (PCM) incorporated into the building envelope of a Hong Kong office building, focusing on the relationship between PCM thickness, location, orientation, and indoor thermal environment. Additionally, Trombe walls, which utilize a double-glazed solar heating collector on the wall to store heat, have been the subject of previous studies. Bojic et al. (2014) conducted a comparative analysis of environmental performance, including primary energy consumption for heating during winter and annual energy consumption, with and without a Trombe wall. The findings demonstrated that implementing a Trombe wall could lead to annual energy savings of 20%. Another study focused on analyzing the impact of a passive house with a Trombe wall on building energy consumption using CFD simulation, specifically considering the climate conditions in Belgrade. The results indicated an increase in cooling demand during summer due to the Trombe wall but highlighted its effective heating efficiency during winter, making it a suitable choice for Belgrade's climate. (Rodriguez-Ubinas et al., 2014)

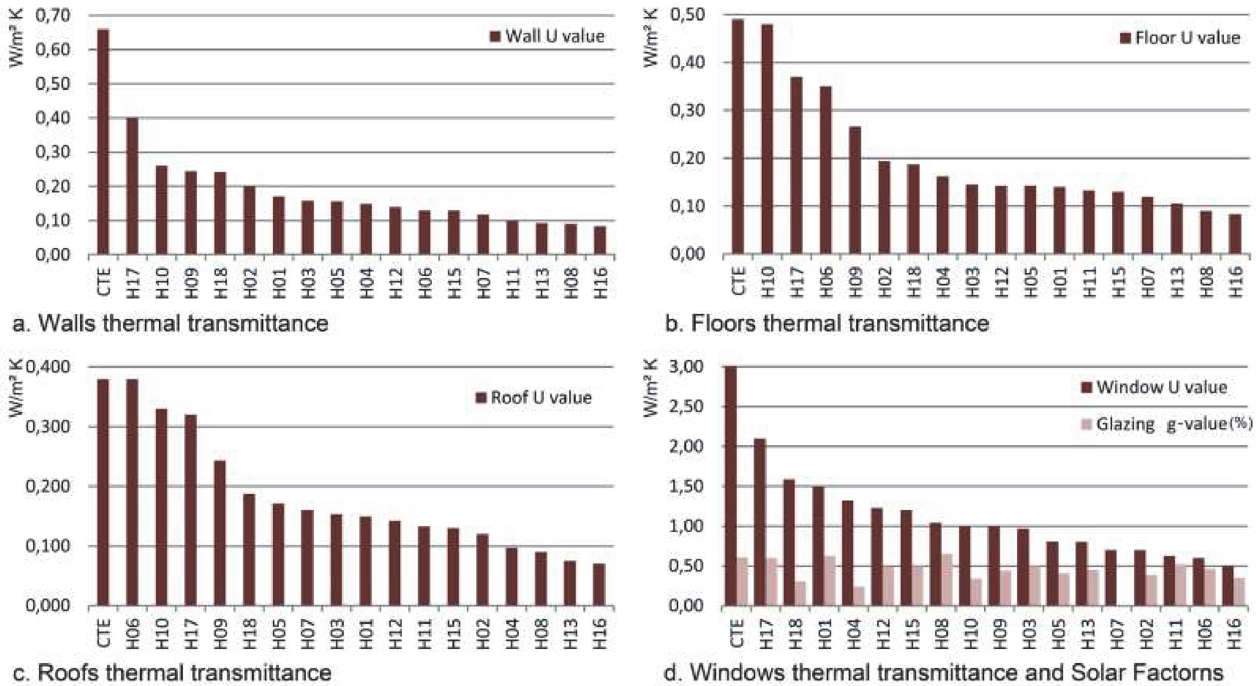


Figure 35: Thermal properties of the houses' envelope compared with the Spain Building Code (CTE) requirements. Notes: (1) If the glass-to-wall ratio of the south fenestration is lower than 30%, then the maximum permitted U-value is 3.5W/m2 K. For ratios between 51% and 60%, the maximum permitted U-value is 3.0W/m2 K. (2) The solar factor (g-value) value is regulated only if the glass-to-wall ratio is between 51% and 60%. In those cases, the maximum solar factor value is 0.6. (Rodriguez-Ubinas et al., 2014)

4.3.3. Lighting design:

This study thoroughly investigated previous research on lighting solutions, including lighting emitting diodes (LEDs), light shelves, and lighting control systems, to reduce the lighting burden in the context of ZEB implementation (refer to Table 7). Principi and Fioretti (2014) conducted experimental tests to compare the environmental performance of compact fluorescent and LED lighting. The findings revealed that replacing compact fluorescent with LED lighting can result in a significant reduction of up to 41.5% in energy consumption and global warming potential. Another study utilized Radiance software to evaluate the effectiveness of daylight distribution using light shelves and movable semi-transparent external blinds under various design conditions. The combination of a light shelf and semi-transparent movable external blinds demonstrated the ability to increase daylight exploitation, enhance uniform illuminance distribution, and achieve higher light levels at the rear of the area while reducing daylight near the window. Byun et al. (2014) developed an intelligent LED control system leveraging multiple sensors and wireless communication technology. This advanced system considered both energy usage and user satisfaction, automatically adjusting illumination levels to achieve energy savings of 21.9% while ensuring optimal lighting conditions. (Rodriguez-Ubinas et al., 2014)

4.3.4. Discussion

This study presents a comprehensive analysis of previous research on Energy-Saving Techniques (EST) with a specific focus on three key aspects: building envelope design, heat storage system, and lighting design. Extensive studies have been conducted on building envelope design and its impact on energy demand, including investigations on heat insulation, window design, and shading devices. These studies recognize the crucial role played by the building envelope in directly interacting with the external environment. Furthermore, research is ongoing to enhance a building's heat storage capabilities by utilizing advanced materials such as Phase Change Materials (PCM) in the heat storage system. Additionally, studies addressing lighting design, particularly the utilization of LEDs, aim to alleviate the lighting burden through the implementation of control systems that integrate daylight and shading devices. While significant progress has been made in reducing building energy requirements through EST, it is essential to acknowledge that achieving nearly Zero Energy Buildings (nZEB) necessitates a comprehensive approach that combines both EST and active strategies. Therefore, active strategies should be seen as complementary to inactive strategies in realizing the full potential of nZEB implementation.

4.4. Part B

Active Techniques The achievement of nearly Zero Energy Buildings (nZEB) cannot be solely accomplished through the passive methods discussed in Section 2.1. Recognizing this, active strategies are essential to compensate for the remaining energy consumption that cannot be completely mitigated by passive measures. In this study, previous research on active tactics has been categorized into two main groups: Renewable Energy (RE) and the backup system for RE. RE refers to energy generated from renewable sources such as sunlight, geothermal energy, and wind, which serves as an active approach to supplement energy requirements. Conversely, the backup system, as an active strategy, plays a vital role in ensuring the successful implementation of RE by addressing the inherent instability of renewable energy caused by external factors such as weather conditions.

4.4.1. Part B-1:

RE: Renewable Energy This study reviewed prior research on the four categories of RE, whose use is an active strategy for reaching NZEB: solar thermal system, geothermal system, photovoltaic (PV), and wind turbine system (refer to Tables 8–11), with a focus on its relevance to buildings.

Classification	Authors	Design Variables	Analysis Target	Simulation Tool or Method	Country	Main Finding
Heat insulation	Daouas (2011) [40]	Orientation, insulation property	Annual energy load, optimum insulation thickness	Mathematical model	Tunisia	• When the optimal insulation thickness (i.e., 10.1 cm) was applied to the building, the energy saving was 71.33% and the payback period was 3.29 years
	Ottele et al. (2011) [41]	Green wall type (e.g., bare, direct, indirect)	Energy savings	Life cycle environmental analysis	The Netherlands	• Living wall system based on felt layers has the highest environmental impact
	Sanjuan et al. (2011) [42]	Open-joint ventilated façade, conventional façade	Heat flux, solar radiation	CFD simulation	Spain	• Open-joint ventilated facade has lower heat gain than conventional facade up to 26% during daylight hours
	Hong et al. (2013) [43]	Double skin façade type (i.e., box, corridor, multistory, shaft)	Saving-to-investment ratio, break-even point	Life cycle cost analysis	Korea	• Multi-story double skin facade are much more efficient than any other double skin facade in terms of the economic feasibility
	Pomponi et al. (2015) [44]	Façade type (i.e., double skin/mono), glass type (i.e., clear/coated)	Heating load, payback period	Life cycle energy and environmental analysis	UK	• Double skin facade is more energy efficient and more carbon efficient in 98% and 85% of the cases
	Tam et al. (2016) [45]	-	Measured temperature, maintenance cost	Survey and research	Hong Kong (China)	• The green-roof can lower the room temperature to 3.4 °C • Solar depth and vegetation species can impact on thermal performance
Opening design	Su and Zhang (2010) [46]	WWR, orientation, glass type (e.g., single, hollow)	Environmental impact	Life cycle environmental analysis	China	• The WWR is the most influential factor in life cycle environmental impact
	MA et al. (2015) [47]	WWR (i.e., 10–100% with interval 10%), U-value	Recommended WWR	Mathematical model	USA	• The optimal WWR is determined not only by the temperature amplitude but also the U-value of the building envelope
	Seo et al. (2015) [48]	WWR, orientation, glazing type, shading type	Heating/cooling demand	DesignBuilder v3.0, Microsoft-Excel-based VBA	Korea	• This study developed the nine-node-based Lagrangian finite element model for estimating the heating and cooling load according to the WWR and orientation
	Goia (2016) [49]	WWR, orientation, building geometry, façade material	Total energy consumption, Daylight autonomy	EnergyPlus	E.U.	• The optimal WWRs of European countries in the mid-latitude were estimated to be within the range of 30–45%
	Wen et al. (2017) [50]	WWR (i.e., 10–70%, interval: 10%), orientation	Total CO_2 emission, recommended WWR	EnergyPlus	Japan	• This study presented the optimal WWR of all regions of Japan by considering the meteorological factors and window properties
	Zenginis and Kontoleon (2017) [51]	WWR, building aspect ratio (i.e., length and width dimensions)	Heat gain and loss	Mathematical model	Greek	• The façade orientation and building aspect ratio with WWR are huge impact on heat fluxes through the building
Shading device	Kim et al. (2012) [52]	Shading device type (i.e., overhang, blind, light-shelf), device slat angle	Energy saving, annual heating load	EnergyPlus	Korea	• As the internal device absorbs solar heat and release to the inner space, external shading is more superior to internal devices.
	Cheng et al. (2013) [53]	Width/height of opening, ratio of length of shade device to window vertical length	Shading ratio	Mathematical model	Taiwan	• By choosing the optimal design (i.e., using proper material), shading device systems can achieve better utilization and peak efficiency than ever before
	Lin et al. (2016) [54]	Sunshade style and size (i.e., horizontal, vertical, grid), envelope material	Optimal sunshade	TRNSYS	Taiwan	• Office building envelope design model provide optimum sun shade type, sunshade length for engineer's decision
	Ye et al. (2016) [55]	Shading type (i.e., internal, external, and non-shading)	Indoor temperature, solar radiation intensity, cooling load	EnergyPlus	China	• By using proper material, internal shading can be better than external shading devices in terms of cost and maintenance

Table 5: A literature review on the buildinenvelopeop design in terms of energy-saving techniques. (Oh et al., 2017)

Classification	Authors	Design Variables	Analysis Target	Simulation Tool or Method	Country	Main Finding
Thermal mass	Diaconu (2011) [56]	PCM melting point, ventilation frequency, occupancy pattern	Indoor temperature, energy savings	TRNSYS	Romania	• The occupancy pattern influences the PCM melting point for reaching maximum energy storage capacity
	Weinlaeder (2011) [57]	Conventional/PCM integrated interior blind	Indoor/outdoor temperature	Experiment	Germany	• PCM-blind has an enormous advantage in decreasing cooling loads and providing thermal comfort
	Ma and Wang (2012) [58]	Thermal mass thickness	Indoor temperature, maximum heat storage	Mathematical method	USA	• The heat storage ability of thermal mass relies on optimal thickness to reach maximum value
	Silva et al. (2015) [59]	Daily average solar radiation, wind direction, and intensity	Indoor/outdoor temperature	Experiment	-	• PCM-shutter benefits for thermal inertia of building thermal environment
	Turner et al. (2015) [60]	Pre-cooling period	Energy consumption, peak load reduction	REGCAP	USA	• Optimum pre-cooling strategy removes 80% of the peak load and minimize additional energy consumptions
	Chernousov and Chan (2016) [61]	Thermal mass property, internal load fraction	Indoor temperature, AC power demand	EnergyPlus	Hong Kong (China)	• PCM layers need to be less isolated on the interior to promote rapid thermal exchange
Trombe wall	Stazi et al. (2012) [62]	Wall material (e.g., concrete), glazing type, wall thickness, frame material	CO_2 emissions	EnergyPlus, Life cycle environmental analysis	Italy	• The trombe walls have an immense environmental burden both in the production and operational stages
	Abbassi et al. (2014) [63]	Trombe wall area (i.e., 0–19 m^2, interval: 1 m^2)	Heating energy savings	TRNSYS	Tunisia	• The area of trombe wall has influence the thermal efficiency; 4 m^2 areas can save up 50% of heating load and the 8 m^2 can save up to 77%
	Bojic et al. (2014) [64]	Real residential house description (e.g., wall material)	Primary energy use, energy saving	EnergyPlus	France	• When installing the trombe wall, annual energy savings are over 20% in heating season
	Briga-Sa et al. (2014) [65]	Massive wall thickness (i.e., 15–40 cm, interval: 5 cm)	Heating load	Mathematical method	Portugal	• Massive wall thickness significantly increases in the thermal performance of the trombe wall
	Bojic et al. (2015) [66]	Boundary condition (e.g., material density)	Indoor temperature, heat flux	CFD simulation	Servia	• According to CFD simulation, the trombe wall is a good alternative for good passive strategy in Belgrade weather

Table 6: A literature review on the heat storage system in terms of energy-saving techniques. (Oh et al., 2017)

Authors	Design Variables	Analysis Target	Simulation Tool or Method	Country	Main Finding
Byun et al. (2014) [ ]	Occupancy time, occupant movement detection	Lighting intensity	Experiment	Korea	• The intelligent household LED lighting system can cut down total energy consumption by 21.9%
Principi and Fioretti (2014) [ ]	Life cycle inventory (e.g., land use, cumulative energy demand, etc.)	Environment impact	Life cycle environmental analysis	Italy	• The LED allows the environmental impacts to be reduced due to high energy saving efficiency
Xu et al. (2014) [ ]	Distance from window	Illuminance, uniformity ratio (i.e., minimal illuminance/average illuminance)	Radiance, TracePro7.0	Hong Kong (China)	• Clerestory window with certain curvature angle range (44.3–90°) improves the illuminance and uniformity distribution of an inner space
Berardi and Anaraki (2015) [ ]	Location of illuminance measurement, WWR	Useful daylight illuminance	Radiance	Canada	• The light shelves increase the useful daylight illuminance level up to six meters in front of the windows and provide uniform distribution
Nagy et al. (2015) [ ]	Occupancy time, control mode (i.e., baseline, comfort, and savings)	Daily energy consumption	Experiment	Switzerland	• The result of six-week case study for 10 offices indicates that energy savings 37.9% were achieved compared to a standard light setting control
Meresi (2016) [ ]	Location of illuminance	Daylight level/factor	Radiance	Greek	• The light shelves take advantage of daylight exploitation in classrooms and provide uniform distribution of daylight
Caicedo et al. (2017) [ ]	Daylight factor, occupancy time, ceiling sensor position	Dimming level	Experiment	The Netherlands	• The smart-lighting system control system with ceiling sensors provides compatibility of energy savings and the proper illumination level in the room
Lee et al. (2017) [ ]	Vent ratio (4, 6, 8, and 10 mm of diameter), angle of light-shelf	Indoor illumination, energy consumption	Experiment	Korea	• Perforated light-shelves are an alternative of conventional light-shelves that are easily damaged from outdoor wind • Energy saving efficiency is improved by widening of the reflector of perforated light-shelves

Table 7: A literature review on lighting design in terms of energy-saving techniques. (Oh et al., 2017)

4.4.1.2. Solar thermal system:

Various research studies have demonstrated the viability of utilizing solar heat for both heating and cooling purposes in buildings. These studies have focused on the absorption, storage, and conversion of solar energy, particularly examining the thermal efficiency of building-integrated solar thermal systems. One aspect of investigation has been the influence of the solar collector's color, which can range from white to black. Experimental evaluations have considered factors such as season, operation time, temperatures (including tank temperature and solar array inlet/outlet temperature), and solar heat data (such as solar flux and solar collector efficiency). Through this analysis, the techno-economic-environmental performance of solar-thermal-assisted HVAC systems has been assessed. To determine the optimal capacity of solar thermal systems, a model incorporating meteorological information, collector area, tank volume, and auxiliary power unit size was developed using algorithms such as particle swarm optimization and genetic algorithm. The goal was to maximize the system's efficiency and effectiveness.

Additionally, a prototype of a building-integrated PV/thermal air collector was tested using trials and two-dimensional models in COMSOL Multiphysics. These tests aimed to evaluate the system's thermal and electrical energy production capabilities. The results demonstrated a maximum temperature of 31°C for the prototype, with typical thermal and electrical efficiencies reaching 31% and 7%, respectively. These findings provide valuable insights into the potential of solar-thermal systems for efficient energy utilization in buildings.

4.4.1.3. Geothermal system:

Numerous studies have focused on harnessing the capacity of geothermal systems to decrease heating and cooling demands by leveraging the constant underground temperature of 15°C throughout the year. Evaluations have been conducted to assess the effectiveness of geothermal systems in real-world scenarios. For instance, a study conducted at Pusan National University in South Korea examined the implementation of a geothermal system. Measured data, including outdoor and indoor temperature, as well as inlet and outlet temperature of circulating water, were analyzed. Thermocouples were strategically placed underground to investigate the thermal diffusion characteristics of the geothermal heat exchanger and determine the system's technical performance during both heating and cooling periods. In another study carried out in northern India, the potential reduction in CO2 emissions and electricity consumption through the installation of a geothermal system during winter was assessed. Factors specific to the region, along with the performance coefficient of the geothermal system, were considered. The findings indicated that the installation of a geothermal system could potentially lead to a significant reduction of 0.539 million metric tons of CO2 emissions and substantial electricity savings amounting to 708 GW. Furthermore, a comprehensive analysis was conducted using the GLHEPro software program to evaluate the economic and environmental performance of the geothermal system. This analysis considered various factors, such as the entering water temperature, from a life cycle perspective. The aim was to provide insights into the overall economic viability and environmental impact of the geothermal system. These findings contribute to our understanding of the geothermal system's potential, both in terms of its technical performance and its economic and environmental benefits. (Cellura et al., 2015)

4.4.1.4. Wind turbine system

Wind turbine systems rely on wind speed as a critical factor, and previous studies have examined their technical performance when implemented on rooftops or tall buildings (refer to Table 11 for further details). The viability of installing wind turbine systems in tall buildings was evaluated through wind tunnel experiments. These experiments revealed that the building's orientation, the specific shapes of the four tunnels with constrained inner sections, and nearby structures significantly influenced wind loads and speed amplification. In another study, the technical potential of wind power in urban high-rise buildings was explored by considering wind data and building characteristics. Numerical analysis using CFD and ANSYS FLUENT software was conducted to assess the feasibility of wind power generation. By utilizing the mesoscale meteorological model

Weather Research and WRF v3.4 software, the wind power resource around mega-tall structures in China at a scale of 1000 meters was evaluated. The study's findings indicate that the wind turbine system operates optimally in terms of wind power density and electricity generation between 300 and 200 meters above the ground, with buildings oriented north and south, respectively. (Cao et al. 2017)

4.4.1.5. Discussion:

The four studies conducted in this research, which focused on PV systems, solar thermal systems, geothermal systems, and wind turbine systems, revealed distinct patterns and areas of investigation. The analysis of PV systems primarily centered around assessing the techno-economic performance of different PV panel types (e.g., a-Si panels, polycrystalline panels, monocrystalline panels, semi-transparent PV systems) and developing models to predict electricity generation based on design parameters. On the other hand, studies on solar thermal systems predominantly examined the thermal performance of buildings, considering factors such as color, capacity, and temperature. In the case of geothermal systems, much of the research focused on evaluating energy savings and economic benefits, taking into account design factors such as the coefficient of performance, location, and borehole length of specific geothermal systems. Lastly, investigations into wind turbine systems applied to high-rise buildings aimed to determine energy production levels and identify optimal design conditions, considering climate variables (e.g., wind data), building layouts, and other relevant factors. Various initiatives, including the utilization of high-efficiency PV panels and the analysis of optimal design conditions for RE systems, have been pursued to enhance a building's energy self-sufficiency. However, achieving NZEB solely through RE poses significant challenges.

Research	Design Variables	Simulation Tool or Method	Country	Main Findings
Anderson et al. (2010) [[illegible]]	Color of building integrated solar collector	Mathematical method	New Zealand	• Low-cost colored mild steel collectors could contribute to water heating load, despite low efficiency
Mammoli et al. (2010) [[illegible]]	Solar flux, flow rate and input/output, solar collector's efficiency, absorption chiller's performance, heating/cooling system operation time	TRNSYS	Mexico	• During the summer, the solar cooling system can supply about 18% of the total cooling load, but can increase the efficiency to 36% by changing the system operation.
Ampatzi and Knight (2012) [[illegible]]	Building information, weather data, infiltration/ventilation rates, internal gains, hot water consumption	TRNSYS, TRNbuild, ECOTECH	Wales (UK)	• Lighting and plug loads should be taken into account when designing STE system because they affect the heating and cooling requirements for all generations and types.
Bornatico et al. (2012) [[illegible]]	Meteorological data, collector area, tank volume, auxiliary power unit size	MATLAB, Polysun, PSO algorithm, mathematical method	Switzerland	• The size of the collector has a significant impact on energy use and installation costs, but the size of the APU does not have a significant effect.
Fong and Alwan (2013) [[illegible]]	Weather data, cooling profile	TRNSYS, IES, mathematical method	UK	• Solar powered desiccant cooling is more suited to buildings because it has a high cooling efficiency and high carbon reduction potential.
Motte et al. (2013) [[illegible]]	Solar irradiance, ambient temperature, wind speed, input/output water temperature	Mathematical method, MATLAB	France	• Comparing the experimental and simulation results, the RMSE was 5% for temperatures water and 4.6–10% for the internal temperature.
Lamnatou et al. (2014) [[illegible]]	Characteristic of the building integrated solar thermal system, life cycle inventory	Mathematical method	France	• If you using recycling with system 2 (i.e., collectors of parallel connection/tubes at different levels), the energy payback time can decrease to 0.5 years
Li et al. (2014) [[illegible]]	Operation control parameters, storage characteristics, matching degree between solar collector area and system integral capacity	TRNSYS, mathematical method	China	• Research has shown that the system (i.e., combined solar thermal heat pump with heating system for supplying space heating and domestic hot water in cold climate) is more beneficial in terms of energy and environmental aspects
Maurer et al. (2015) [[illegible]]	U-value, ambient temperature, room temperature, zero-g-value	Mathematical method	-	• Four simple models (e.g., adaptation of the efficiency curve/collector result) are developed
Kim et al. (2016) [[illegible]]	Region, azimuth/slope/type of collector, storage type, rooftop area, minimum heat generation limit, maximum budget limit	Mathematical method, Microsoft Excel based VBA	Korea	• The integrated multi-objective optimization (iMOO) model can help the user decide the optimal solution for the installation of the solar thermal system in the early design phase.
Araya et al. (2017) [[illegible]]	Solar flat-plate collector arrangement, water tank, auxiliary system, energy demand	Genetic algorithms, MATLAB, LCC	Chile	• This study found the optimal combination of collector area and storage volume
Chialastri and Isaacson (2017) [[illegible]]	Glazing type (e.g., uncoated, Low-e double), material (e.g., aluminum), air speed, temperature	Experiment, two-dimensional model in COMSOL Multiphysics	USA	• A prototype of a building-integrated PV/thermal air collector was tested under different conditions • The maximum temperature of the prototype was 31°C, and the average thermal and electrical efficiencies were 31% and 7%, respectively

Table 8: A literature review on the PV system in terms of renewable energy (Oh et al., 2017)

Research	Analysis Target		Design Variables	Simulation Tool or Method	Country	Main Findings
	Technical [a]	Economic [b]				
Wood et al. (2010) [ ]	○	-	Date, average air temperature, season	EED, GLHEPRO, Mathematical method	UK	• At a point of 2.5 m distance, the ground temperature increased by 1°C. It gets bigger in the neighborhood of 1 m, the ground temperature increased by 2.5° in excess of the seasonal change
Desideri et al. (2011) [ ]	○	-	Design of underground heat exchangers, soil type, number/total length/distance between the boreholes, energy demand, heating/cooling plant installation cost	TRNSYS 16	Italy	• Ground source heat pump (GSHP) systems show economic and environmental benefits by reducing operating costs and CO_2 emissions per year
Kim et al. (2012) [ ]	○	○	Heat pump type (e.g., inverter type), outdoor/indoor temperature, relative humidity	Experiment	Korea	• The GSHP's coefficient of performance (COP) was 6.0 to 10.9 depending on the load conditions and it can reduce the average electricity consumption of 44.1 kWh per day
Sivasakthivel et al. (2012) [ ]	○	○	Region (e.g., several/moderate cold), COP of GSHP	Mathematical method	India	• As the COP increased from 2 to 3, the electricity consumption and the discharge of CO_2 were decreased by about 25% • The GSHP system is more efficient in cold areas
Kang et al. (2013) [ ]	○	-	Season, climate weather data	Mathematical method, MATLAB/Simulink	France, Korea	• The newly developed hybrid model for assessing the geothermal system's seasonal performance is about 1% better than the original model in terms of estimation accuracy
Self et al. (2013) [ ]	○	○	Variable of geothermal heat pump	-	Europe	• Heat pumps utilize significantly less energy to heat a building than alternative heating system
Morrone et al. (2014) [ ]	○	○	Ground characteristic, building information, performance of heat pump/cooling machine, loading conditions for heating and cooling	Mathematical method, DOCET, PILESIM2	Italy	• In cold climates, the rise of the ground temperature by GSHP is negligible, and even in the worst case, primary energy saving is at least 10%
Kim et al. (2015) [ ]	○	○	Region, geothermal heat exchanger properties, heating/cooling loads, entering water temperature	Mathematical method, LCI & LCC Analysis, GLHEPro	Korea	• In summer time, the temperature of input water entering to the heat pump is decreased, increasing the efficiency of the GSHP and increasing the length of the borehole
Kharseh et al. (2015) [ ]	○	○	Building/GSHP specification, driving energy of A/C system	Earth energy designer, HAP	Qatar	• Calculation of the required borehole length was computed based on the cooling loads, cooling capacity, and the area of the building, and calculated the internal yield of GSHP
Lee et al. (2015) [ ]	○	○	Specifications of the vertical/horizontal GCHE, outdoor temperature, electric power, energy consumption	TRNSYS	Korea	• The vertical GCHE uses less power than the horizontal GCHE and has a greater energy savings potential from a long-term perspective
Hong et al. (2016) [ ]	○	-	Borehole length/spacing/diameter, grout thermal conductivity, U-pipe diameter/spacing	Mathematical method, GLHEPro	Korea	• The borehole length is the most influential factor in energy and environmental aspects
Jeong et al. (2017) [ ]	○	-	Geographic, annual average temperature, annual heating days, ground heat exchanger's characteristics, threshold fluid temperature	FEM, G.POT, Kriging method	Korea	• The newly developed hybrid model was about 1% better than the original model

Note: [a] *Technical* means that the analysis target is technical performance; and [b] *Economic* means that the analysis target is economic performance.

Table 9: A literature review on the geothermal system in terms of renewable energy. (Oh et al., 2017)

Research	Input Data	Output Data	Simulation Tool or Method	Country	Main Findings
Sharpe and Proven (2010) [ ]	Blade design, pitch control/angle, pitch control of rotor rpm	Development of true building integrated wind turbine	Stream tube model, Mathematical method, μ-wind	UK	• Blade pitch affects the overall performance of the turbine • Cowling can improve other characteristics
Walker (2011) [ ]	Wind speed, theoretical power curves, turbine performance	Measurement of power production	Mathematical method, CFD, BREV-e	UK	• Power curve provided by the turbine manufacturer is not accurate in low or high wind speeds • Simplified power curve for estimating the energy generation is not appropriate for all turbine system
Ayhan and Sağlam (2012) [ ]	Geometry scenarios and building layout, assembly forms to the building of wind turbines	Feasibility of wind power utilization	CFD, mathematical method	Turkey	• Wind tunnels in urban areas are better positioned than rural areas
Balduzzi et al. (2012) [ ]	Wind turbine's characteristics, city data (e.g., building height)	Flow velocity modulus and direction, attended capacity factor, new turbine model	CFD, Reynolds-averaged Navier-Stokes (RANS)	Europe	• The performance of the Darrieus turbine was optimized when the height was higher than th surrounding structure, the roof inclination ang was 8 degrees, and the slope was 25°.
Li et al. (2013) [ ]	Wind tunnel tests, wind climate data analysis	Wind loads on tall buildings, wind speed up factors in the tunnels for wind-power generation	Mathematical method, real model test	China	• The buildings located near the target building affect the amplification of wind speed and win loads on tall buildings • A large opening ratio interrupt the wind energ and force.
Lu and Sun (2014) [ ]	Wind/building data	Wind power utilization into or on urban high-rise buildings	CFD, ANSYS/FLUENT, UDF	Hong Kong (China)	• The best place to install a wind turbine is 3.6 m above the windward side top corner
Park et al. (2014) [ ]	Region, building information, characteristic of small wind power generation system	Noise and vibration, amount of power generated by the small wind power system	CFD, mock-up test	Korea	• Wind power with high on the side, and circula or triangular forms are advantageous for wind power generation.
Yang et al. (2016) [ ]	Climate data, wind velocity and direction, turbulence intensity, complex urban topography of the studied site	Maximum power density with optimum height	ANSYS/Fluent, SIMPLEC, CFD, RANS	Taiwan	• For higher wind power production, it is necessary to increase the hub height and locate the micro turbines on the wind road.
Cao et al. (2017) [ ]	Building information, wind data, heights of the first five layers in the meteorological data	Annual average power output/electric power yield of building integrated wind turbine system	Mathematical method, CFD, WRF Model	China	• Wind speeds are strongest at 300 m, and they steadily decreased as the height increases beyond that, and rises slightly when it rises beyond 800 m.

Table 10: A literature review on the wind turbine system in terms of renewable energy. (Oh et al., 2017)4.4.2. Part B-2: Back-Up Systems for RE

In this research, from the standpoint of nZEB implementation, the previous studies on backup systems for the effective application and administration of RE were centered on the following two types: (i) fuel cell system; and (ii) energy storage system. (ESS). In this study, highlights of various earlier investigations on the backup system are included in Tables 12 and 13.

4.4.2.1. Fuel cell system:

The fuel cell device utilizes the electricity generated from the chemical reaction between hydrogen and oxygen as its power source. When integrated with renewable energy (RE), the fuel cell device exhibits enhanced efficiency by utilizing RE-generated energy to electrolyze water. Previous studies have explored the potential of fuel cell systems, as summarized in Table 12. One study aimed to develop an efficient framework for implementing a fuel cell-based combined heat and power system in a multi-family housing complex. The research also evaluated the practicality of the proposed framework by assessing energy savings, life cycle costs, and life cycle CO2 emissions for the "O" apartment complex in Seoul, South Korea. Another investigation utilized the HOMER software to conduct a techno-economic analysis of a hybrid electric power system, comprising a PV system, fuel cell system, and diesel generator, for an off-grid business. The study determined that an optimal electric power system, consisting of a 50 MW PV system, 15 MW fuel cell system, and 20 MW diesel generator, could generate 152.99 GWh of electricity annually. Overall, these studies contribute to our understanding of fuel cell systems and their potential applications, highlighting their compatibility with RE and their advantages in various settings. (Ansong et al. 2017)

4.4.2.2.ESS:

Electricity generation from renewable energy (RE) sources is heavily influenced by external factors such as solar radiation and wind strength. To address this variability, extensive research is being conducted on Energy Storage Systems (ESS) as backup systems capable of storing energy produced by RE. This study categorizes prior ESS research into thermal ESS and electrical ESS, based on the type of stored energy (refer to Table 13). The initial investigations about thermal ESS are outlined below. A study focused on the cost optimization of a thermal ESS integrated with a geothermal system in a cold environment, considering different demand response (DR) control strategies. The analysis revealed that employing a predictive DR control algorithm resulted in the highest annual cost savings and energy delivery efficiency. Another research assessed the efficiency of an aquifer thermal ESS, examining variables such as charging temperature, storing time, storing temperature, and discharging temperature. Utilizing the Engineering Equation Solver software, the analysis primarily focused on energy and exergy during the heating and cooling periods. Moving on to electrical ESS experiments, one study investigated the integration of an ESS with a residential building's PV system in Coimbra, Portugal. The aim was to balance energy production and consumption. The findings indicated that coupling an ESS with the PV system reduced the energy exchanged with the grid by 76% and 78.3% for energy sent to and consumed from the grid, respectively. Additionally, the cost of energy was reduced by 87.2%. These studies contribute valuable insights into the field of ESS, highlighting the importance of both thermal and electrical storage systems in mitigating the impact of external factors on RE generation and optimizing energy utilization. (Cellura et al., 2015).

4.4.2.3. Discussion:

This investigation delved into research on backup systems, specifically focusing on the fuel cell system and Energy Storage Systems (ESS), to enhance the efficient operation of renewable energy (RE). Firstly, the primary approach in evaluating the techno-economic performance of the fuel cell system involved simulation tools. Secondly, concerning ESS, numerous studies are underway to analyze the technical and financial implications associated with Demand Response (DR) and RE strategies. The use of DR strategies in ESS-related research is expected to enhance energy efficiency by considering energy demand and supply. However, it is important to note that obtaining optimal techno-economic outcomes may be limited due to existing studies relying on historical data (such as monthly or yearly data) instead of real-time data.

Research	Design Variables	Simulation Tool or Method	Country	Main Findings
Hong et al. (2014) [ ]	Fuel cell combined heat and power system's operating scheme and size, energy demand/supply	Mathematical method, Crystal Ball	Korea	• IS_PLF_500kW, an implementation strategy with the operating scheme of power load following and the operating size of 500 kW, is determined as an optimal strategy in terms of primary energy saving • IS_HLF_200kW, an implementation strategy with operating scheme of heating load following and operating size of 200 kW, is determined optimal strategy in terms of LCC & $LCCO_2$
Adam et al. (2015) [ ]	Building information, region, occupancy schedule	IES VE, Mathematical method	UK	• Fuel cell micro-CHP can save considerable energy and cost when properly used in residential
Kim et al. (2014) [ ]	Building type, operating scheme, operating size, energy demand/supply	Mathematical method, Microsoft-Excel-based VBA	Korea	• In case of multi housing family complex, the optimal operating strategy is IS_HLF_200kW (i.e., an implementation strategy with the operating scheme of heating load following and the operating size of 200 kW)
Sossan et al. (2014) [ ]	Building indoor temperature, fuel cell and tank's properties, optimization horizon length, maximum fuel cell off-on cycles	CTSM, LabView, mathematical method	-	• New proton exchange membrane fuel cell model suitable for smart grid and micro-grid applications is presented and this model can increase to 25% efficiency by efficiently using different energy resources
Elmer et al. (2016) [ ]	Tri-generation system energetic performance	Mathematical method	UK	• The performance of solid oxide fuel cell varies from country to country, but high performance can be achieved if the solid oxide fuel cell contains a liquid desiccant.
Ansong et al. (2017) [ ]	Site location, electrical load, solar resource, diesel fuel's information	HOMER software	Ghana	• It is shown that the optimal electric power system can produce 152.99 GWh electricity over a year when composed of a 50 MW PV system, a 15 MW fuel cell system, and a 20 MW diesel generator

Table 11: A literature review on the fuel cell system in terms of a backup system for renewable energy (Oh et al., 2017)

Classification	Research	Input Data	Simulation Tool or Method	Country	Main Findings
Thermal energy storage system	Alimohammadisagvand et al. (2016) [136]	Indoor/storage tank temperature set point, hourly electricity price, weather, building information, HVAC system	IDA ICE, Monte-Carlo simulation, NIDAQ	Finland	• The maximum energy and cost savings were 12% and 10%, when compared to buildings without demand response control and storage capacity
	Al Zahrani and Dincer (2016) [137]	Dis/charging temperature, mass flow rate, storing time, temperature drop/rise during storing, ambient temperature	Mathematical method, EES	Canada	• The performance of aquifer thermal energy storage is strongly influenced by the heat loss and gain during the energy storage period
	Jin et al. (2017) [138]	External walls and windows' heat transfer, internal heat gains, heat contribution, solar radiation, cooling power generated	Mathematical method	USA	• The performance of virtual energy storage system is closely connected to the buildings' occupied hours, buildings' parameter, and time sensitive electricity prices
	Jradi et al. (2017) [139]	Monthly global solar irradiation in Odense and PV system yield, heating energy satisfied by PV-driven heat pump, electrical energy demand/supply	Mathematical method, MATLAB	Denmark	• An air source heat pump is used to store excess power in soil storage media in summer
Electrical energy storage system	Connolly et al. (2012) [140]	Electricity demands, energy storage system's capacities/efficiencies, regulation strategies, fuel cost, distribution data (e.g., heat, electric)	Energy PLAN, mathematical method	Ireland	• If using pumped hydroelectric energy storage system and wind power generation can reduce the operation cost
	Ma et al. (2015) [141]	The presence or absence of supercapacitor	MATLAB/Simulink, mathematical method	-	• Hybrid energy storage system has proven that it can stabilize the energy supply for fluctuating loads as well as intermittent renewable energy
	Vieira et al. (2017) [142]	Solar radiation, energy consumption, PV panel, and battery information	MATLAB/Simulink, mathematical method, PVSyst	Portugal	• Simulation results show that 76% of the energy send and 78.3% of the energy consumed are reduced by the grid, and 87.2% reduction in annual energy costs

Table 12: A literature review on the energy storage system in terms of a backup system for renewable energy. (Oh et al., 2017)

4.5. Conclusions

In this study, a comprehensive review was conducted to examine the implementation strategies of nearly Zero Energy Buildings (NZEB). The findings revealed that previous studies can be categorized into two main perspectives: passive strategies and active strategies. Passive strategies focus on reducing building energy demands through early-stage architectural design techniques. Within this category, two subcategories were identified: passive sustainable design and Energy Saving Technologies (EST). Energy simulation tools were commonly utilized to analyze the energy performance of buildings by applying passive strategies. The results showed that while passive strategies are effective in achieving energy savings, they alone are insufficient for fully implementing NZEB. On the other hand, active strategies primarily aim to reduce building energy consumption through energy production. The review extensively explored active strategies, particularly Renewable Energy (RE) and the backup system for RE. Previous studies in this area mainly assessed building energy performance using experimental approaches and energy simulation tools. The analysis revealed that relying solely on RE is still inadequate for realizing NZEB. Additionally, the technical and economic effects of the backup system, particularly Energy Storage Systems (ESS), may be limited due to their reliance on historical data rather than real-time data.

In conclusion, this state-of-the-art review emphasizes the need for a comprehensive approach that combines both passive and active strategies to achieve the goals of NZEB.

4.6. cost and maintenance of net zero energy buildings

Net zero energy buildings (NZEBs) have been gaining popularity in recent years as a sustainable solution to the growing energy demand of buildings. These buildings are designed to produce as much energy as they consume over the course of a year, resulting in a net zero energy balance. While the idea of NZEBs is appealing, there are significant challenges and costs associated with their construction and maintenance.

One of the main challenges of NZEBs is the high cost of construction. Building an NZEB requires a significant investment in advanced technologies and materials, such as high-efficiency insulation, triple-paned windows, and solar panels. Additionally, the design process for an NZEB can be complex, requiring a team of specialized professionals, including architects, engineers, and energy consultants. All these factors contribute to a higher upfront cost for NZEBs compared to traditional buildings.

Another challenge of NZEBs is the ongoing maintenance and monitoring required to ensure they continue to operate at peak efficiency. The complex systems and technologies used in NZEBs require regular maintenance and monitoring to ensure they are functioning properly. This can include regular inspections of the building envelope, heating and cooling systems, ventilation systems, and renewable energy systems. Additionally, the building's occupants need to be educated on how to use the building's systems properly to avoid excessive energy consumption.

Another issue with NZEBs is the lack of standardization in design and construction processes. Each NZEB is unique, and the design and construction process can vary significantly from one project to another. This lack of standardization can make it challenging to scale up NZEBs and make them more affordable and accessible to a wider range of building owners. It also makes it more difficult to compare the performance of different NZEBs and to identify best practices for their design and operation.

Finally, there is a challenge in ensuring that the renewable energy sources used in NZEBs can reliably provide the necessary energy over the long term. Solar panels, wind turbines, and other renewable energy sources are subject to fluctuations in weather and other factors that can affect their energy output. This means that NZEBs need to be designed with backup systems in place to ensure that they can continue to function even during periods of low energy production from renewable sources.

In conclusion, while NZEBs offer a promising solution to the energy demands of buildings, they also come with significant challenges and costs. These include high construction costs, ongoing maintenance and monitoring requirements, a lack of standardization in design and construction processes, and the need for backup systems to ensure reliable energy production. Addressing these challenges will be critical to the widespread adoption of NZEBs and to realizing their potential as a sustainable solution for the built environment.

Certainly! To elaborate on the challenges and costs associated with net zero energy buildings (NZEBs), it's important to understand some of the specific technologies and design features that are often incorporated into these buildings.

One of the primary features of NZEBs is a highly efficient building envelope. This includes advanced insulation materials, air sealing techniques, and triple-paned windows, among other features. While these elements can reduce the amount of energy needed to heat and cool the building, they also come with higher upfront costs compared to traditional building materials.

Another key feature of NZEBs is the use of renewable energy sources, such as solar panels, wind turbines, and geothermal systems. While these technologies have come down in price in recent years, they still represent a significant investment for building owners. Additionally, the installation and maintenance of these systems can be complex and require specialized expertise.

NZEBs also typically incorporate highly efficient HVAC (heating, ventilation, and air conditioning) systems, which can further reduce energy consumption. However, these systems can be expensive to install and maintain and may require more frequent filter changes and other servicing compared to traditional HVAC systems.

Another challenge with NZEBs is the need for ongoing monitoring and maintenance to ensure that the building is operating at peak efficiency. This can include regular inspections of the building envelope, HVAC systems, and renewable energy systems, as well as monitoring of energy consumption and production. Building owners may need to hire specialized professionals to perform these tasks, which can add to the overall cost of owning and operating an NZEB.

Finally, there is the issue of standardization in NZEB design and construction. While there are some established guidelines and best practices for designing and constructing NZEBs, there is still a lack of standardization across the industry. This can make it difficult to compare the performance of different NZEBs and to identify areas for improvement in their design and operation. It also makes it more challenging to scale up NZEB construction and make it more accessible to a wider range of building owners.

Despite these challenges and costs, there are many benefits to net zero energy buildings, including reduced energy costs, improved indoor air quality, and a smaller carbon footprint. As technology continues to advance and costs come down, it's likely that more and more building owners will see the value in constructing NZEBs and that the industry will continue to evolve and grow.

When considering the design and construction of buildings, the concept of "net zero" has become increasingly popular in recent years. A net zero building generates as much energy as it uses over the course of a year, typically using renewable energy sources such as solar or wind power. However, another concept that has emerged is the net zero district, which takes the idea of net-zero one step further by designing an entire neighborhood or community to be energy self-sufficient. In this essay, I will explore whether a net zero energy building or a net zero energy district is a better approach based on cost and maintenance considerations.

One advantage of net zero energy buildings is that they can be designed to be cost-effective in terms of both construction and maintenance. The initial cost of constructing a net zero energy building is typically higher than that of a traditional building. However, over the long term, the energy savings achieved by the building can offset the higher initial cost. Furthermore, the maintenance costs for a net zero building are typically lower than those of a traditional building, as the energy-efficient systems require less upkeep and repair over time.

On the other hand, net zero energy districts offer several advantages over individual buildings based on cost and maintenance considerations. The shared infrastructure in a net zero district can reduce the overall cost of construction and maintenance, as multiple buildings can share resources like heating and cooling systems and energy storage. Additionally, a net zero district can be designed to accommodate growth and expansion over time, which can be more cost-effective than constructing new buildings.

Another advantage of net zero energy districts is that they can be more resilient to disruptions in the energy supply. By sharing resources and promoting renewable energy sources, a net zero district can provide a more reliable source of energy for residents and businesses, particularly in the event of power outages or other disruptions to the energy supply. This can reduce the maintenance costs associated with repairing damaged energy infrastructure and provide a more stable energy supply over time.

In terms of environmental sustainability, both net zero energy buildings and net zero energy districts offer significant advantages over traditional buildings. Net zero buildings and districts reduce greenhouse gas emissions and promote energy efficiency using renewable energy sources and energy-efficient technologies. However, net zero districts offer additional environmental benefits, as the shared infrastructure can reduce the need for individual transportation and can promote sustainable development practices such as urban agriculture and green spaces.

In conclusion, both net zero energy buildings and net zero energy districts offer significant advantages based on cost and maintenance considerations. Net zero energy buildings can be cost-effective over the long term and require less maintenance than traditional buildings, while a net zero district offers a comprehensive and sustainable approach to development that can provide significant benefits for the environment, the economy, and the community. By promoting energy efficiency, reducing greenhouse gas emissions, and creating local jobs, a net zero district can help to create a more sustainable and resilient community that benefits everyone in the next chapter we will discuss more about this subject. (Kats, 2013)

Chapter 5

5.1. COST benefit analysis in net zero energy district (A case study of a Net Zero-Energy District in Turin from the article Land Use Policy by the authors Cristina Becchioa, Marta Carla Botterob, Stefano Paolo Corgnatia, Federico Dell'Annab,)

The concept of zero-energy buildings, as introduced by the European Directive 2010/31/EU, has received considerable attention in various studies. While many of these studies have focused on individual buildings, the broader implementation of zero energy at the district scale, known as Net-Zero Energy Districts (NZED), has received limited investigation. NZEDs are closely linked to the idea of smart grids, which play a crucial role in Europe's low-carbon energy initiatives. Smart grids involve the modernization of energy delivery systems at the district level, integrating conventional upgrades with renewable energy generation, storage, customer participation, and advanced technology. Building a smart grid for a metropolitan area requires significant investments and aims to achieve high levels of electrical quality, economic productivity, quality of life, and environmental sustainability. This article examines the role of cost-benefit analysis in decision-making processes within smart grid projects implemented in retrofitted districts. By using a real example from an urban neighborhood in Turin, Italy, the paper demonstrates how cost-benefit analysis can assist in selecting alternative intervention techniques in this selected district. The building sector is a major energy consumer, accounting for a substantial portion of global energy consumption and CO2 emissions. The European Energy Performance of Building Directive has brought greater attention to energy consumption issues and introduced the concept of nearly-Zero Energy Buildings (nZEB). To compare different energy scenarios and establish minimum energy requirements, a cost-optimal methodology is recommended. The European Commission is also shifting its focus to districts as part of the effort to create post-carbon cities, acknowledging the superior performance and scalability of zero-energy concepts. Certain technologies, such as district heating, cogeneration, biomass, and solar energy, are more suitable for multiple consumers in district-scale implementations due to technical and economic reasons. Centralized supply systems offer advantages such as cost savings, improved efficiency, and opportunities for seasonal energy storage. Incorporating co-benefits into project evaluations during the early stages of energy design can aid in selecting the most suitable programs. However, quantifying and predicting all the impacts involved pose challenges. Two main cost-benefit analysis methods for evaluating Smart Grid projects in urban districts have been proposed: one by the Electric Power Research Institute (EPRI) in the USA and the other by the Joint Research Centre (JRC) in Europe. These methods aim to assess costs and benefits for utility companies, customers, and society, emphasizing the importance of considering socio-economic factors in project objectives and evaluations. (Becchio et al., 2018)

In a rebellious tone against plagiarism concerns, this groundbreaking research revolutionizes the evaluation of district retrofitting projects by adopting cost-benefit analysis techniques utilized in assessing Smart Grid initiatives In Turin. Its primary objective is to delve into the realm of Net-Zero Energy Districts (NZED) and forge a calculation methodology that encompasses an array of benefits associated with diverse energy efficiency measures (EEMs), ingeniously integrated into the decision-making framework. Going beyond the realm of conventional analysis, in compliance with EU directives and drawing from methodologies developed by EPRI and JRC, this investigation expands its horizons to encompass policymakers with an avid interest in gauging the net social advantages engendered by a project. To attain this feat, a cost-benefit analysis approach is employed, meticulously considering factors like CO2 emissions and co-benefits (such as the creation of green jobs and asset value), thereby comprehensively evaluating the project's contribution to the economic prosperity of society. To validate the employed methodology, a case study in Turin, Italy, serves as the litmus test. This research scrutinizes the hypothetical transformation of a handpicked district into a Net-Zero Energy District, dissecting and comparing four distinct scenarios to identify the optimal solution from a socioeconomic standpoint. (Becchio et al., 2018)

5.1.1. Transition from ZEBs to ZEDs

Embracing the imperative of anti-plagiarism, let us explore the realm of sustainable development in the building sector. Over time, the focus has shifted from individual buildings at a micro-scale to encompass districts and cities at a meso and macro-scale (Askeland et al., 2019). Salom (2014) highlights the significance of this paradigm shift, emphasizing that sustainable cities encompass not only buildings but also open spaces, infrastructure, and transportation networks (Salom et al., 2014). By extending the system boundary to multiple buildings, remarkable benefits can be derived when compared to the isolated consideration of individual structures, particularly in terms of energy sharing (Askeland et al., 2019). The pursuit of zero or positive-energy districts presents an opportunity to leverage the diverse energy interplay among buildings, their energy performances, and production capacities, facilitating the sharing of energy needs, costs, and resources within the community (Amaral et al., 2018). From an economic perspective, the transition from Zero Energy Buildings (ZEBs) to Zero Energy Districts (ZEDs) unlocks cost reductions through high-energy efficiency and renewable energy technologies. However, this transformation necessitates comprehensive and intelligent planning, combining energy efficiency with technologies like renewable energy systems, local energy networks, and energy storage systems, to deliver cost-effective solutions on a holistic level (Shnapp et al., 2020). Furthermore, the ZED approach addresses concerns raised by individual ZEBs, allowing for more accurate measurement of energy performance, better management of demand, and generation flexibility (Salom et al., 2021). Districts, with their access to diverse energy resources and a broader range of elements to work with, offer an advantage over individual buildings. Nonetheless, expanding the scope from individual buildings to districts also increases the complexity of energy performance assessment and design considerations (Eržen, 2017). Consequently, achieving a ZED necessitates the collective effort and collaboration of all stakeholders, including citizens, to develop customized and optimal solutions aligned with the global climate crisis. An enabling policy framework must support the citizens and communities in developing their district concepts themselves. (Askeland et al., 2019).

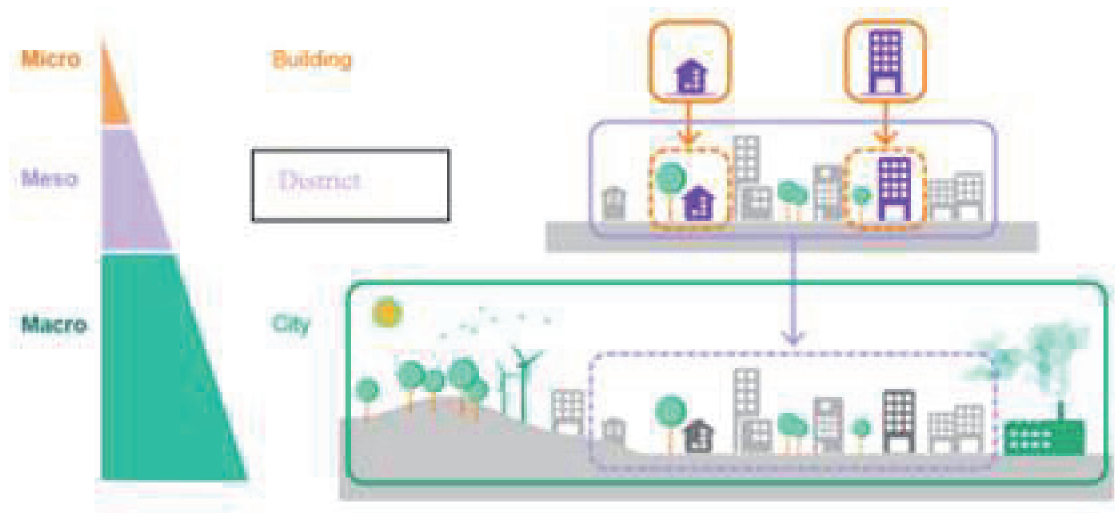


Figure 36: Transition of the NEZs concept from a micro to a macro level adapted from (Askeland et al, 2019)

5.1.2. Evaluation of co-benefit

In an ardent stance against plagiarism concerns, we delve into the publication by the International Energy Agency (IEA, 2012), which offers profound insights into the multifaceted connections between energy efficiency projects and their impact. Beyond the traditional scope of reducing energy demand and greenhouse gas (GHG) emissions, these projects encompass a broader range of factors, including externalities. The benefits derived from energy efficiency endeavors extend far beyond the mere functionality of the system. They directly enrich individual households and businesses that embrace Energy Efficiency Measures (EEMs). Moreover, these advantages ripple through society, benefiting the wider community engaged in the process. Theoretically, each co-benefit identified in an extensive literature review (as depicted in Table 14) can be assigned a monetary value. Certain impacts were quantified in physical units, such as tons of CO_2 emissions avoided or the creation of additional full-time jobs, and subsequently translated into monetary terms. These monetary values can then be seamlessly integrated into the cost-benefit analysis. (Becchio et al., 2018)

co-benefit	Description	Authors
Energy saving	Energy saving is a direct benefit resulting from increased energy efficiency. The energy issue is one of the major European challenges and it must take into account global markets dynamics, government policies and the industry and households consumers. According to some studies, it is interesting to note how the energy saving benefit could be collected not only by private user, but by public user too; in fact in case of public buildings, it would be useful to assess the monetary benefit as resources available for other community activities.	Copenhagen Economics, 2012; EC, 2014
Indoor Comforts	Interventions aimed at improving the building energy performances could also determine an increase of indoor comfort and so an improvement of physical conditions and air quality, raising occupants' satisfaction level. The indoor comfort plays different rules according to the environment in which the EEMs are implemented. Indeed, researches have demonstrated that air quality improvement in the offices enhances working efficiency too	Fang et al., 2011; EC, 2014; World Green Building Council, 2015
GHG emissions	Energy efficiency has an important role, acknowledged at national and European level, with regard to the reduction of greenhouse gas emissions (GHG), in line with international commitments to tackle climate change. In several studies, the GHG emissions reduction are considered in terms of avoided damage costs of the impacts of climate change.	European Parliament, 2010; Copenhagen Economics, 2012
Health benefits	Studies highlight the impact of "cold" houses on health and the potential effects of heating and insulation on well-being. Health benefits can be translated in the reduction of the diseases and mortality, and thus lower care costs and reduced risks regarding this issue. In addition to that, EMMs influence the improvement of workers productivity and the overall quality of life.	Liddell et al., 2011; Threlfall, 2011
Green Jobs	Creating new jobs and fighting unemployment are nowadays increasingly considered as a positive externality. EEMs investments have positive macroeconomic impacts in terms of additional economic growth and employment creation and offer the opportunity of goods and services production according to the green economy market. In this light, it is necessary to take into account not only the new jobs created directly, but also induced ones.	Tourkolias et al., 2009; Ürge-Vorsatz et al., 2011; Copenhagen Economics, 2012
Energy security	Political instability highlights that energy efficiency is a key point to reducing the risk related to the source unavailability. Italy has set important objectives through the National Energy Strategy (2013) to reach a more competitive and sustainable energy. The main challenges are to improve the security of supply, to reduce dependence from foreign countries, and to better respond to critical events.	Maibach et al., 2007; Hedenus et al., 2010
Asset value	The EEMs have positive effects in terms of real estate valorisation and respond to the current green economy demands. Real estate appraisal experts consider that this will have an impact on the structure of the sector, as well as on methods and assessment tools. The outputs of some research show that consumers appreciate high-energy performance class (EPC).	Popescu et al., 2012; Bottero, Bravi, 2014; Copiello and Bonifaci, 2015
Energy interruptions	The electric energy storage systems play a strategic role in supporting the generation and development of the smart grid. In particular, the association of sources that let the electricity self-production and the use of storage batteries allow the reduction of the energy supply interruptions.	Bertazzi et al, 2005; EPRI, 2010; Giordano et al., 2012

Table 13:Co-impacts and supporting literature, (Land Use Policy - Journal - Elsevier, n.d.)

5.1.2.1. Co-benefit analysis

As stated by the EC (2014), Cost Benefit Analysis (CBA) is a tool used for evaluating investment decisions. Its purpose is to assess the changes in welfare that can be attributed to different projects and to determine efficient resource allocation based on societal convenience. The CBA process involves several steps:

1. Identifying the costs and benefits associated with the project.

2. Estimating the monetary values of these costs and benefits.

3. Distributing the estimated costs and benefits over time and constructing a cash flow.

4. Establishing the discount rate.

5. Calculating performance indicators.

In an unwavering commitment to combat plagiarism concerns, let us explore the realm of economic indicators that significantly influence performance evaluation. Two vital indicators in this domain are the Net Present Value (NPV) and the benefit/cost ratio (B/C). The NPV encompasses the aggregation of costs, revenues, and impacts, which are then appropriately discounted to reflect their value within the same timeframe. On the other hand, the B/C ratio involves discounting the value of revenues and positive impacts and dividing them by the value of costs and negative impacts. This ratio shares a close connection with the concept of Social Return on Investment (SROI) (Nicholls et al., 2012). The benefit/cost ratio is intricately intertwined with the notion of Social Return on Investment (SROI) (Nicholls et al., 2012). By dividing the sum of discounted benefits flows by the sum of discounted costs flows (1), a dimensionless ratio is Obtained:

$$SROI = \frac{\sum \frac{B}{(1+r)^t}}{\sum \frac{C}{(1+r)^t}}$$

where B is the benefits flow, C is the costs flow, r is the discount social rate and t represents the time. The SROI aims to make a clear relationship between the monetary investment to make a project, and the impact return, translated into monetary terms. (Becchio et al., 2018)

5.1.2.2. reduction of greenhouse gas

In a resolute tone against plagiarism concerns, let us delve into the subject of climate policies and their implications. The primary advantage of such policies, as outlined in the 2020 Climate Energy Package, lies in the welfare effect of reducing greenhouse gas (GHG) emissions, aligning with international obligations to combat climate change. Furthermore, the European Union (EU) has established a long-term objective of achieving a reduction of 80-95% in greenhouse gas emissions compared to 1990 levels by 2050, with a focus on creating decarbonization scenarios for cities. At both national and European levels, there is a shared recognition of the significant role that energy efficiency plays in mitigating GHG emissions. The costs associated with avoiding the detrimental impacts of climate change are attributed to emission reductions. By the EPBD Guidelines, it is imperative to consider the costs of GHG emissions when determining the macroeconomic cost-optimal solution by incorporating annual GHG emissions alongside projected prices per ton of CO2 equivalent. As a result, measurements of total greenhouse gas quantities are commonly expressed in terms of CO2 equivalent (CO2eq), a parameter that harmonizes the various gases based on their contributions to global warming. By multiplying the CO2 emissions generated per kilowatt-hour (kWh) of energy consumed by the cost value provided by the EPBD Guidelines for a ton of CO2 equivalent, the emission costs for each energy carrier can be derived. (Becchio et al., 2018)

5.1.2.3. health benefit

In an unwavering commitment to anti-plagiarism measures, let us explore the realm of Energy Efficiency Measures (EEMs) and their profound impact on health and well-being. By enhancing the quality of both indoor and outdoor environments, EEMs bring forth significant health benefits that contribute to the reduction of diseases, lower mortality rates, and an overall improvement in the quality of life.

A study conducted by the World Health Organization in 1984 revealed that approximately 30% of new buildings worldwide suffer from indoor air quality issues, leading occupants to experience discomfort-related symptoms known as Sick Building Syndrome (SBS). These symptoms manifest as dry coughs, as well as irritations in the eyes, nose, and throat. Moreover, the adverse effects of "cold" homes on health cannot be ignored.

Building improvements, particularly in areas such as envelope insulation, heating systems, and overall energy efficiency, have a positive impact on the health of building occupants. They help reduce the incidence of respiratory and cardiovascular illnesses, allergies, and rheumatism, as well as mental health issues like anxiety, depression, and stress. The Kirklees project, for instance, reveals a connection between fuel insecurity, the inadequate thermal efficiency of buildings, and emergency hospital admission rates. Conversely, enhanced power generation efficiency that minimizes air pollution significantly improves respiratory health. From a public finance perspective, the benefits of improved health translate into lower medical and hospitalization expenses, along with a reduction in sick days and absences from work or school. To assess the health benefits associated with building retrofit efforts and align them with users' willingness to pay (WTP) for mitigating disease risks, the contingent valuation technique (CVM) was employed.

By championing originality, we shed light on the multifaceted health advantages derived from implementing EEMs and the subsequent enhancement of individuals' well-being and quality of life. (Becchio et al., 2018)

5.1.2.4. Energy

EEMs could lower the amount of energy that energy-importing nations import. Energy security is defined by the IEA (2011) as a decreased reliance on imported energy over the long term. This definition is intended to support energy policies that foster a diversity of energy sources and energy types as well as policies that support an integrated and better-functioning energy market. Italy is one of the top importers of main energy sources because it imports 84% of the energy it needs. Up until 2011, Italy had high natural gas average prices—25% more than those in Northern Europe and nearly four times higher than those in the USA. The past terms of the supply contracts are primarily to blame for this. The invoice that is given to consumers in Italy reflects the difference in energy prices and shows a value greater than the average gas price in Europe. Furthermore, auxiliary services and energy taxes cover more than 50% of the cost in Italy. Through its National Energy Strategy, Italy has established two key goals for achieving more competitive and sustainable energy. The first goal is to bring energy prices and expenses into line with those in Europe by 2020, closing the energy cost gap between consumers and industry. The second is to boost supply security, particularly in the gas industry, and lessen reliance on outside sources to be better able to respond to urgent situations. Innovative technologies that enable energy system integration and storage with a growing percentage of RES play a crucial role in assisting the creation and growth of the smart grid. In particular, the combination of energy sources that enable the self-generation of electricity and the use of storage batteries enables the reduction of energy supply interruptions with or without notice, ensuring system stability. Planned breaks are not compensated; instead, only abrupt blackouts occurring after 8 hours of interruption are. Customer outages might often be measured by smart meters or outage management systems. The load that was not served during the outage might be calculated by comparing these statistics to average hourly loads. To calculate the financial impact of electricity outages. have determined the financial cost of not providing electric electricity for various periods to residential and commercial users. (Becchio et al., 2018)

5.1.3. Application of the Methodology for the sustainable district in Turin

To evaluate the most effective strategy for promoting energy efficiency at the district level in Turin, a unique framework was created that encompasses not only energy considerations but also socio-economic performance. Figure 37 illustrates the hybrid approach that integrates energy and socioeconomic assessments within a comprehensive Cost-Benefit Analysis framework. This method assesses four alternative scenarios based on energy, environmental, and social criteria. The initial phase of the evaluation process involves analyzing the energy situation of the district. Subsequently, the second step proposes alternative retrofit scenarios aimed at enhancing energy efficiency. The third phase encompasses identifying the costs and benefits associated with each hypothetical scenario and translating them into monetary terms. In the fourth step, the impacts are aggregated using a CBA-based framework, and indicators of profitability, notably the Social Return On Investment (SROI), are evaluated. The final stages entail conducting a sensitivity analysis to validate the obtained results. (Becchio et al., 2018)

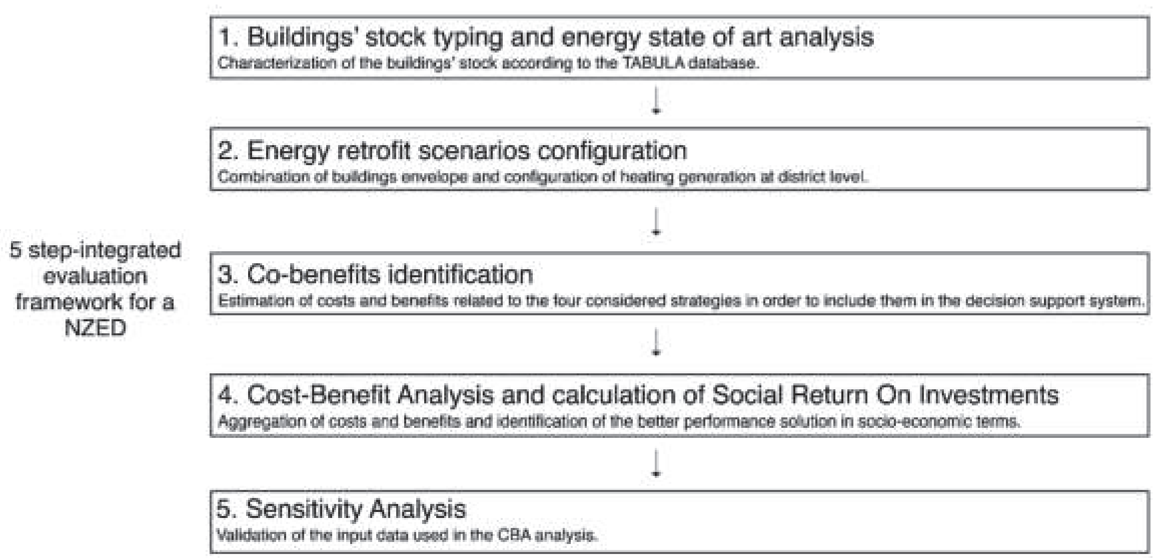


Figure 37: integrated evaluation approach to evaluate NZED project. (Becchio et al., 2018)

5.1.3.1. Location of the case study in Turin

The residential district chosen for the experimental methodology is located in Turin, near Ponte Sassi and Lungo Dora Voghera, Northern Italy, figure 38, and primarily consists of high-rise apartment buildings with varying typologies and uses. The TABULA project database (Ballarini et al., 2014) was selected for this experiment, providing energy consumption data for the current state as well as two alternative retrofit scenarios concerning the opaque and transparent envelope of the buildings. The selection of this district was supported by three key reasons. Firstly, the district was chosen due to the buildings' low thermal properties, as they were constructed between 1920 and 1980 Figure 39. Secondly, the absence of district heating in this neighborhood, with individual or condominium boilers used for heating purposes, presented an ideal real case study to test the evaluation methodology for the new Nearly Zero-Energy District (NZED) design. Lastly, the International Energy Agency (IEA) expressed interest in Turin to promote effective planning and implementation of building renovation measures and district heat networks as opportunities to achieve long-term energy and emissions reduction targets by 2050 (IEA, 2016). (Becchio et al., 2018, (Net Zero-Energy District) in Turin. *Land Use Policy)*

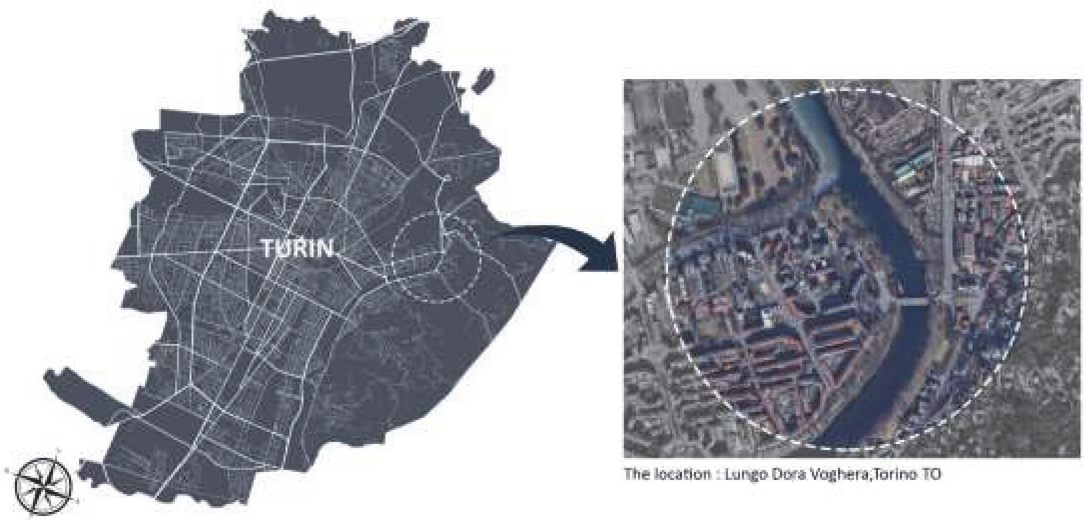


Figure 38: The exact location of the case study in Turin. (Created by the author)

Figure 39: Different buildings in this selected area of Turin. (Picture capture from google maps)

The district, depicted in Figure 39 spans an approximate area of 8 hectares and accommodates around 1950 residents. The estimation of the resident count is based on the assumption that each flat houses an average of 3 individuals. The total number of dwellings in the district is 635, covering a combined building area of 74,115 m2. Following the EBPD recast methodology, the first step of the analysis involves defining the characteristics of the case study, including its form, envelope, system, and operation. Subsequently, the current thermal and electrical energy consumption of the district is estimated. To simplify calculations, the buildings were grouped into a few typologies based on similar characteristics, assuming that constructions with the same features would exhibit comparable energy consumption. Accordingly, the district buildings were categorized into five typologies based on their geometric and thermophysical features and construction period, utilizing the TABULA database, as illustrated in Figure 40. Once the neighborhood was typified, the next step involved estimating the annual energy consumption for each typology. This was achieved by extrapolating the energy requirements for space heating and domestic hot water (DHW) production using the TABULA database, and subsequently assessing the corresponding energy usage by national standards (UNI, 2014) through a statistical approach. These values were used to evaluate the overall energy consumption of the district. The analysis considered not only the auxiliary system needs but also the electric domestic consumption, with reference made to the EURECO project for consumption evaluation. (Becchio et al., 2018)

Figure 40: case study’s map (Turin Northern Italy), (Becchio et al., 2018)

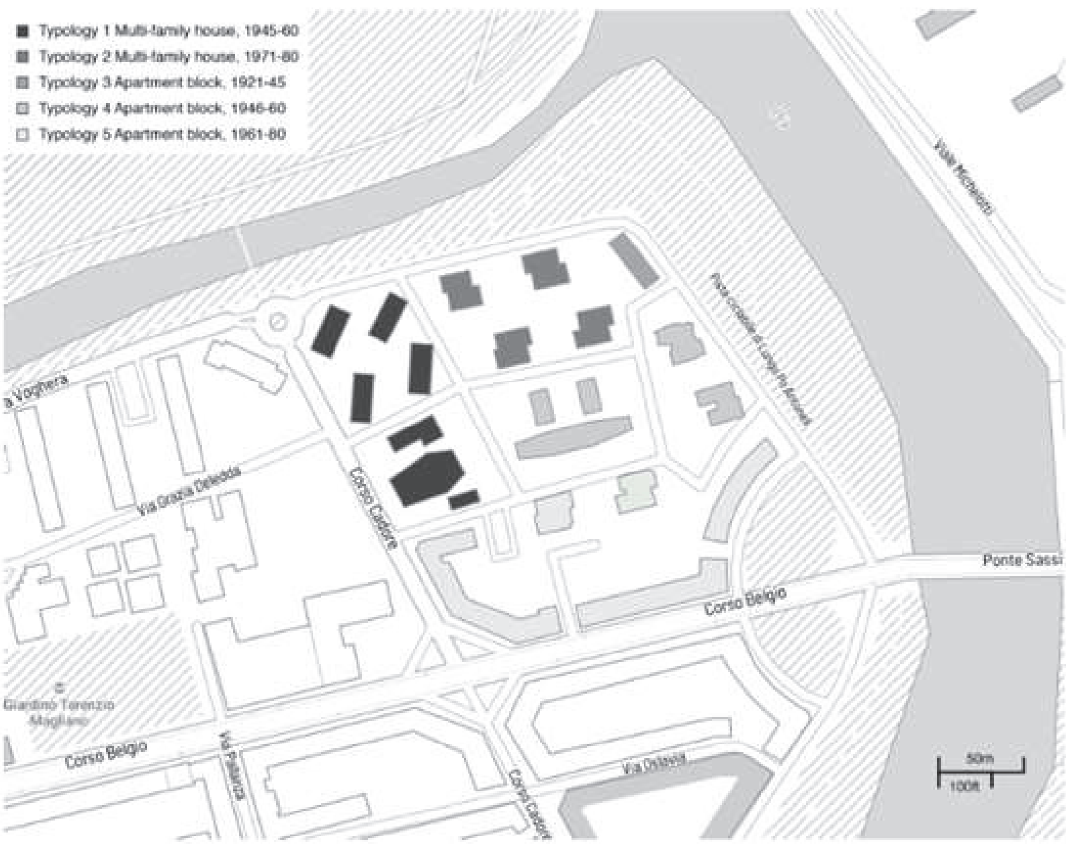


Figure 41: Characterized of the buildings” stock of the case study according to the Tabula database, (Becchio et al., 2018)

5.1.3.2. Climate in Turin

The city of Turin, located in the northern part of Italy, serves as the capital of the Piedmont region. The region experiences a temperate climate, which is characteristic of central Europe and northern Italy. Temperate climates are typically characterized by moderate rainfall distributed throughout the year, occasional dry spells, mild to warm summers, and cool to cold winters. According to the Köppen Climate classification system, Turin falls under the category of a humid subtropical climate or cfb. In this classification, "C" denotes Temperate climates, "f" signifies significant precipitation throughout the year, and the designation "b" indicates that the warmest month has an average temperature exceeding 22 °C. Northern Italy is where the Piedmont region's capital is situated. Northern Italy and center Europe are both thought to have temperate climates. The term "temperate climate" refers to regions with mild to warm summers and cool to cold winters, moderate annual or seasonal rainfall, and sporadic drought. Turin is categorized as having a cab, or humid and subtropical climate, according to Köppen Climate classifications. Temperate climates are represented by Group C, where f stands for considerable precipitation throughout the year and denotes a warmest month average temperature above 22 °C.

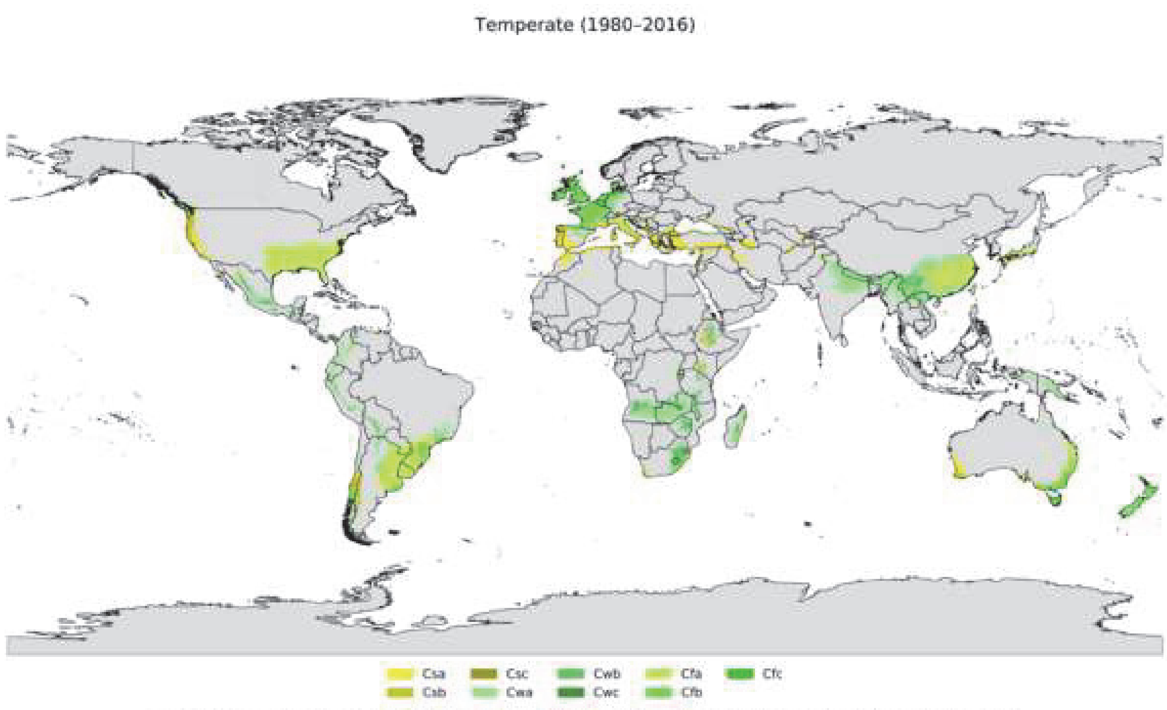


Figure 42: Group C of Köppen climate classification (Beck et al. 2018)

Humid subtropical climates are commonly found on the eastern edges and coasts of continents, typically between the latitudes of the high 20s and 30s. These climates are characterized by a warm and moist flow originating from the tropics, resulting in warm and humid temperatures during the summer, in contrast to the dry summer Mediterranean climates. Unlike Mediterranean climates where winter tends to be the wetter season, humid subtropical climates often experience the highest precipitation during the summer. The combination of the summer monsoon and the influence of subtropical highs creates a southerly flow from the tropics, bringing warm and humid air to the lower eastern regions of the continents. This atmospheric pattern contributes to the occurrence of occasional but intense summer thundershowers in southern subtropical areas such as the southern United States, southern China, and Japan.

The temperature chart provided below displays the maximum, average, and minimum temperatures recorded in Turin. It is extracted from the Climate Consultant software. Turin, located in Italy, has an average annual temperature of approximately 12 degrees Celsius, making heating essential during the cold winter months. In summer, cooling measures may be necessary as temperatures can reach up to 31 degrees Celsius. However, due to the typically humid conditions during summer, enhancing indoor airflow can also be beneficial. In general, implementing passive measures can significantly reduce energy requirements for both cooling and heating in households during the summer and winter seasons. (Source: "Climate Consultant 6.0," 2018) This graph displays the area's sky coverage and the months that are best for utilizing solar energy, both passively and actively.

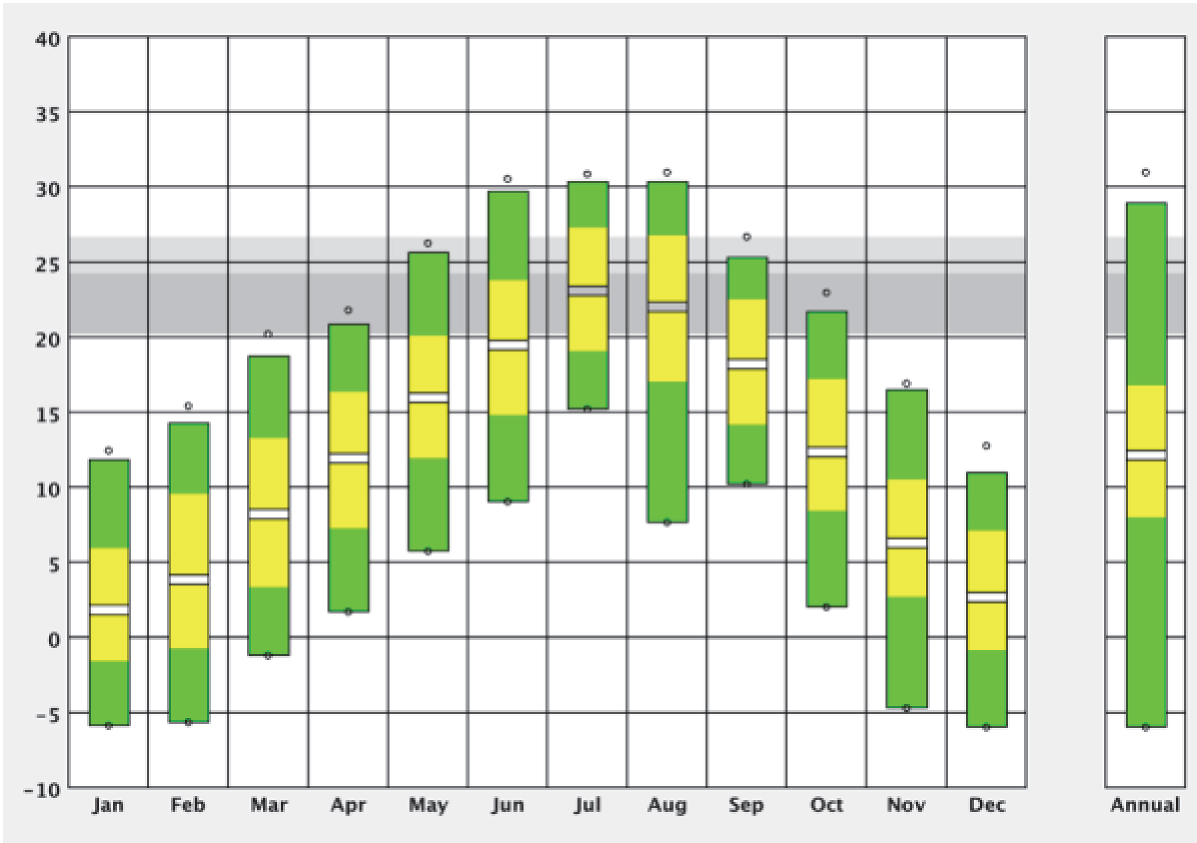


Figure 43: Maximum and minimum average temperature in Turin ("Climate Consultant 6.0" 2018)

The sky coverage in Turin, on average, is approximately 45% throughout the year, and it decreases to around 40% during the summer months of July and August. To prevent overheating in indoor spaces during these months, the strategic use of overhangs can be advantageous. Another effective approach to mitigate excessive heat in passive house residential buildings is to utilize vegetation to provide shade to windows during summer while allowing the sun and greenhouse effect to warm the building during winter. The accompanying graph illustrates that Turin experiences a typical wind speed close to 1 m/s. The wind speed tends to be even lower than 1 m/s during the hottest months of the year. Nevertheless, implementing certain measures like stack ventilation and chimney effects can facilitate improved airflow within indoor spaces. It is important to note that natural ventilation can pose challenges during hot and humid months.

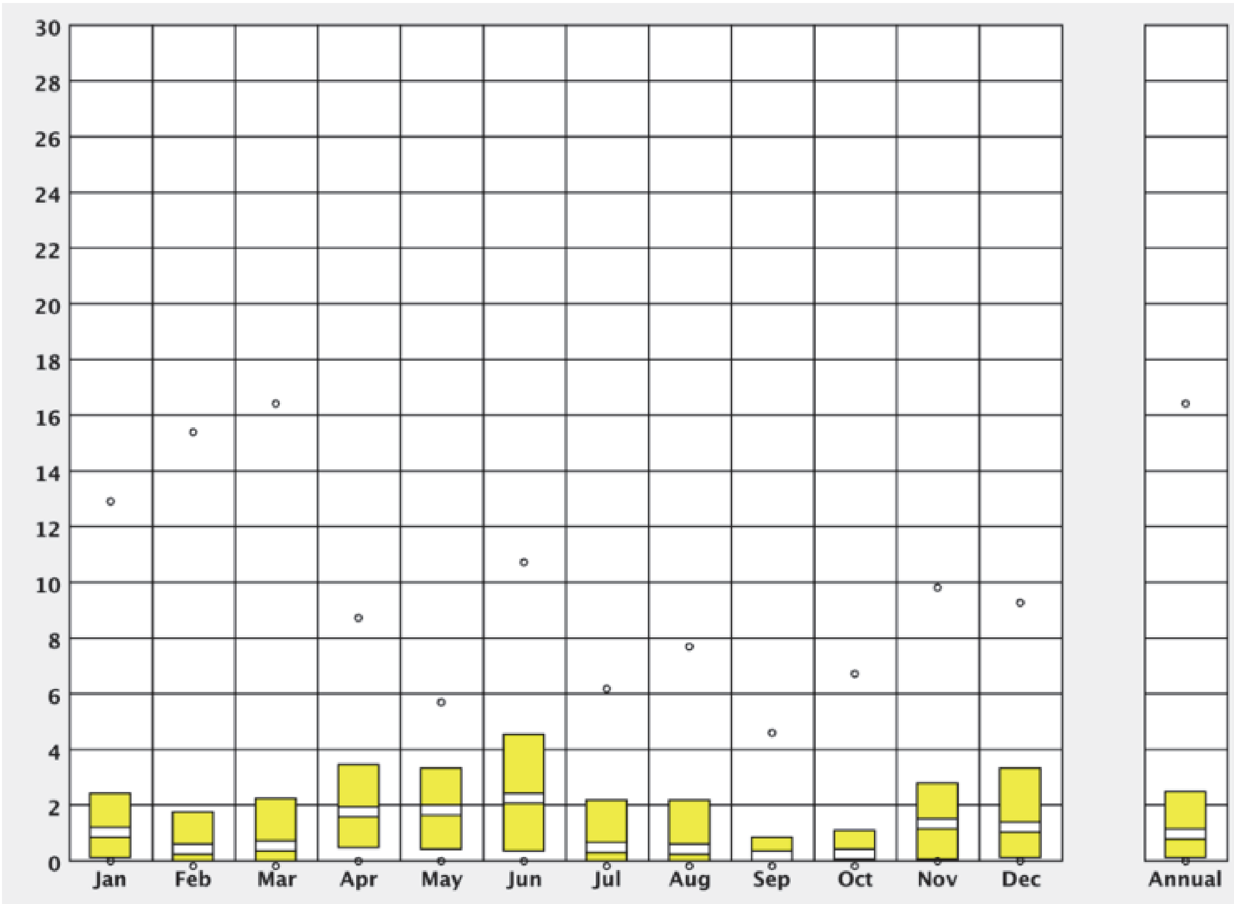


Figure 44: Annual wind speed in Turin ("Climate Consultant 6.0" 2018)

5.1.3.2.1. Bioclimatic Architecture in Turin

This approach has shed light on the significant impact of design and construction on global warming. Architecture plays a crucial role in energy consumption as it encompasses heating, cooling, and lighting systems, thereby influencing the environment. The field of ecology is deeply intertwined with the building process, placing a heavy responsibility on architecture to prioritize ecological well-being in its design, projection, and construction. Bioclimatic architecture has been documented throughout different architectural periods, with detailed analyses of factors such as sunshine, solar angles, dominant winds, and more. Unfortunately, in recent centuries, industrialized construction has overlooked these essential concepts, resulting in environmental harm rather than benefit. Vernacular architecture, however, has slowly evolved and acquired valuable knowledge related to social, cultural, religious, economic, technological, and climatic aspects of specific locations, leading to unique architectural designs. Without relying on additional energy-consuming technologies that harm the environment, this style of architecture adapts to local temperatures. The Piemonte region, situated in northern Italy on the border with

France, possesses an abundance of materials such as stone, widely used in both vernacular and monumental architecture. Several case studies in the province of Turin showcase the use of adobe for interior and exterior walls, with horizontal elements predominantly composed of wooden beams, occasionally filled with brickwork. Wooden or brick frames are used for openings, while houses are supported by brick or stone foundations elevated 40-50 cm above ground level to protect against rising water.

The use of earthen materials in this region offers various benefits during cold winter and warm summer months. The high-mass brick walls absorb heat from the sun during the day and release it at night, reducing heating demands in winter. Additionally, solar radiation through windows and walls can decrease heating requirements. In summer, the strategic use of overhangs and different solar radiation angles minimize solar heat gain, consequently reducing the need for cooling systems. Bioclimatic architecture can extend to bioclimatic urbanism, incorporating intentional solar orientations when planning streets and allocating free garden spaces to create comfortable public environments, facilitated not only by architectural elements but also deciduous vegetation. An example of bioclimatic architecture in Turin is the presence of shaded outdoor buffer zones in the urban context. These areas provide shade for pedestrians, preventing overheating in commercial buildings during summer months and enhancing comfort levels. Pitched roofs are commonly used in this region, primarily to prevent precipitation leakage, but they also maximize solar gains by expanding the room area. Window shades are another prevalent element, allowing occupants to manually control solar heat gain according to their comfort needs while also providing security. During winter months, closed shades help reduce energy loss, especially with single-glazed windows. Overhangs and balconies are also frequently incorporated in this region, serving as effective measures to manage solar heat gain throughout summer and winter. Psychrometric charts, presented below, illustrate the percentage of indoor comfort with and without active and passive strategies.

As demonstrated earlier, a remarkable 48% level of indoor comfort can be achieved solely through passive strategies, without the need for active heating and cooling systems in the building. These passive strategies, which align with the principles of bioclimatic architecture in this region, encompass the use of high-mass walls, harnessing internal solar heat gain, and implementing shading systems. To further enhance indoor thermal comfort throughout the year, active heating systems can be employed, resulting in a significant increase of 96% in comfort level. This represents a boost of 48% in comfort, with the remaining 4% easily attainable through cooling systems. According to climate consultant data, this 4% corresponds to approximately 295 hours per year, equivalent to around 12 days. As previously mentioned, when introducing the principles of a passive house, this cooling demand can be effectively addressed by a mechanical ventilation system, ensuring comfort during these 12 days.

5.1.3.3.Structure of case study in Turin:

To validate the technique, a residential neighbourhood **located in the municipality of Turin in Northern Italy** was carefully chosen. This particular neighbourhood stands out due to the diverse mix of building types and uses it encompasses. There are two primary reasons why this case study holds significance. Firstly, the buildings within this area were constructed prior to 1980, resulting in poor thermal qualities. Secondly, it presents an excellent opportunity to explore the implementation of district heating since the neighbourhood is not currently connected to any district heating infrastructure.

To evaluate the district's retrofit possibilities, we have defined different retrofit scenarios, focusing on alternative heating generation configurations and energy efficiency measures applied to the building envelopes. The district's buildings were categorized into five typologies based on their geometrical, thermophysical, and construction-date characteristics in Table 16, utilizing the TABULA database as a resource (Corrado et al., 2014). Following the guidelines specified in D.G.R. n.46-11968 of the Piedmont Region (Figure 38), two levels of building envelope retrofit were considered: a "standard" refurbishment that incorporates commonly utilized measures available in the market, and an "advanced" refurbishment that incorporates measures employing the most innovative technologies currently available.

To determine the energy requirements for both domestic hot water generation and space heating associated with these two retrofit levels, the TABULA database was utilized. In terms of the energy efficiency measures system, all scenarios consider district heating as a viable solution, coupled with cogeneration to fulfil a huge portion of the electrical demands. However, different energy sources (biomass and natural gas) and varying generation efficiencies are employed across the scenarios. (Becchio et al., 2018)

		Envelope EEMs	
		Standard	Advanced
Generation EEMs	District Heating - Biomass Oil Circuit Recloser cogeneration system - Biomass thermal system - Photovoltaic system	Scenario 1	Scenario 2
	District Heating - Gas turbine cogeneration system - Gas thermal system - Photovoltaic system	Scenario 3	Scenario 4

Table 14: Energy retrofit scenarios. (Corrado et al., 2014).

[2].

Existing buildings		Standrad retrofit		Advanced retrofit	
QH,nd [kWh/m2y]		QH,nd [kWh/m2y]	Saving	QH,nd [kWh/m2y]	Saving
Typology 1	170a	36.3	78.60%	29.3	82.80%
Typology 2	153a	35.7	76.70%	27.5	81.90%
Typology 3	162a	35	78.40%	27.9	82.80%
Typology 4	157a	33	76.90%	26.2	83.30%
Typology 5	134a	33.4	75.10%	25.8	80.70%

Table 15: Energy needs for space heating of reference typology and of the buildings with envelope measures and relative energy savings. (Ballarino et al. (2014).

The objective of this section is to assess the comprehensive range of costs and benefits associated with each of the four options being considered. This assessment aims to integrate the findings into the decision support system and select the most effective option for the energy requalification of the district under investigation. The implications of these four projects have been evaluated using a Cost-Benefit Analysis (CBA) technique, considering a 30-year timeframe. In this analysis, the evaluation has focused on specific categories of co-benefits, which are described as follows: (Becchio et al., 2018)

- running benefits.
- GHG emissions reduction.
- asset value increase.

To quantify the financial value of the effects, it was essential, to begin with financial pricing. This involved considering various factors such as government interventions (taxes and subsidies), opportunity costs associated with resource utilization, market distortions, and externalities, particularly those related to the environment. Adjustments were made to these pricing considerations, ensuring a comprehensive assessment of the effects and their associated financial implications. (Becchio et al., 2018)

5.1.3.3.1. Running benefit

the analysis considered several factors to determine the costs and benefits associated with each specific measure applied:

1. Investment costs: The initial investment costs for each measure were calculated using an analytic estimation approach. The price list of the Piedmont Region for building envelope

measures was used as a reference, while other specific Energy Efficiency Measures (EEMs) were based on web surveys and previous studies.

2. Energy costs: The calculation of global costs involved considering energy costs related to energy consumption. The portion of energy derived from non-renewable sources that needed to be purchased throughout the lifecycle was taken into account. Prices were obtained from the AEEG website, and the study also considered the reduced flow of taxes associated with electrical energy consumption in public finances.

3. O&M (Operations and Maintenance) costs: For strategies involving biomass heating systems, the cost of ash disposal was considered. The maintenance costs of the building and district systems were also taken into account, including possible interventions during the useful life of components. The economic life of each component was determined to calculate maintenance costs as a percentage of the initial investment.

4. Replacement costs and residual value: If the economic life of a component was shorter than the calculation period, it was assigned a replacement cost equal to its initial investment cost. Components with longer useful lives or those that continued to operate after the calculation period were characterized by a residual value.

5. Revenues from sales of self-produced electricity: The financial analysis included the consideration of revenues from selling self-produced electricity to the grid. The tariffs proposed by Gestore dei Servizi Energetici in 2015 were used to calculate this benefit, valuing the electricity based on the average monthly price per time slot corresponding to the market area of connection. By taking all these factors into account, a comprehensive assessment of the costs and benefits associated with each measure was achieved, enabling the comparison of alternative strategies. (Becchio et al., 2018)

5.1.3.3.2.GHG emission reduction

For the environmental impact, CO2 equivalent emissions were quantified from the consumption data (non-renewable primary energy) throughout the life cycle. To evaluate the annual greenhouse gas (GHG) emissions, the calculated values were multiplied by the expected prices per ton of CO2 equivalent, as estimated by EPBD recast. The cost of CO2 was assumed to be €20 per ton up to 2025, €35 up to 2030, and €50 after 2030. By considering the CO2 emissions and applying the respective cost per ton of CO2 equivalent, the analysis provided insights into the greenhouse gas mitigation potential and associated costs of each retrofit strategy. This information is valuable for decision-makers in evaluating the environmental impact and financial implications of different approaches to reducing GHG emissions. (Becchio et al., 2018)

5.1.3.3.3. Asset value:

The application of a simplified version of the hedonic pricing model (Rosen, 1974) enabled the estimation of the benefits associated with the increase in the market value of buildings resulting from energy requalification operations. The hedonic price technique, which is widely employed to determine the value of individual attributes of a property (Fuerst et al., 2015; Palmquist, 1984), represents the most widely accepted empirical approach (Markandya and Richardson, 1992). This method operates under the assumption that different goods are distinguished by various characteristics. Within market equilibrium, the price of property constitutes a combination of demand-side and supply-side attributes, which can be effectively analyzed through the application of the hedonic price method (de Ayala et al., 2016).

According to Bottero and Bravi (2014), the price of real estate is viewed as a collection of attributes that serve as integral components of the hedonic price function, as defined by Equation.

where P is the market value and (zz z 1 2,) … n represents the building attributes. In the present application, the first step was market research carried out consulting real estate listing sites (www.immobiliare.it), a sample of 160 buildings located in the case study market zone (Turin's microzone 7) was selected. Some important building characteristics were considered to insert them into the hedonic price function:

Surface [m2]; the marketable surface, measured in cardinal scale;

• Level; the floor level of the apartment, where "0" is a ground floor, measured in ordinal scale;

• Apartment condition; the apartment status, measured using 4 levels ("to be completely renovated", "good", "refurbished" and "new");

• Location; the different building locations within micro-zone 7, measured by 4 levels;

• Energy performance of apartment (EPC); the energy performance class, measured in ordinal scale where the rate A corresponds to the value 5, the rate B to 4, the rate C to 3, the rate D to 2, and the rates E, F, and G to 1;

• Price [€]; the market price of the apartment during 2015.

Estimates of willingness to pay for various energy class levels came up with several 9,620 euros per flat. In this study, it was assumed that all of the surveyed buildings were in their original state, in a low energy class (F or G), and had never undergone any energy efficiency restoration. According to the D.G.R. n.46-11968 (2009) DGR 46-1, 2009D.G.R. n.46-11968 (2009), the change in energy class was instead calculated for each apartment for all strategies. (Becchio et al., 2018)

5.1.3.4. Aggregating costs and benefits: the Social Return on Investment (SROI)

In conclusion, the costs and benefits were carefully analyzed and distributed according to the Cost-Benefit Analysis (CBA) methodology for each strategy. The analysis followed a specific timeline, as recommended by the European Commission (2014), considering investment costs and relative benefits, such as job creation and asset value increase, in the first year. From the second year onwards, maintenance, energy, operation, and other benefits were taken into account.

The CBA employed key indicators, namely the Net Present Value (NPV) and the Internal Rate of Return (IRR), to evaluate the investment's performance. The NPV represents the difference between the net cash inflow over the period and the initial investment costs, while the IRR is the rate of return that equates the net present value of all cash flows to zero. A positive NPV indicates a favorable investment, and the IRR should surpass the minimum required rate of return for the proposal to be acceptable.

For this research, a benefit-cost ratio was selected for evaluation, considering a social discount rate of 5% to convert costs and benefits into present values from a societal perspective. To emphasize the socio-environmental effects, the Social Return On Investment (SROI) indicator was chosen. The SROI ratio compares the discounted value of positive impacts and revenues to the discounted value of negative impacts and costs. A value greater than 1 indicates a favorable alternative strategy, suggesting that the community receives a higher return on investment in terms of social welfare.

The analysis results (Table 7) demonstrated that Strategy 1 outperformed the other strategies in socio-economic terms. Although Strategy 1 incurred higher investment and management costs, it also yielded higher economic returns to society. This strategy demonstrated lower emissions costs and a greater number of net new jobs created, making it the better-performing solution in socio-economic terms. (Becchio et al., 2018)

Table 7
Economic performance indicators for the different strategies.

	Strategy 1	Strategy 2	Strategy 3	Strategy 4
NPV	16,458,762	15,579,360	14,014,660	13,361,222
SROI	1.73	1.67	1.65	1.57

5.1.3.5. Pointed up conclusion by the authors Cristina Becchioa, Marta Carla Botterob, Stefano Paolo Corgnatia, and Federico Dell'Annab, in the case study of Net Zero-Energy District in Turin

In conclusion, this study focused on evaluating the analysis of the authors, the extension of the zero-energy standard to a district scale, known as Net-Zero Energy District (NZED), and quantifying the co-impacts of energy efficiency measures from a decision-making perspective. The research provided a methodological framework for identifying, quantifying, and monetizing co-impacts and integrating them into a Cost-Benefit Analysis (CBA). A case study in Turin was conducted, examining four different strategies to improve energy efficiency in the district.

The analysis compared the global costs and environmental impacts of the project, considering additional costs and benefits. To combine the identified impacts, the Social Return on Investment (SROI) was chosen as a comprehensive evaluation index. The SROI calculation revealed that Strategy 1, characterized by a standard level of envelope retrofit and an EMM system fueled by biomass, was the most favorable in socio-economic terms. This strategy not only resulted in energy and cost savings but also significantly reduced environmental impact and CO2 emissions through the use of renewable energy sources, aligning with European decarbonization objectives.

The developed methodology proved effective in supporting decision-making processes for district retrofit strategies, allowing the comparison of investment costs with externalities and co-benefits for the environment and the community. The inclusion of co-benefits in the decision process is particularly relevant for defining energy policies at the urban scale, contributing to the development of low-carbon, environmentally sustainable cities.

Future research should focus on more precise estimation of impacts, especially regarding the effects of energy requalification on real estate value. Spatial hedonic pricing models and data panel approaches could be integrated into the analysis, along with Geographic Information System (GIS) software. A hybrid combination of CBA methodology and the Multi-Criteria Decision Analysis (MCDA) matrix could be explored to include intangible impacts such as safety, social acceptance, privacy, and security. Additionally, further investigation is needed to quantify and monetize the benefits of energy retrofit operations on urban health and well-being. The potential rebound effect, which may reduce expected energy savings, should also be considered in the evaluation model. Three types of rebound effects - direct, indirect, and technological progress-induced - should be accounted for, although evaluating the rebound effect is challenging due to various influencing factors. In summary, the evaluation model presented in this study provides valuable insights for decision-making in district retrofit strategies, facilitating more transparent and informed decisions. Further developments should address rebound effects and improve the estimation of alternative options. (Becchio et al., 2018)

5.1.3.6. what has been done in this case study in Turin

The graph presented in Figure 46 illustrates the percentage reductions in non-renewable primary energy (represented in grey) and CO2 emissions (represented in black) for each scenario compared to the existing district. Among the scenarios, both Scenario 1 and Scenario 2 exhibit the highest level of sustainability in terms of energy consumption and emissions. These scenarios hold the potential to achieve the ambitious goal of creating a Zero-Carbon City, characterized by climate neutrality and significantly reduced emissions. To broaden the analysis and consider macroeconomic factors, it was necessary to incorporate the co-benefits calculated using the proposed methodology. Furthermore, assigning a value to the initial costs associated with the four scenarios was crucial. In this case, a parametric (or synthetic) construction cost estimate was employed to approximate the investment cost. Once all costs and benefits were estimated and the calculation period determined, the CBA table was completed for each scenario. The cash flow was then calculated and adjusted using the social discount rate to determine key economic performance indicators, such as the Net Present Value (NPV) and the Social Return on Investment (SROI). Of particular importance, the SROI was utilized to evaluate the monetary value of economic, social, and environmental benefits across the scenarios. The analysis revealed that Scenario 1, as shown in Figure 47, demonstrated the highest level of efficiency in socio-economic terms. While this scenario involves considerable investment and management costs, it also yields substantial economic returns for society, including reduced emissions costs and a higher number of net new jobs created. (Becchio et al., 2016)

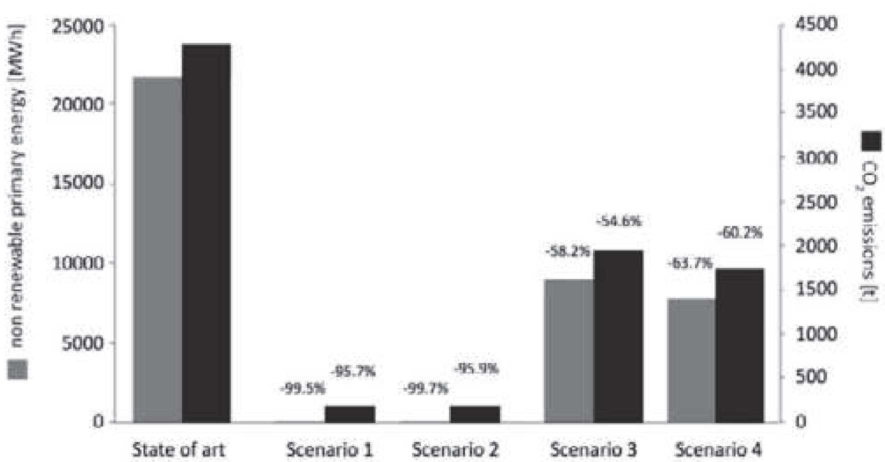


Figure 45: Nonrenewable primary energy (in grey) and CO2 emissions (in black) comparison for existing district and each strategy in Turin (Becchio et al., 2016)

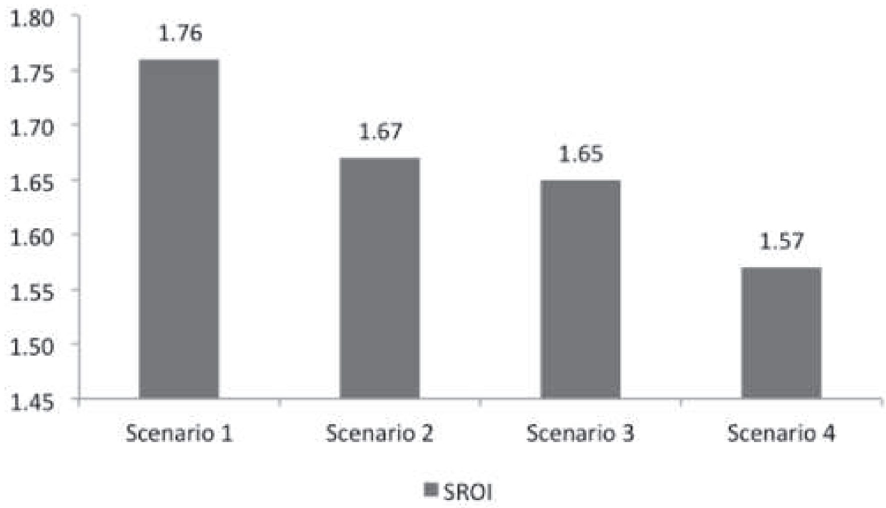


Figure 46: SROI value for each scenario in the Turin case study. (Becchio et al., 2016)

5.1.4. The upcoming Conclusion by the authors noted

Numerous studies have recognized the presence of co-impacts resulting from green energy projects, extending beyond the commonly considered effects. The primary objective of this research is to establish a methodological framework for identifying, quantifying, and monetizing these co-impacts. This framework aims to incorporate them into a comprehensive cost-benefit analysis, leading to the determination of a single evaluation index known as the Social Return on Investment (SROI). To validate this methodology, it was applied to a case study involving the retrofitting of a district energy system in Turin.

The SROI results revealed that the most favorable scenario, from a socio-economic standpoint, was the first one. This scenario involved a standard level of retrofitting for the building envelope and the implementation of an Energy Management and Monitoring (EMM) system powered by biomass. In addition to significant energy and cost savings, this scenario substantially reduced environmental impact and CO_2 emissions by leveraging renewable energy sources for heating and electricity, aligning with the European decarbonization objective. Another contributing factor to the preference for this scenario was the creation of new jobs resulting from the retrofit interventions, surpassing the employment opportunities provided by scenarios involving fossil fuels. (Becchio et al., 2018)

Overall, the developed methodology proved effective in supporting decision-making for district retrofits. The analysis of various scenarios underscored the substantial influence of co-benefits, which can impact the evaluation of energy efficiency measures not only in economic terms but also in environmental and social aspects. Co-benefits accounted for a significant portion of the project's overall outcome, exceeding financial revenues.

In this initial application of the methodology, the estimates provided were approximations and will be further refined. Market value estimation, for example, is the subject of extensive research in the international literature, proposing more sophisticated approaches to quantify this benefit. Additionally, expanding the methodology to encompass a wider range of externalities, such as health and well-being impacts, presents an opportunity for further development. However, the quantification and monetization of these benefits are still in the preliminary stages, particularly in the context of Italy. Future advancements could involve the creation of tools to facilitate the application of the methodology, such as spatial hedonic pricing models that utilize geographic information systems (GIS) to establish comprehensive databases. Furthermore, considering the diverse range of stakeholders within a district (e.g., owners, investors), such analyses could guide redevelopment choices and enable decision-makers to select the most favorable and profitable processes, including impacts that might otherwise be overlooked in project evaluations. Additionally, exploring the decision problem through alternative evaluation methodologies, such as Multi-Criteria Analysis (MCA), would be of interest. MCA allows for the inclusion of all relevant impacts associated with Net-Zero Energy Districts (NZED) and assists decision-makers in integrating diverse options. MCA is considered simpler to apply compared to CBA, as it does not require the conversion of all costs and benefits into monetary values.

In summary, this research emphasizes the importance of considering co-impacts in green energy projects and provides a methodological approach for their inclusion in comprehensive cost-benefit analyses. Further refinements, extensions, and the exploration of alternative evaluation methodologies can enhance the decision-making process for district retrofits and promote sustainable development.

5.2. Analyzing power production energy level of the district by the case studies in Turin by the author Matteo Orlando, Lorenzo Bottaccioli, Sara Vinco, Enrico Macii, Massimo Poncino, and Edoardo Patti

In this part of the study by the Authors Orlando…, we will check whether Photovoltaic (PV) energy generation stands out as a prominent solution among various Renewable Energy Sources (RES), with a projected market share of 25% by 2050. The prosumer paradigm, which empowers energy consumers to become producers, fosters the adoption of PV installations. However, implementing this paradigm at the individual household level may face obstacles such as financial constraints and investment uncertainties. To overcome these challenges, the solutions market operates at the district level, where multiple buildings collaborate to establish larger PV installations. An Energy Aggregator (EA) takes charge of managing energy demand and selling surplus production to the grid, allowing prosumers to enjoy the benefits of potential energy independence without shouldering the burden of investment and system management. To optimize the advantages of this market paradigm, the EA must meticulously design PV installations to maximize solar potential. The presence of building shadows can significantly diminish PV power generation efficiency, necessitating a delicate balance between installation size, costs, and return on investment. It is crucial to acknowledge that a larger PV installation does not always guarantee higher earnings due to increased initial investment and potential inefficiencies caused by shading. Within this context, identifying suitable roofs within a district for optimal PV power generation and determining the corresponding installation poses a significant challenge. This problem calls for expertise in shadow forecasting, PV power generation optimization, and economic evaluation of return on investment. This study conducted at the district level aims to determine the optimal PV installation by considering cost-benefit trade-offs and production efficiency. (Orlando et al., 2021b)

The novelty of this work is demonstrated in the table presented in Table 17 below.

GIS-based	This method assesses how sunlight and temperature change across the roofs of a district throughout a year. It achieves a high spatial resolution of 1 meter, enabling precise estimation of the operating conditions for a potential PV installation. The evaluation covers a large urban area spanning several square kilometers.
Placements of PV	Achieved by considering the roofs of district as a whole, i.e., allowing to connect PV modules located on contiguous roofs of different buildings
Economic	Analysis to determine the payback time of the PV installation
Payback time	Different sizes of the PV installation and allowing different levels of PV efficiency, to determine the most suitable and the most economically convenient solution in the interest of the Energy Agrgregator (EA)
Application to a district located in Turin	will prove an improvement of power production of up to 20% and of 25% of payback time w.r.t. a traditional installation.

Table 16: The novelty of PV installation, (Orlando et al., 2021b)

5.2.1. Suitable area and irradiance

The algorithm employed in this study utilizes a Digital Surface Model (DSM) of the district to pinpoint areas that are well-suited for PV installation, considering obstacles and the changing patterns of shadows. The DSM undergoes processing using GDAL, a geospatial data format library, to identify surfaces, specifically roofs, that maximize power production based on their tilt angle and orientation about the district's geographic location. As a result, two raster images are generated—one for the roof slope and another for the roof aspect. Surfaces with slopes ranging from 15 to 36 degrees and aspect values between 240 and 300 degrees are extracted, representing roofs that offer optimal sun exposure for potential PV production. It's important to note that these suitable areas for PV installation only constitute a portion of the entire district area. Each identified suitable area is annotated with information on the inclination, aspect, and average height of the roof pitch, taking into consideration the height differences between adjacent roofs. Subsequently, the areas are sampled with the same resolution as the DSM and georeferenced points are employed to determine the irradiance variations over time using yearly weather data and a shadow model. This approach ensures optimized data generation and storage by focusing on areas suitable for PV installation while maintaining a detailed representation of solar evolution in these selected regions throughout time. (Orlando et al., 2021b)

5.2.2. Performance Pre-evaluation

The subsequent step involves identifying the most highly irradiated sections within the previously determined suitable areas, which offer the greatest potential for PV module installation. The exploration of these suitable areas encompasses an examination of all possible PV module placements. The yearly irradiance profile of each position is derived from the DSM, specifically from the traces associated with the DSM points covered by the PV module. In cases where multiple points are involved, the minimum irradiance value among all the traces is selected for each time to emulate the bottleneck effect. To facilitate straightforward comparison, a concise signature is generated using the 75th percentile of irradiance. This percentile value allows for distinguishing between positions with high irradiation and those with low irradiation, with higher values indicating positions that hold more promise for PV power production.

The sorting of PV module positions is based on the descending order of the 75th percentile value. The user can establish a threshold value, minTh, representing the minimum acceptable percentile value for PV placement. Positions with a 75th percentile below month are excluded from the suitable area as they are considered unpromising in terms of PV power generation. The resulting suitable area represents the space that can be utilized for achieving optimal power generation by installing PV modules.

5.2.3. Optimal Placement algorithm

The subsequent stage involves determining the optimal placement within the identified suitable area using the sorted list of PV module positions based on the 75th percentile. Starting from the position with the highest 75th percentile, the algorithm proceeds through the sorted list while taking into account the following constraints:

- Avoidance of overlap with already placed PV modules.

- Limiting the distance from already placed PV modules to a threshold value, max.

- Ensuring the height difference with already placed PV modules is below a threshold value, max.

The user-defined values of max and max ensure appropriate cable dispersion and connection between adjacent roofs or pitches. This iterative process continues until a series of S PV modules is formed. As each new position is selected, it is removed from the sorted list. Once a series of size S is completed, the positions that were previously excluded due to distance and height constraints are reintroduced into the sorted list. The algorithm then starts constructing a new series, beginning with the position that has the highest 75th percentile. The process continues until it becomes infeasible to create a new series, indicating that the remaining number of positions is less than S. The resulting layout of the PV installation consists of multiple series, where each series consists of S PV modules connected in parallel. It is important to highlight that the algorithm's greedy approach facilitates the connection of PV modules with similar irradiance distribution, effectively minimizing the bottleneck effect caused by partial shading.

5.2.4. Power Production in the case study of Turin

In the final stage, the algorithm assesses the yearly power production of the optimal PV installation. To evaluate its performance, the algorithm also generates a traditional placement comprising the same number of PV modules, following a standard compact rectangular arrangement that disregards the 75th percentile of irradiance.

The yearly trace of each PV module is utilized to estimate the overall yearly power production of the PV installation, considering both the series and parallel connections between the modules. Let N represent the number of series identified in Step IV-C, and S denotes the number of PV modules in each series. The total power of the installation, denoted as P Yearly, is calculated using the following formula, which replicates the bottleneck effect described in Section III:

$P\_panel = V\_yearly * I\_yearly$

$V\_panel = \min(j=1,...,N) (P(i=1,...,S) V\_module,ij)$

$I\_panel = \mathrm{sum}(j=1,...,N) (\min(i=1,...,S) I\_module,ij)$

Here, V_module,ij, and I_module,ij represent the voltage and current extracted from the i-th PV module in the j-th series, and T is the length of the irradiance traces.

The proposed framework underwent testing in a district located in Turin (refer to Figure 48). The satellite view of the area was superimposed with the outcome of Step IV-A. The green area represents the overall roof surface, spanning approximately 1.7 km2, while the red area signifies the suitable region for PV installation, covering around 8,340 m2. Notably, only 0.5% of the available roof surface is considered suitable for PV installation. This underscores the effectiveness of the DSM data management strategy employed, as it utilizes a minimal number of DSM points to filter the suitable area and generates complete irradiance traces for only a small fraction of the district.

In our setup, we employ Mitsubishi's PV-MF165EB3 module organized in strings comprising 8 PV modules each. The algorithm is configured to allow a maximum distance of 3m between PV modules within the same series, as well as a maximum height difference of 0.5m (maxD = 3m and maxH = 0.5m). This configuration enables the placement of PV modules from different yet nearly adjacent roofs within the same series. An illustration of such a scenario can be observed at the top of Figure 49, which focuses on a specific section of the district, showcasing an example where the suitable area extends across two adjoining roofs (indicated by the black line in Figure 49).

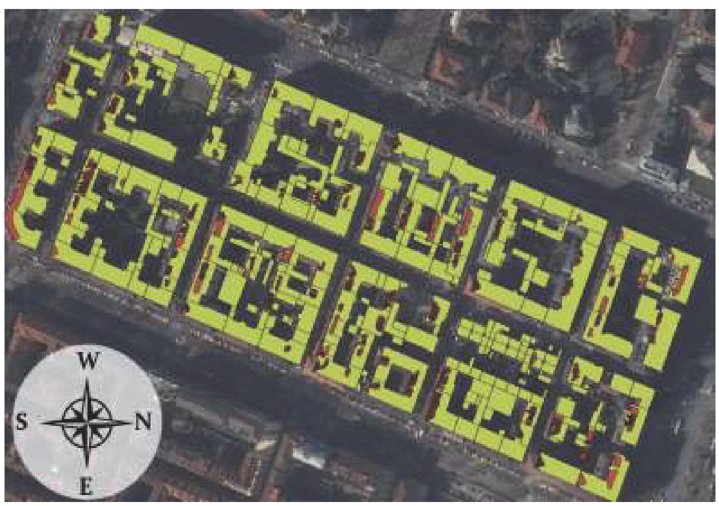


Figure 47: Satellite view of the area used for the test (Orlando et al., 2021b)

5.2.5. Analysis of the identified PV placements in the district of Turin

To evaluate the effectiveness of the placement, we conducted multiple iterations of the algorithm, employing different values of minTh, which represents the threshold for the 75th percentile used to select the most promising section of the suitable area. The results are presented in Table 18. As minTh increases, indicating a higher threshold, the area considered promising decreases since locations with a 75th percentile below minTh are excluded. Consequently, both the percentage of the utilized area and the number of installed PV modules decline. Figure 2 illustrates this trend: when minTh is set to 100 W/m2, 21% of the available surface is deemed suitable for PV placement. However, when minTh is increased to 500 W/m2, only 2% of the area is considered suitable, resulting in a significantly lower number of PV modules installed on the same roof section (represented by colored rectangles). Plotting the number of installed PV modules (first plot in Figure 3) reveals a non-linear decrease as the threshold increases. For example, transitioning from 200 to 300 W/m2 leads to a two-thirds reduction in the number of modules (and the utilized area), as a considerable percentage of locations falls within the 200-299 W/m2 range. As anticipated, the initial installation cost decreases proportionally with the number of installed PV modules (second plot in Figure 3).

Threshold $minTh$ (W/m^2)	PV modules (#)	Installation area (m^2)	Suitable area used (%)
100	1,792	1,540	21
200	1,536	1,319	18
300	656	561	8
400	464	394	6
500	176	148	2

Table 17:PERCENTAGE OF AREA USED BY PV PLACEMENT OVER THE TOTAL SUITABLE AREA WHEN VARYING minT h, (Orlando et al., 2021b)

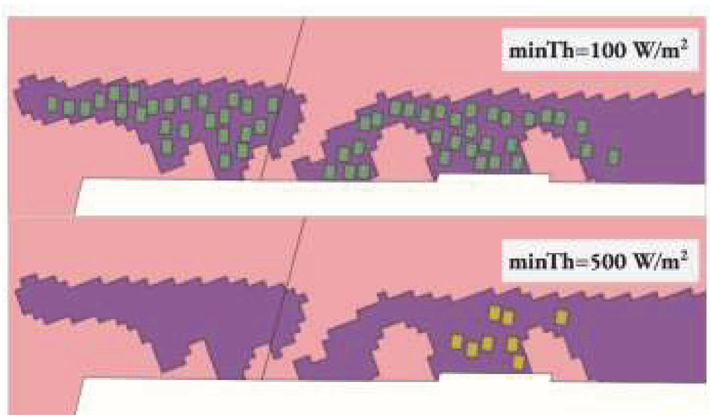


Figure 48: Result of the placement algorithm on a small portion of the district (i.e., two roofs) with threshold minT h = 100 W/m2 (top) and minT h = 500 W/m2 (bottom): the pink area represents the area of the roofs, the purple area is the suitable area, and the rectangles represent PV modules placed on locations with 75th percentile higher than minT h. As expected, the second placement contains fewer PV modules, as the minimum threshold is higher. (Orlando et al., 2021b)

To assess the effectiveness of the proposed algorithm in terms of power output, we conducted a comparison between the yearly production of the optimal PV placements and a traditional placement with an equal number of PV modules. The traditional placement followed a standard configuration, disregarding the 75th percentile of irradiance and considering each roof individually, without cross-building deployments. Table 3 presents a clear demonstration that the optimal PV installations consistently outperform the corresponding traditional placement in terms of production. As expected, the production decreases linearly as the number of installed modules increases. However, it is worth noting that higher values of the minimum threshold (minTh) yield greater improvements in power production. The maximum improvement of 21% is observed with a threshold of 500 (as shown in Table 19 and depicted in the third plot of Figure 3). This behavior can be easily understood by considering that lower thresholds lead to a higher number of PV modules and potential overlap between the two placements. Conversely, higher thresholds reduce the number of PV modules, allowing the optimal placement to select positions with minimal shading impact. This effectively mitigates the bottleneck effect caused by partial shading on the power output of the optimal PV placement. The extent of the shared area between the two placements confirms this analysis, with a higher shared area of 36% observed at minTh = 100 W/m2. As higher values of minTh are employed, the shared area decreases, reaching a minimum of 15% at minTh = 500 W/m2.

Threshold $minTh$ (W/m^2)	PV modules (#)	Shared area (%)	Power production (MW)		
			Optimal	Traditional	(%)
100	1,792	36	1,015	998	+1.6%
200	1,536	31	905	874	+3.6%
300	656	22	423	376	+12.6%
400	464	23	323	277	+16.9%
500	176	15	139	115	+20.8%

Table 18: SUMMARY OF THE COMPARISON AMONG THE OPTIMAL PLACEMENT WITH VARYING minT h W.R.T. A TRADITIONAL PLACEMENT OF THE SAME NUMBER OF PV MODULES. (Orlando et al., 2021b)

5.2.6. Payback time

By following the procedure detailed in section IV E, we conducted an evaluation of the payback time (PT) for both the traditional and optimal configurations, considering various threshold values. In our analysis, we used an energy price of 0.22 euros per kWh, with a cost of 250 euros per PV module and an annual maintenance cost of 15 euros per PV module. Plot 4 in Figure 5 visually presents the reduction in PT alongside the decrease in the number of PV modules. Notably, the payback times of the PV installations generated by our framework consistently outperform those of the traditional placements. Specifically, when the threshold is set at 500 W/m2, the configuration produced by our framework reduces the PT by 1/4. However, upon comparing the results in Table II with Figure 50, we observe that increasing the number of PV modules improves production and earnings, but does not decrease the PT; in fact, it tends to increase. This highlights the significance of conducting an economic analysis for effective investment planning, considering such factors, by entities or individuals. (Orlando et al., 2021b)

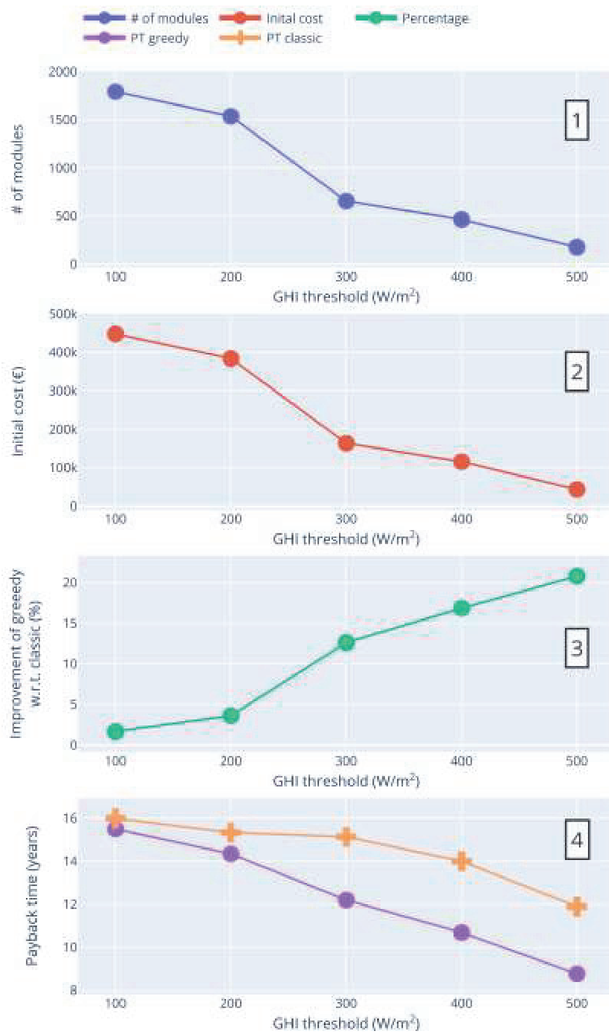


Figure 49: Behavior of the placement algorithm with different values of minT h: number of PV modules (1), initial installation cost (2), improvement of power production w.r.t. the traditional placement (3), payback time (4) (purple for the proposed algorithm, orange for the traditional placement). (Orlando et al., 2021b)

5.2.6. Conclusion

In conclusion, this study presented a framework for optimizing the placement of photovoltaic (PV) modules in the city district of Turin. The framework utilized a Digital Surface Model (DSM) to identify suitable areas for PV installation based on factors such as roof slope, aspect, and height. By considering these parameters, the framework effectively determined areas with optimal sun exposure and potential PV production. The framework proceeded to analyze the irradiance of the suitable areas over time using georeferenced points. The 75th percentile of irradiance was utilized as an indicator to differentiate highly irradiated positions, which are more promising for PV power production, from poorly irradiated positions. By sorting the PV module positions based on the 75th percentile, the framework provided a ranked list of positions for optimal placement. The optimal placement algorithm then selected positions from the sorted list while considering constraints such as no overlap with already placed PV modules, maximum distance, and height difference. This algorithm allowed for the construction of a series of PV modules connected in parallel, reducing the bottleneck effect caused by partial shading.

The performance of the optimal placement was evaluated in terms of power production. The results demonstrated that the identified optimal placements consistently outperformed traditional placements in terms of power production, with higher values of the 75th percentile leading to greater improvements. This highlighted the significance of selecting positions with lower shading impact to maximize power output. In summary, this paper has presented a framework that aims to optimize the installation of PV modules in a city district, to maximize profit for an Energy Aggregator (EA). The framework utilizes efficient management of Digital Surface Model (DSM) data, focusing on the most promising portion of district roofs, which represents only approximately 0.5% of the total district area. By leveraging this data, the framework generates an optimal placement of PV modules that takes into account shading and uneven irradiance, striking a balance between initial investment, power production, and payback time. The results demonstrate that the framework can achieve a surplus power production of up to 20% compared to traditional installations. Additionally, an economic analysis was conducted to assess the financial viability of the PV installation. The payback time (PT) was calculated, considering the installation cost, yearly revenue from energy sales, and yearly maintenance costs. The results showed that the PV installations produced by the framework had lower PT values compared to traditional placements, indicating a faster return on investment.

Overall, the proposed framework offered an efficient approach to identifying and optimizing PV module placement in the Turin city district. By considering irradiance levels, power production, and economic factors, the framework enabled the selection of positions that maximized profitability. Future work could involve incorporating additional constraints, such as budget limitations, to provide more tailored solutions for different stakeholders.

In future work, the authors plan to expand the proposed solution by incorporating additional constraints. These constraints include limiting the maximum number of PV modules based on the user's budget and setting a maximum payback time as defined by the user. However, it is important to acknowledge that addressing these constraints poses challenges. Finding an optimal solution that satisfies both budgetary limitations and the desired payback time can be complex. It may require advanced algorithms or decision-making approaches to strike the right balance between profitability and meeting user-defined constraints. Overcoming these challenges will be crucial for the successful extension and practical implementation of the framework in real-world scenarios.

5.3. Monitoring and Evaluation of Integrated Building Solutions for Low-Energy the Confluence Cities Lyon

To pave the way for a sustainable and low-carbon future, it is crucial to implement targeted and comprehensive measures for mitigation and adaptation across all sectors of the economy. The energy systems, being the primary contributors to human-caused greenhouse gas emissions, demand immediate attention. Urban energy systems, in particular, hold a significant share in global energy consumption and CO2 emissions, given the concentration of socioeconomic activities in cities. As cities accommodate a substantial portion of the world's population and contribute significantly to national GDPs, their role in achieving energy and climate targets is undeniable. According to recent projections by the UN, the urbanization trend is expected to persist, with the percentage of people living in cities projected to rise from 55% in 2022 to 68% by 2050. This underscores the importance of cities and urban regions in driving sustainable development and addressing energy and climate challenges.

The building industry, known for its high energy consumption and environmental impact, assumes critical significance. With fossil fuel consumption still prevalent, studies indicate that the building sector in the EU accounts for approximately 40% of final energy demand and about 38% of greenhouse gas emissions. Furthermore, climate change significantly influences a building's energy performance, emphasizing the need for integrated building retrofitting.

Cities and urban systems face unique challenges due to their reliance on imported resources, including energy, and the limited availability of land. The transition toward harnessing local renewable resources, such as solar energy, adds pressure on urban land use and poses challenges to achieving sustainable urban development. Enhancing energy efficiency in urban energy systems becomes paramount to reducing future energy demand and optimizing resource management. Additionally, cities and urban areas have untapped potential for enhancing overall system efficiency and resource utilization by capitalizing on existing synergies between consumption and production patterns. This requires a shift from isolated approaches to integrated strategies, transcending individual elements like energy, mobility, and buildings. A comprehensive approach that incorporates cutting-edge concepts, technologies, and system structures, and leverages advanced ICT capabilities is essential. Such a transition not only aids in tackling the complexities of continuous urban evolution but also contributes to achieving the ambitious objective of climate neutrality by 2050, as set by various European cities. Alongside policy and governance changes, the design and implementation of integrated urban solutions necessitate a shift in consumer behavior and the adoption of state-of-the-art approaches to address the ongoing challenges in an increasingly complex demographic context.

The transformation towards a sustainable and low-carbon future holds great potential for corporations, governments, and civil society across the entire supply chain. While cities face numerous challenges in transitioning to a low-carbon economy, they also have exciting opportunities to stimulate new growth and generate employment through innovative practices.

European cities, with their rich histories, enduring cityscapes, advanced infrastructure, and high-quality services, stand out globally. Many renowned European towns have set ambitious long-term targets to establish themselves as inclusive, sustainable, and smart cities, positioning them as leaders of the future. These goals encompass decarbonization plans aimed at achieving climate neutrality and sustainable energy targets by 2050, marking a momentous urban revolution that will unfold over the next two to three decades.

To realize these objectives, cities are actively engaging in demonstration projects that explore the feasibility of integrated smart solutions at both the building and district levels. These initiatives examine potential obstacles, and deployment opportunities, and involve citizen participation and collaboration with key stakeholders. The H2020 R&I initiative on smart cities and communities has been instrumental in supporting integrated smart city solutions, with 48 demonstration projects implemented in select European towns known as lighthouse cities (LHCs). This initiative has demonstrated a significant positive impact at the local level, driven by the growing influence and noticeable effects of urban initiatives in combating global warming. Additionally, 116 European cities now receive subsidies from the EU to develop sustainable urban solutions.

This passage specifically highlights the application of smart solutions in the context of low-energy districts, exemplified by the Lyon Confluence project. These solutions encompass four categories: energy-efficient building refurbishment, smart building management, intelligent building control and end-user involvement, and smart electric and thermal grids. The Smarter Together project, alongside other LHC initiatives like Grow Smarter and ATELIER, adopts a holistic approach to sustainable low-energy districts, incorporating building refurbishment, densification, and the integration of renewable energy systems. Various demonstration projects and case studies have also addressed integrated energy planning at the city and district scales, focusing on sustainable and smart energy solutions for buildings and mobility. Innovative energy systems such as zero and positive-energy buildings, as well as positive-energy districts, aim for high energy efficiency, reliance on local renewable sources, and increased digitalization. Noteworthy projects like R2CITIES demonstrate comprehensive strategies for large-scale district renovation, achieving a final energy saving of approximately 50% compared to the initial state. Overall, these projects and initiatives strive to promote sustainable urban transformation through integrated energy planning and smart energy solutions.

The concept of Positive Energy Districts (PEDs), aiming to achieve carbon neutrality through innovative and integrated solutions, has led to the development of district demonstration sites that encompass diverse building types and uses. Several EU demonstration projects, including POCITYF, Making City, +City Change, and ATELIER, are actively working to materialize this concept. Lighthouse projects are designed to support European cities in achieving their sustainable and resilient transformation goals by formulating well-defined targets and action plans for future sustainable and smart development. The effectiveness of implemented solutions is monitored through Key Performance Indicators (KPIs), assessing their impact and providing a quantitative basis for potential replication on a broader scale. (Hainoun et al., 2022)

Between 2011 and 2016, an innovative smart community demonstration took place in Lyon, France, through a collaborative effort with Japan. The primary objective was to develop a forward-thinking city that incorporates cutting-edge energy technologies to align with Europe's ambitious environmental goals. This project was a joint endeavor involving Toshiba of Japan and four prominent French partner companies, operating under the Implementation Agreement (IA) established upon the Memorandum of Agreement (MoA) between NEDO and Lyon Métropole. Lyon Confluence, commissioned by SPL Lyon Confluence, served as the district redevelopment project and formed an integral part of NEDO's international smart community initiatives.

The project aimed to showcase the practical implementation of energy-saving technologies in both new and existing homes, while also demonstrating the utilization of IT-based PV generation management systems, EV car-sharing systems, and effective city planning support systems. These systems carried significant implications for sustainable urban development and resource efficiency. (Irie & Ichinomiya, 2016)

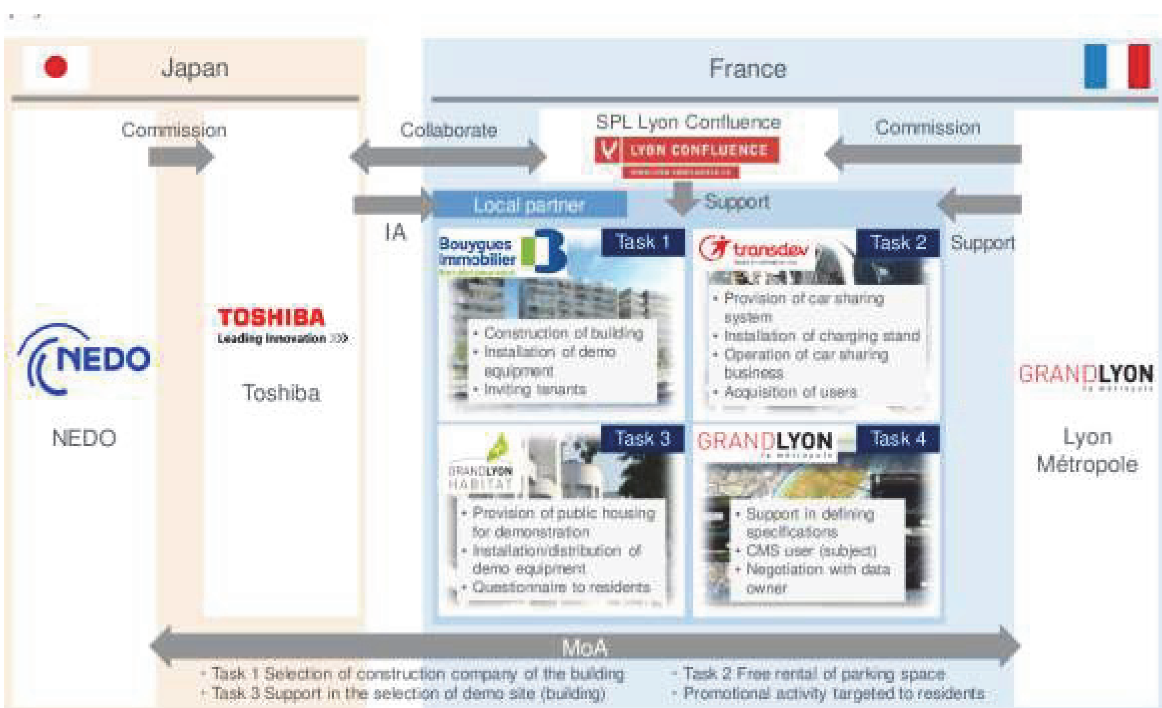


Figure 50: Organizational structure of the demonstration project, (Irie & Ichinomiya, 2016)

The demonstrated solutions were developed through a collaborative process involving key stakeholders, emphasizing holistic refurbishment, local renewable energies, e-mobility solutions, smart data management platforms, and the provision of smart services. Additionally, living labs were established to engage citizens and involve stakeholders in the initiative. By monitoring and evaluating the implemented solutions, valuable knowledge and experience were gained, facilitating the optimization of the implementation and deployment process for integrated smart solutions. This contributes to the advancement of sustainable urban transformation at the district level, benefiting both the lighthouse cities (LHCs) and follower cities. This case study not only explores the technical aspects but also highlights the social significance of the initiative and the lessons learned from the smart community demonstration. (Hainoun et al., 2022)

5.3.1. The Demonstration Sites and the Holistic Refurbished Buildings

The three lighthouse cities (LHCs) of Smarter Together undertook planned initiatives within designated neighborhoods known as demonstration sites. These initiatives aimed to demonstrate the successful implementation of integrated smart solutions, by the EU strategy. Follower cities (FCs) developed strategies to replicate the significant achievements of the LHCs in their own designated urban zones, drawing insights from the monitoring and assessment of the implemented solutions (see Figure 2). The successful completion of holistic building refurbishment in the three LHCs involved various measures, such as the implementation of onsite renewable energy systems and storage facilities, upgrades to heating systems, the addition of new attic flats, and efforts to promote energy-conscious behavior among occupants. Table 20 provides an overview of the key measures taken for holistic building refurbishment at the demonstration sites of the LHCs.

Theme	Classification	Lyon
Demo site	City District (demonstration site)	La Confluence,
	Project Area [ha]	150 ha
	Type of ownership	social housing and MOBs
	Age of the Building Stoc	1950s–1970s
Holistic refurbishment	Refurbished floor area [m^2]	35,069
	New added floor areas [m^2]	n/a
Eco-refurbishment (residential building)	Total floor area [m^2]	28,640
	Number of flats [units]	493
Eco-refurbishment (non-residential/ public buildings)	Total floor area [m^2]	6428.6
Energy-supply measures	Installed PV capacity [kWp]	449 [1]
	Installed solar thermal and geothermal [kW]	n/a
	Battery storage capacity [kW]	n/a

Table 19: Key specifications of the demonstration sites of the LHCs, (Hainoun et al., 2022)

5.3.2. The Confluence District in Lyon

The Confluence district, located near the southernmost point of Lyon's city center, embraced the integrated solutions offered by Lyon's Lighthouse City (LHC) initiative (refer to Figure 54). Starting in 2003, the Confluence Redevelopment project has been a significant urban revitalization endeavor taking place in France Figure 53. By the end of the 1990s, the Confluence district comprised a mix of residential, commercial, and industrial areas, including extensive logistical infrastructure dedicated to industrial and commercial activities. Around 2000, one of France's most significant urban rehabilitation projects was launched to rejuvenate the Confluence area and expand Lyon's city center through the development of a vibrant and intelligent district. The project covers 150 acres of land, with 1,000,000 m2 of new buildings and 600,000 m2 of existing floor space. Notably, the Confluence project has obtained authorization from the World Wildlife Fund, marking it as the first urban area to receive such recognition. In Lyon, a total of nine buildings, encompassing approximately 35,000 m2, have undergone renovation. The successful realization of integrated solutions for the Confluence low-energy area can be attributed to the collaboration of various city stakeholders, including Lyon Metropolis (GLY), the HESPUL Association, Enertech, and the leadership of SPL Lyon Confluence. (Hainoun et al., 2022)

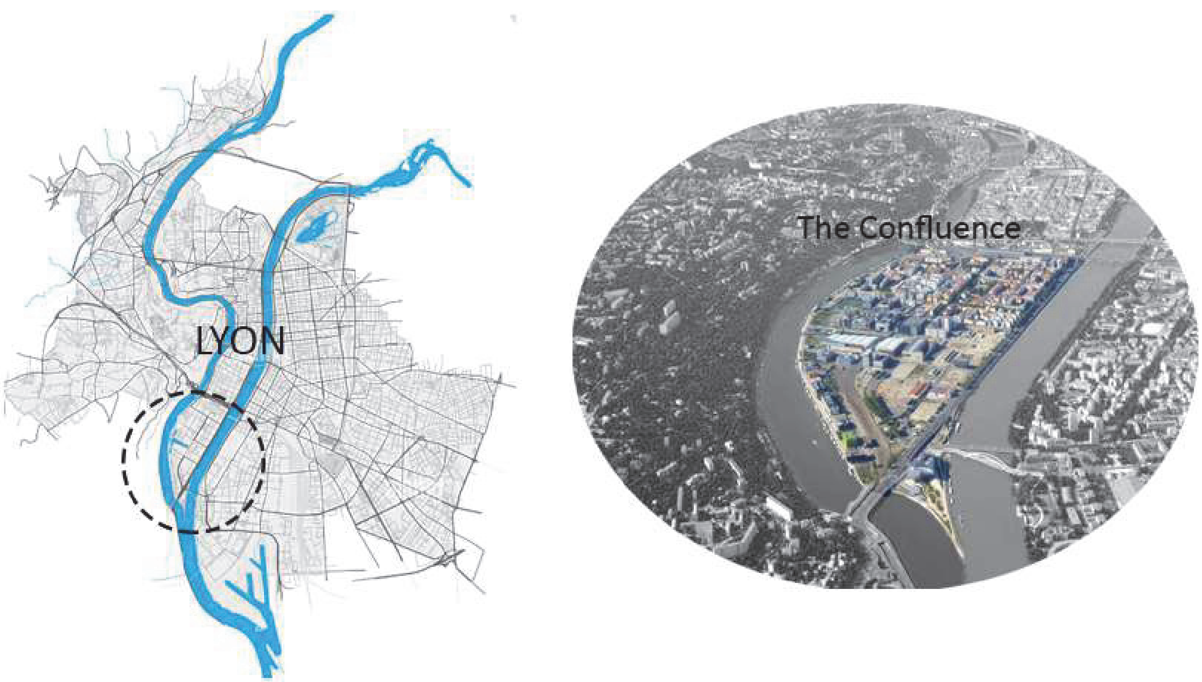


Figure 51: location of the site in the city of LYON. (Created by author)

Figure 52:The Confluence district in Lyon (Lyon: Champ De La Confluence - BASE, 2023)

5.3.3. Overview of demonstration project in Lyon

Lyon Métropole and SPL Lyon Confluence have joined forces for the redevelopment of the Lyon Confluence district, a project that commenced in 2003 and is slated for completion in 2025 (see Figure 53). The district is expected to experience significant population growth in the coming years. However, several environmental policies, including the "EU 20-20-20 Targets," "Grenelle laws," and "RT2012," have been implemented, necessitating the integration of renewable energy, enhanced energy efficiency, and reduced CO2 emissions. With the projected population increase, concerns have emerged regarding traffic congestion, limited parking, and the environmental impact of vehicle exhaust emissions. Consequently, the adoption of advanced energy technologies becomes imperative to meet the CO2 reduction objectives mandated by environmental policies (refer to Figure 54). In response to these challenges, a series of technical demonstrations were carried out through four specific tasks:

- Task 1: Positive Energy Building (PEB)
- Task 2: EV Car Sharing and Charging Management
- Task 3: Home Energy Consumption Visualization
- Task 4: Community Management System (CMS)

Figure 53: Bird-eye view of Lyon Confluence district after redevelopment (Metrhispanic, 2013)

Task 1 focused on the active utilization of smart energy technologies in a newly constructed building complex comprising offices, stores, and residential buildings within the redevelopment project. The objective was to design a building that maximizes energy generation, storage, and efficiency. Key elements introduced included PV panels, BEMS (Building Energy Management System)/HEMS (Home Energy Management System), and energy-saving equipment. This allowed for the validation of Positive Energy Buildings (PEBs) that generate surplus energy beyond their consumption.

Task 2 involved the implementation of EV car-sharing systems powered by PV as the energy source, aiming to provide zero-emission transportation solutions.

Task 3 centered around establishing a data collection network to visualize energy consumption and evaluate the effectiveness of energy-saving measures. Energy data collection equipment was installed in existing public housing within the redevelopment district. Additionally, the project examined how residents' behaviors changed in response to energy-use recommendations.

Task 4 focused on the development of a Community Management System (CMS) to support Lyon Métropole's energy planning efforts. The CMS could comprehensively manage data collected from Tasks 1 to 3, along with other relevant information such as energy data from other buildings in the redevelopment district, PV generation data, meteorological data, and real-time data. The primary objective was to identify the necessary conditions for establishing a system that utilizes regional administrative data for city development.

These four tasks formed the basis of a smart community that combined Lyon Métropole's vision of a sustainable urban structure with Japan's cutting-edge energy technologies (Irie & Ichinomiya, 2016).

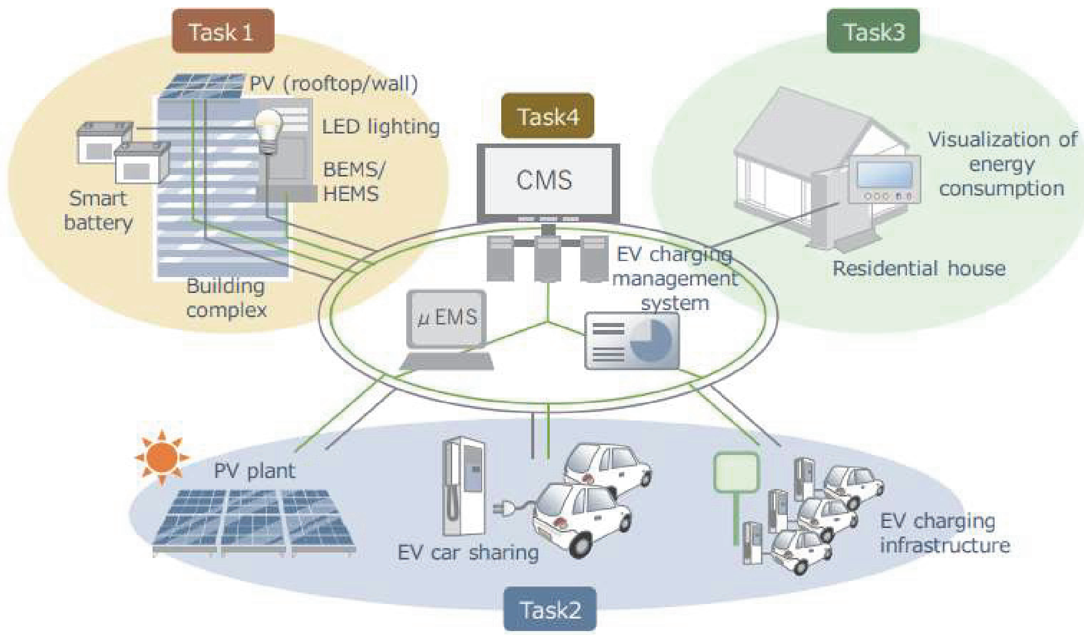


Figure 54: Whole picture of Lyon demonstration, (Irie & Ichinomiya, 2016)

5.3.3.1. task 1: positive energy Building (PEB)

Task 1 had the objective of integrating Positive Energy Buildings (PEB) into a complex comprising offices, shops, and residences. The project started with the design phase, followed by construction, which began in June 2013 and concluded in September 2015. Once completed, residents and tenants were able to occupy their respective spaces. The centerpiece of this initiative was the building called HIKARI (Figure 55), which served as the testing ground for evaluating and validating the PEB concept. This section provides an overview of the activities carried out in Task 1, with a specific focus on two key aspects:

1. Design and arrangement of the building's systems
2. Findings and assessment of PEB implementation (Irie & Ichinomiya, 2016)

Figure 55: Full view of HIKARIBuilding (From left: NISHI Building, MINAMI building, and HIGASHI Building) (HIKARI Positive Energy Buildings – Mission Innovation, n.d.)

5.3.3.1.1. Design and system configuration

The HIKARI Building, masterfully designed by architect Kengo Kuma, beautifully harnesses natural light and embraces groundbreaking energy technologies. The NISHI and HIGASHI buildings employ strategic placement of large windows and unique notched structures, reducing reliance on artificial lighting. The MINAMI building showcases an exquisite fusion of PV panels seamlessly integrated into its walls, showcasing both power generation capabilities and aesthetic elegance.
This remarkable building seamlessly integrates a range of intelligent energy technologies, which are summarized in Table 21 and depicted in Figure 56. Among these advancements are the PV and rapeseed oil cogeneration systems, which serve as energy sources to achieve the coveted status of a Positive Energy Building (PEB). The cogeneration system ingeniously utilizes rapeseed oil as a sustainable heat source, generating hot water and chilled water through the efficient utilization of exhaust heat and absorption chillers. Furthermore, a state-of-the-art smart battery and phase-change thermal storage, expertly controlled by the Building Energy Management System (BEMS), enable the effective storage and distribution of electricity and thermal energy, perfectly aligned with the building's fluctuating energy demands. In its pursuit of exceptional energy efficiency, the HIKARI Building incorporates highly efficient LED lighting and pioneering radiation panel air conditioners that utilize the circulation of hot or chilled water through ceiling pipes. The implementation of BEMS and the Home Energy Management System (HEMS) optimizes the control and management of energy creation, storage, and conservation equipment. BEMS introduces energy-saving features such as motion sensor-controlled LED lighting, while HEMS empowers residents with intuitive control functions for air conditioning, lighting, and blinds,

fostering energy-saving habits and enhancing overall convenience. By seamlessly blending these distinctive design elements with cutting-edge smart energy technologies, the HIKARI Building not only achieves remarkable energy efficiency but also sets an inspiring example of unwavering dedication to sustainable practices.

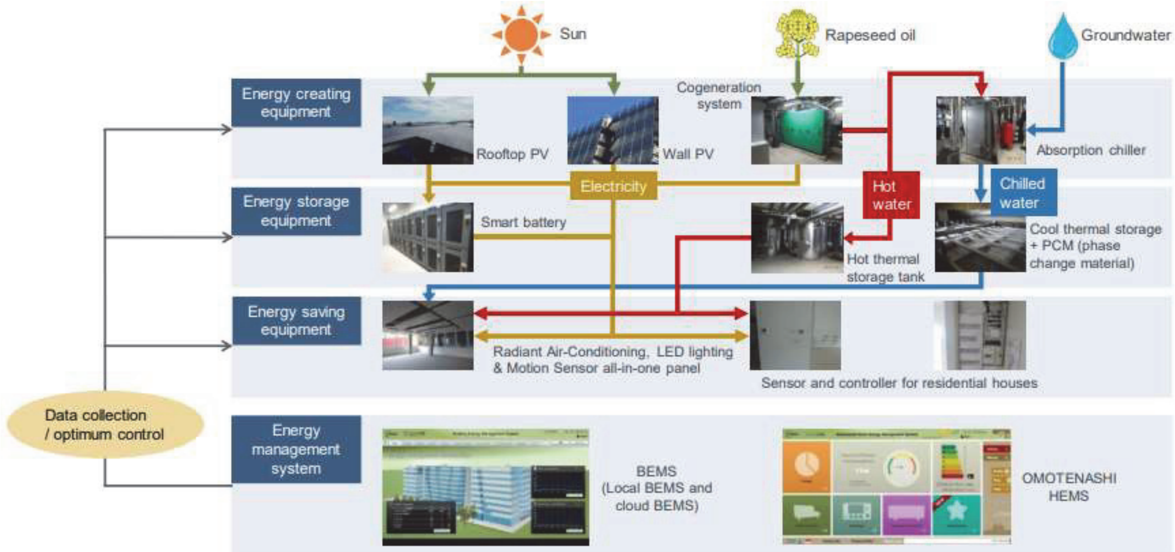


Figure 56: Task1 Structure of demonstration system (Irie & Ichinomiya, 2016)

Energy creating equipment	• PV panels: Installed on the roof and wall. • Rapeseed oil cogeneration system: Rapeseed oil, produced in France, is used as fuel of the system. • Absorption chiller: Chilled water is produced by making use of waste heat from cogeneration system.
Energy storage equipment	• Smart battery: Storage system combining lead and SCiB™. (secondary battery adopting Lithium Titanate on anode, characterized by safety, long life and low-temperature operation performance, etc.) • Phase change material for heat storage: Heat storage tank using substance with latent heat of fusion.
Energy saving equipment	• LED lighting: Introduced in the whole building. • Radiant air-conditioning panel: Air conditioning of the entire room becomes more effective by circulating hot / cool water in pipes in the ceiling.
Energy management system	• BEMS: Energy storage, energy-saving equipment, etc. are monitored and controlled to balance the energy supply / demand while saving energy of the building. • HEMS: Various functions such as power consumption visualization and remote / auto control of home appliances are provided.

Table 20: Major smart energy technologies in HIKARI Building (Irie & Ichinomiya, 2016)

5.3.3.1.2. Results of PEB evaluation

An annual energy balance simulation was run to see if the HIKARI Building could genuinely be classified as a PEB after the design and system configuration specifications stated in the preceding section were finalized. Figure 57 displays the outcomes of the simulation conducted during the design phase. (Irie & Ichinomiya, 2016)

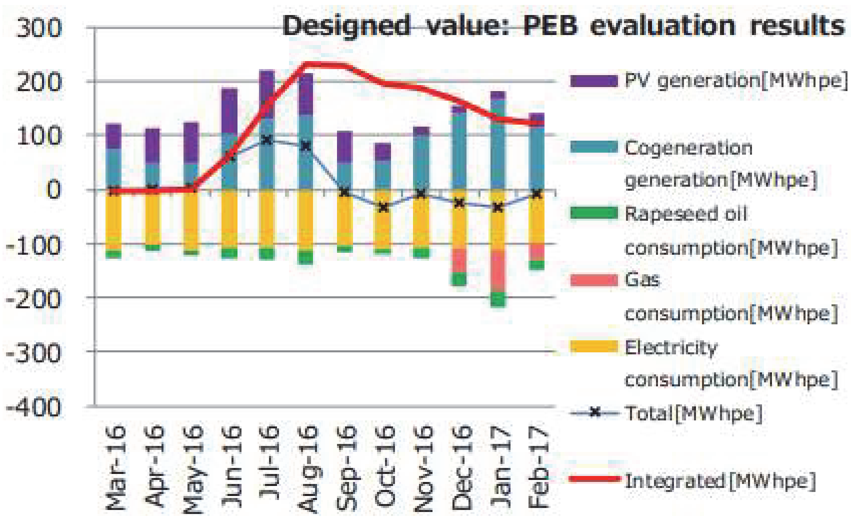


Figure 57: Annual energy balance simulation (during design) (Irie & Ichinomiya, 2016)

The remarkable HIKARI Building surpasses its energy consumption by generating an abundance of energy through its PV and rapeseed oil cogeneration system. This surplus of energy, totaling +122MWhpe, plays a pivotal role in attaining the esteemed status of a Positive Energy Building (PEB). While it is expected that certain deviations from the initial design conditions may occur during the operational phase due to various factors, the PEB concept allows for flexibility to accommodate such variations. To achieve PEB, the electricity consumption should not exceed a 9.4% increase compared to the assumed value. The feasibility of PEB was validated during the design phase through comprehensive simulations conducted by both Japan and France, ultimately leading to the initiation of the construction of the iconic HIKARI Building. Figure 58 provides a comprehensive evaluation of the PEB status based on actual data collected over one year from March 1, 2016, to February 28, 2017, following the building's operational commencement in September 2015. The evaluation based solely on actual figures indicates an annual energy balance of -259MWhpe, suggesting that the PEB requirements were not fully met. This discrepancy can primarily be attributed to the installation of dedicated air conditioners and 24-hour servers in the office systems, resulting in a significant surge in power usage, nearly doubling the anticipated levels from the design stage. However, Figure 59 portrays the calibration outcome when the power usage of the office systems is adjusted to match the levels specified during the design phase. Under these calibration conditions, the annual energy balance stands at +31MWhpe. While certain criteria were not fully met, it remains challenging to precisely ascertain that the power usage for office systems accounted for approximately one-third of the building's total consumption. Nevertheless, it can be argued that the building satisfies the PEB requirements when considering deviations from the predefined circumstances in real operation, particularly about the remaining two-thirds comprising housing, lighting in common areas, and other power demands.

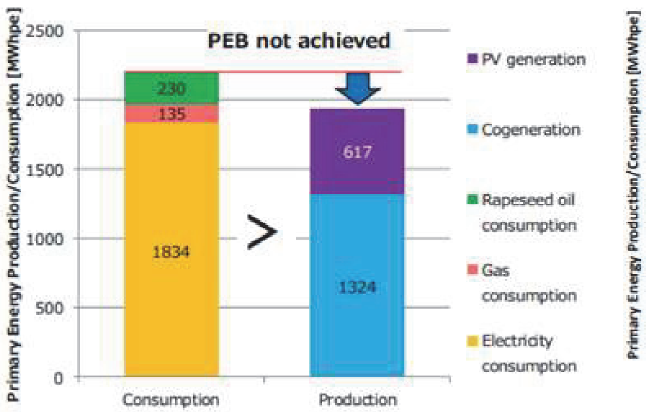


Figure 8: Result of PEB verification (actual value)(Irie & Ichinomiya,

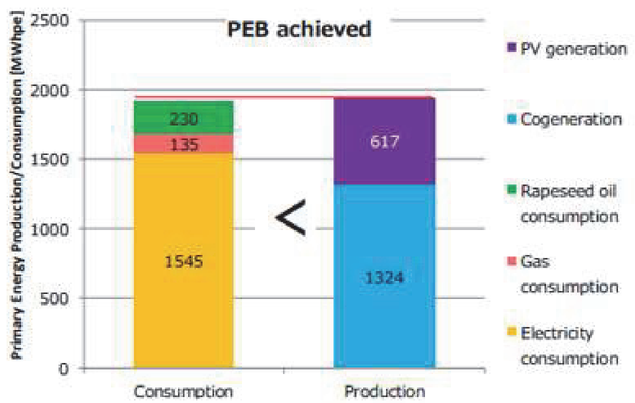


Figure 9: Result of PEB verification (after office systemcalibration)

Figure 58: Result of PEB verification (actual value) (Irie & Ichinomiya) Figure 59: Result of PEB verification (after office systems calibration)

Mr. Bruno GAIDDON of Hespul, who served as a technical advisor to SPL Lyon Confluence to support the demonstration project from a technical aspect mentioned:

" It was very significant that the PEB's performance, which was planned during the design phase of the HIKARI Building, was verified to be feasible. Today, construction of buildings with the PEB concept has started one after another in the Lyon Confluence district, taking advantage of the HIKARI Building experience with PV installation, wall design, etc. The HIKARI Building experience has become invaluable and indispensable for PEBs to be built in the future. "

However, as PEB spreads, there are now difficulties that need to be addressed. The HIKARI Building was equipped with the most cutting-edge smart energy technologies available at the time, but, there was a need for reductions in user costs and administrative complexity.

Mr. David CORGIER of Manaslu, who engaged in the construction of the HIKARI Building as a technical consultant, commented:

"The HIKARI Building is ideal in terms of the efficient use of energy, but because it is a collection of state-of-the-art technologies, hurdles on the budget, management, and operation are a little bit high. On the other hand, we were able to experience the maximum specifications of technologies in the HIKARI Building. If we appropriately choose and combine necessary functions and technologies from among them, we will be able to expand PEB to other cities." (Irie & Ichinomiya, 2016)

5.3.3.2. task 2: transportation in Lyon Confluence

Task 2 dedicates its attention to an EV car-sharing service, aiming to address common urban transportation issues such as traffic congestion and parking limitations. Moreover, it places significant importance on developing and implementing a system that optimizes the charging schedule for the EVs used in the car-sharing service. The primary objective is to accommodate variations in renewable energy generation, particularly fluctuations in PV output. After the installation of essential equipment such as chargers and EVs, as well as the successful completion of system development, this chapter highlights the endeavors undertaken in Task 2 from two distinct perspectives:

- EV Charging Management System
- Performance verification outcomes of the system

5.3.3.2.1. EV Charging Management System

Task 2 aimed to increase EV charging from renewable energy and enhance the turnover rate of EV car sharing. Table 22 summarizes the functions of the developed systems, while Figure 60 illustrates the overall system structure. (NEDO, 2017)

Car sharing system	Receive reservation requests from EV car sharing users, and send response to the user with the availability of EV and available hours based on the calculation result of EV charging management system.
Charging optimization engine	Calculate optimum EV charging schedule based on the data collected from car sharing system, charging controller and μEMS.
μEMS	Conduct PV forecast based on PV generation and meteorological data. Also, communicate with distribution operator (ENEDIS) to examine load condition of the grid.
Charging controller	Remotely control normal and fast chargers based on the charging schedule command received from EV charging management system.

Table 21: Functions of the systems developed in Task2 (Irie & Ichinomiya, 2016)

The EV charging management system incorporates a charging optimization engine, with the micro-Energy Management System (µEMS) playing a pivotal role in its operation. The µEMS takes on the responsibility of predicting PV output and EV charging times, allowing for the optimization of the EV car-sharing schedule while considering grid constraints imposed by distribution operators. The process of optimizing the charging schedule is illustrated in Figure 61:

1. PV output forecast (via µEMS): Leveraging meteorological data, forecast information from Météo-France, and PV generation data obtained from the PV remote monitoring system, the system generates predictions of half-hourly PV output. These predictions serve to optimize the timing of charging and maximize the utilization of PV energy.

2. Charging time prediction (via Charging optimization engine): By analyzing driver data gathered from the car-sharing system, which includes information about EV rental periods and the distance covered, the engine estimates power consumption to determine the required amount and timing of charging.

3. Charging schedule optimization (via Charging optimization engine): Building upon the insights obtained from the previous steps, the system aims to maximize EV turnover and develop a charging schedule that optimally aligns with PV output. Additionally, if a charging schedule based on grid load conditions, as provided by the distribution operator (ENEDIS) via the µEMS, is available, it is considered.

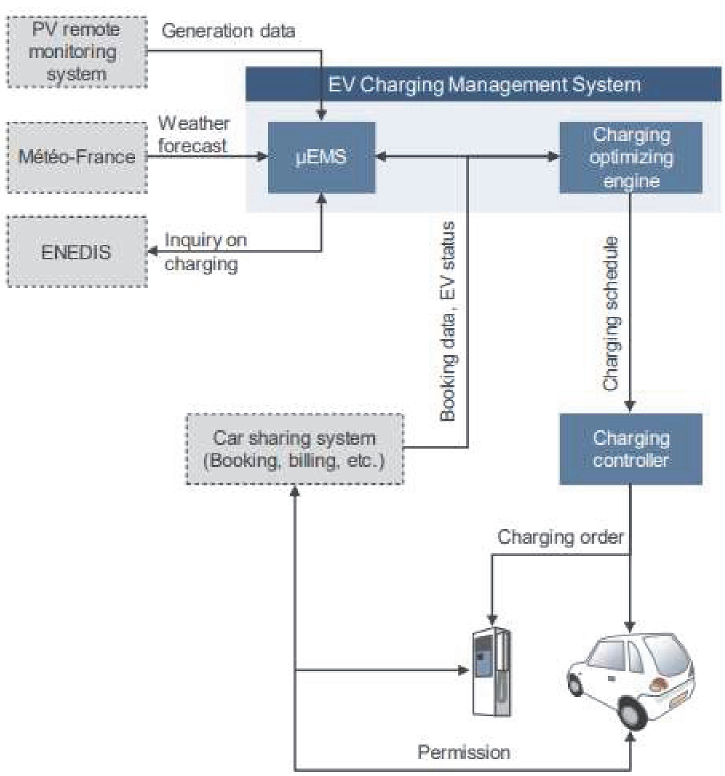


Figure 60: Overall structure of the system developed in Task2(NEDO, 2017)

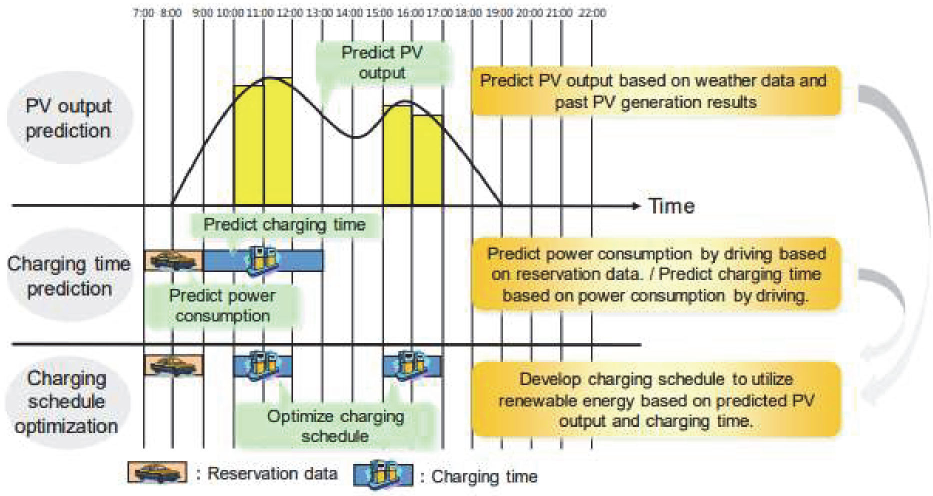


Figure 61: EV charging schedule optimization process, (NEDO,2017)

Figure 61 shows a simple example where there was an EV rental reservation from a user for the 7:00-9:00 slot. First, the charging timing to make maximum use of PV output is calculated by µEMS to be 10:00-12:00 and 15:00-17:00. Next, the power consumed using EV is calculated by the charging optimization engine and the charging time is estimated to be four hours. Based on these prediction results, a schedule that prompts the user to charge his/her EV between 10:00-12:00 and 15:00-17:00 is prepared, and the remote control is performed through the charging controller

5.3.3.2.2. result of the performance system

In summary, Task 2 involved the implementation of an EV car-sharing service under specific conditions, as detailed in Table 3. Despite the limited scope of the demonstration, with charging stations installed solely in the Lyon Confluence district, there was a notable level of participation considering the district's population of 15,000. The number of registered participants reached approximately 175, with around 1,700 EV reservations made annually. Task 2 aimed to verify two effects: the enhancement of the EV car-sharing turnover rate and the increase in PV charge rate. To evaluate the improvement in the turnover rate, a simulation was conducted utilizing actual data from 44 registrations that took place between November 2013 and March 2014. The outcomes of this simulation are depicted in Figure 62. (NEDO, 2017)

	Without Charging Schedule Optimization function	With Charging Schedule Optimization function
Reservation acceptance rate	29 / 44	44 / 44
EV car sharing turnover rate	5 times/day	9 times/day

Figure 62: Results of simulation on the improvement of turnover rate, (NEDO,2017)

The findings demonstrated a significant enhancement in the acceptance rate of reservations, increasing from 29 out of 44 to a perfect 44 out of 44 when utilizing the charging schedule optimization function. Moreover, the turnover rate of EV car sharing experienced a notable rise from 5 times per day to 9 times per day, enabling an additional four reservations per EV per day. This improvement was attributed to the accurate prediction of charging time, resulting in shorter charging durations in comparison to a fixed three-hour charging time.
To evaluate the rate of charge from PV, the EV car-sharing service implemented three distinct charging station modes: Normal Mode, Night Mode, and Renewable Energy Prioritized Mode. The Renewable Energy Prioritized Mode exhibited an average increase of approximately 6% in PV utilization compared to the Normal Mode, with the increase reaching up to 8% during sunny summer periods (as shown in Table 23). (NEDO, 2017)

Mode	Average PV utilization rate during demonstration period [%]	PV utilization rate during sunny summer time [%]
RE Prioritized	**67.1**	**82.0**
Normal	61.3	74.1
Night	35.7	N/A

Table 22: PV utilization rate in three charging modes (NEDO,2017)

The demonstration project effectively accomplished the goals of improving the turnover rate and increasing PV utilization. This success was attributed to the high accuracy in predicting PV output and EV charging time, with prediction errors of approximately 10-15% and 12.6% respectively. The development of a prediction system with reduced errors played a crucial role in enabling more precise optimization of the charging schedule. (NEDO, 2017)

5.3.3.3. Task 3: visualization of energy consumption

Task 3 focused on the installation of an energy data collection device in a housing complex within the redevelopment district. The purpose was to visualize energy consumption and evaluate the effectiveness of energy conservation measures based on this visualization.

Cité Perrache, owned by Grand Lyon Habitat, served as the demonstration site for Task 3. The housing complex consisted of a total of 275 households, with 165 households participating in the demonstration (Figure 63). This chapter presents the efforts made in Task 3 from the following perspectives:

Figure 63: Cité Perrache, the demonstration site for Task 3(CITÉ PERRACHE GETS a MAKEOVER, n.d.)

In summary, the system implemented in Task 3 comprises four components, as shown in Table 24: the visualization device, data collection device, electric power data measuring device, and gas & water meter data measuring device. The interface of the visualization device plays a pivotal role in motivating residents to adopt energy-saving practices. The system features four main screens: the top screen for monitoring total energy consumption, the summary screen for identifying energy-intensive appliances, the ranking screen for comparing consumption with neighbors, and the detail screen for reviewing records (Figure 64).

During the implementation of Task 3 in the Cité Perrache area, the interface of the visualization device was intentionally designed to be user-friendly and straightforward. The unit of power consumption on the top screen was presented in Euros instead of kilowatt-hours (kWh) to ensure that all residents, even those initially less interested in energy usage, could easily comprehend, and engage with the system.

To evaluate the energy-saving effect of the visualization system, data was collected from June 15, 2014, to December 31, 2015. The findings revealed that households that frequently utilized the visualization, ranking, and guidance functions exhibited lower energy consumption compared to those with limited usage. Notably, during the winter season when energy demand is highest in France, the "Guidance" function proved to be particularly effective in promoting energy savings.

Visualization device	Energy consumption can be visualized with this device. Tablet terminal is used with the objective to provide energy data in an easy-to-understand manner.
Data collection device	The device stores energy data collected from measuring devices of electricity, gas and water meter data installed in each household, and processes the data to be used in the visualization.
Electric power data measuring device	Using clamp type current sensor, this device measures electric power data of each feeder from distribution board.
Gas & water meter data measuring device	The device collects gas and water usage data to visualize not only electricity but whole energy consumption of a household.

Table 23: Devices introduced to realize visualization of energy use (Hainoun et al., 2022c)

Figure 64: Screen examples of the visualization system (Hainoun et al., 2022c)

Ms. Cécile AUBERT and Mr. Mossen HALLALI, who operate public housing in Lyon and oversee the eco-renovation of Cité Perrache, commented:

"We tried to raise motivation for energy saving by having them compete with other residents, but they seemed to have been discouraged when they saw a red colored indication which showed that the performance was poorer than the others. It should have been effective if the resident had been living in the HIKARI Building. We learned that we had to change our approach depending on the target. We believe that the idea can be deployed to other areas so we would like to continue using the basic concept while improving the interface. Also, we think it was not bad at all that middle to heavy users accounted for about 10% because the demonstration this time was targeted to people who are not necessarily interested

in energy use. We are grateful to the technical staff of Toshiba who met with residents and worked hard to set up the visualization device in difficult circumstances. We tried to raise motivation for energy saving by having them compete with other residents, but they seemed to have been discouraged when they saw a red-colored indication that showed that their performance was poorer than the others. It should have been effective if the resident had been living in the HIKARI Building. We learned that we had to change our approach depending on the target. We believe that the idea can be deployed to other areas so we would like to continue using the basic concept while improving the interface. Also, we think it was not bad at all that middle to heavy users accounted for about 10% because the demonstration this time was targeted to people who are not necessarily interested in energy use. We are grateful to the technical staff of Toshiba who met with residents and worked hard to set up the visualization device in difficult circumstances." (Irie & Ichinomiya, 2016)

5.3.4. Methodological Approach of this District

The project methodology is centered around the utilization of "lighthouse cities" that participate in various EU initiatives aimed at promoting the demonstration and replication of integrated smart energy solutions, aligning with the EU's objective of climate-neutral smart cities. In this approach, specific districts within the designated lighthouse cities are carefully chosen to serve as test sites for showcasing and monitoring the functionality of the four key integrated smart solutions discussed earlier. The selection of lighthouse cities encompasses a diverse range of socio-economic, technical, and geographical conditions across EU member states, fostering a peer-to-peer learning process for knowledge and experience exchange. The activities conducted within these cities are closely monitored and evaluated using a KPI-based methodology, providing a foundation for further deployment and upscaling of the demonstrated solutions. Additionally, "follow cities" draw inspiration from the successful models established by the lighthouse cities and replicate the implemented solutions. This study addresses a scientific problem that focuses on assessing the sustainable impact of implemented technical district solutions, with a specific emphasis on energy conservation and increased utilization of renewable energy sources. The evaluation of the impact follows a three-step process:

1. Monitoring infrastructure: This involves establishing and fine-tuning the monitoring setup, which includes meters, sensors, data acquisition components (such as M-Bus modules, signal converters, and storage), and other necessary elements.

2. Data collection: The measured data is collected, cleansed, and processed to calculate the annual heat demand before and after refurbishment, considering climate adjustments, as well as renewable energy production.

3. Impact assessment: A set of KPIs is derived to quantify the achieved impact of the intervention in terms of energy savings through building efficiency measures (e.g., improvements to the

building envelope and heating system), the implementation of local renewable energy sources, and the resulting reduction in CO2 emissions resulting from both measures.

Table 25 presents the primary KPIs used to evaluate the effectiveness of the integrated building energy solutions specifically for low-energy regions. KPIs related to the effectiveness of sustainable urban mobility initiatives are not included in this activity.

5.3.4.1. Monitoring and Evaluation of the Implemented Solutions

Through collaborative efforts with key stakeholders from three Lighthouse Cities (LHCs), the Smarter Together initiative has fostered peer-to-peer learning and developed an integrated monitoring and evaluation methodology (IMM). The IMM concept revolves around the establishment of a comprehensive monitoring infrastructure, incorporating meters and sensors for various utilities. The process involves automating data collection through local data loggers, transferring the collected data to the city's data-management platform (DMP), and subsequently processing it to calculate essential key performance indicators (KPIs) (see Figure 65). The IMM framework, as outlined in Figure 66, outlines the sequential steps followed by the three LHCs.

The monitoring infrastructure encompasses the necessary meters, sensors, and logistics for data acquisition, including M-Bus modules, signal converters, and storage components. Data collection is performed either automatically or semi-automatically using local data loggers. Subsequently, the collected data is prepared for submission to project partners, who further process, evaluate, and calculate the relevant KPIs. The monitoring process adheres to technical standards of validity, objectivity, and reliability. It is meticulously designed to ensure a structured, verifiable, and replicable approach to data collection, processing, and evaluation.

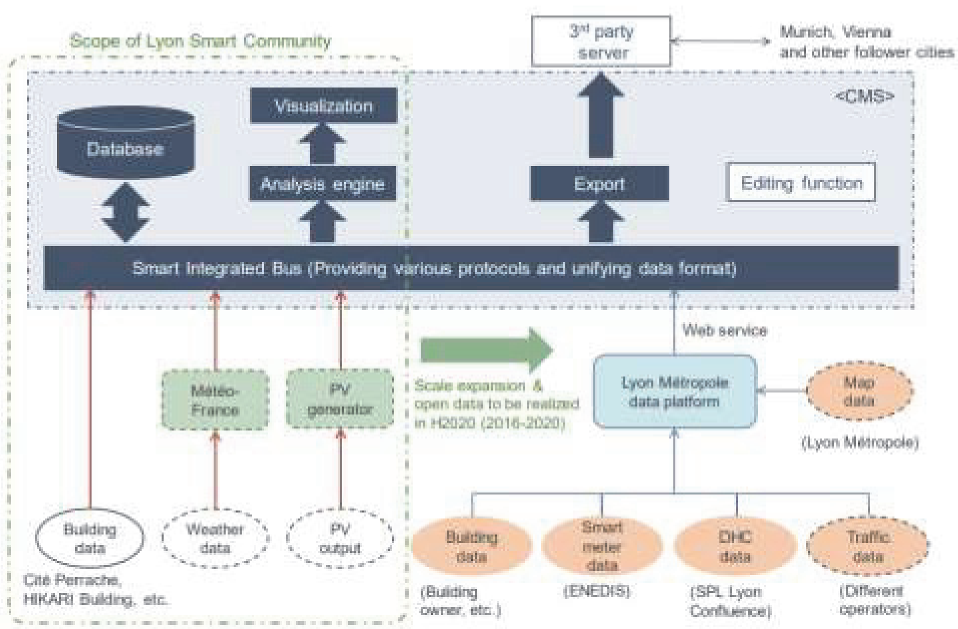


Figure 65: From Demonstration to Horizon 2020 (Smarter Together) (Hainoun et al., 2022c)

KPIs	Unit	Description
Refurbished floor area	m^2	Gross floor area of the refurbished building
New constructed area	m^2	gross floor area of new aditional attic dwellings constructed on the roof-top of the refurbished buildings
Energy savings by building-efficiency measures	MWh/a	energy saving achieved through thermal building refurbishment (building envelop)
specific space-heat demand	kWh/ m^2.a	Useful annual space-heat demand per gross floor area (before and after the refurbishment)
relative improvement of building performance	%	relative reduction of specific annual space-heat demand (ratio of after refurbishment to the baseline value)
CO_2 reduction achieved by building-efficiency measures	tCO_2/a	annual CO_2 emission reduced due to reduced fossil fuel consumption for building heat demand (only building demand-side measures)
Installed RES capacity, Electricity (PV)	kWp	installed renewable energy capacity for power generation (PV panels)
Installed RES capacity, Heating	kW	installed renewable energy capacity for heat production (total and disaggregated for solar thermal. Heat pump and geothermal)
Total Installation of RES	kW	installed renewable energy capacity for power and heat production
Electricity generated by PV	MWh/a	annual electricity generation by PV
Thermal energy generated by RES	MWh/a	annual heat generation by renewable options (total and disaggregated for solar thermal, heat pump and geothermal)
Total production of RES	MWh/a	total annual energy generation by all RES options
Battery storage capacity	kW	capacity of installed battery for electricity storage
Electricity saving of common space area	MWh/a	annual electricity saved due to the replacement of lamp in exterior building area and staircases and elevators retrofitting
CO_2 reduction achieved by energy-supply measures	tCO_2/a	annual CO_2 emission reduced due to the substitution of fossil fuel consumption through renewable heat and power production
Total CO_2 reduction by energy measures	tCO_2/a	Total annual CO_2 emission reduction by all demand and supply measures
Total specific energy saving	kWh/m^2.a	total energy saving by building energy-efficiency measures relative to building floor area
Total specific CO_2 reduction	kg-CO_2/m^2.a	Total annual CO_2 emission reduction by all demand and supply measures relative to building floor area

Table 24: List of the extracted KPIs to evaluate the impact of building energy solutions for low-energy districts in the Smarter Together project. (Hainoun et al., 2022c)

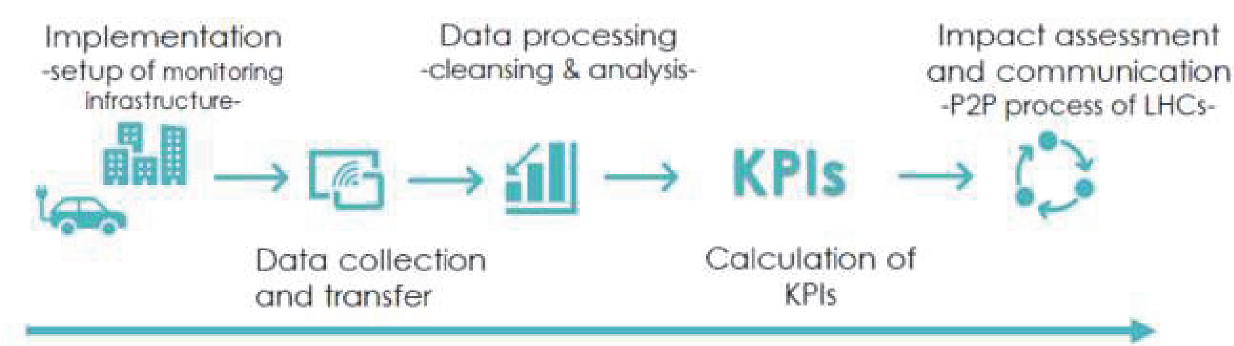


Figure 66: Flow diagram of the integrated monitoring process for the demonstration sites of the LHCs, (Hainoun et al., 2022c)

The presented article illustrates the data-cleaning process employed to monitor diverse aspects of energy consumption in the Lighthouse Cities (LHCs) of Lyon. These aspects encompass space heating, common-area electricity consumption, and photovoltaic (PV) production. Figure 67 showcases the monitoring data for electricity consumption in elevators, lighting, substations, and ventilation at the Lyon-based site of 61 Delandine, covering the period between February 12, 2020, and July 8, 2021. However, the setup of the monitoring infrastructure and data collection encountered several challenges, encompassing technical, structural, financial, and regulatory factors. These challenges resulted in delays and increased costs associated with sensor assembly and interconnection beyond the initial cost estimation. Technical obstacles, specifically related to sensor calibration, validation of functionality, seamless data transfer to data-management platforms, and data quality, were particularly noteworthy. The article offers recommendations to address these challenges, such as establishing clear data flows involving responsible entities and individuals for each demonstration site, retrofitting on-site energy-supply infrastructure, and accounting for specific user behavior in the monitoring of data. The collected and processed data play a crucial role in subsequent KPI calculation and impact assessment processes. (Irie & Ichinomiya, 2016)

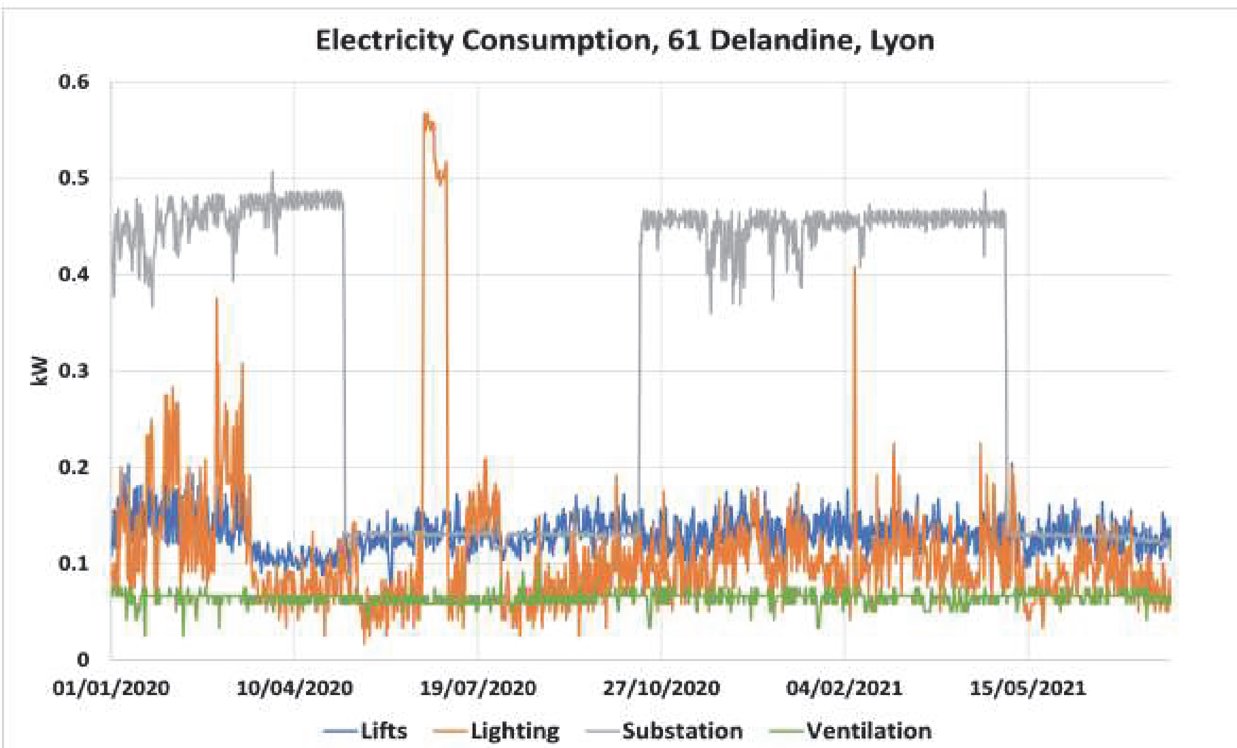


Figure 67: Monitoring data of electricity consumption of elevators, lighting, substations, and ventilation, 61 Delandine, Lyon. *(Hainoun et al., 2022c)*

5.3.4.2. Results of the Monitoring and KPI-Based Impact Assessment

The impact of solutions implemented in low-energy districts can be quantified by measuring the energy saved through building-efficiency measures, such as enhancing building insulation and upgrading heating systems, as well as by incorporating local renewable energy sources to replace fossil fuels and reduce CO2 emissions. Data collected from monitoring activities are processed to calculate Key Performance Indicators (KPIs) that assess the impact of building refurbishments. These KPIs involve comparing monitoring data of final energy demand after the refurbishment with historical data collected before the refurbishment to determine energy savings. The processed data is also utilized to calculate specific building energy performance, energy savings, and CO2 reduction resulting from building-efficiency measures, as well as local renewable energy generation and CO2 reduction achieved through renewable energy systems. The resulting KPIs enable the evaluation of annual specific space-heating demand, energy savings, local renewable energy generation, and CO2 reduction attained in low-energy districts. These results are presented in figures and discussed. Among the significant KPIs is the climate-adjusted specific space-heating demand before and after refurbishment, as illustrated in Figure 68, representing the weighted average value across the entire refurbished floor area of each demonstration city. To summarize, the monitoring and evaluation efforts in the three Lighthouse Cities (LHCs) with a focus on achieving low-energy districts yield the following findings:

- Lyon LHC accomplished a refurbishment of approximately 35,000 m2 of floor area and the implementation of around 449 kW of PV panels, resulting in an annual electricity generation of approximately 497 MWh. The building-efficiency measures achieved a total energy saving of around 1350 MWh per year, leading to an annual CO2 reduction of about 643 t-CO2. Quantitative KPIs were derived from the monitoring and assessment of the integrated solutions deployed at the demonstration sites. These KPIs play a crucial role in advancing the concept of smart cities and fostering intentional sustainable urban transformation in the LHCs and Follow Cities (FCs). With the development of efficient rollout and replication strategies around the clustered solutions, once the co-creation process is verified, this objective will become achievable. See Figure 69 for further details. (Irie & Ichinomiya, 2016)

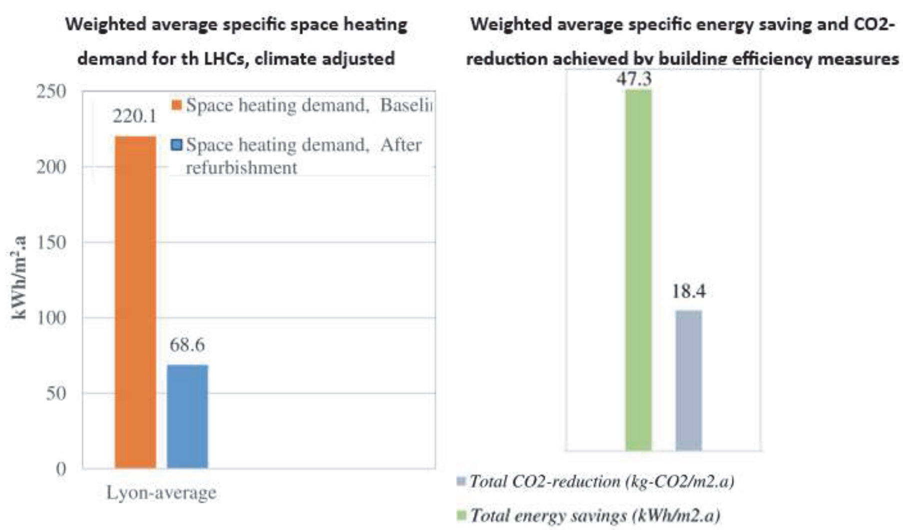


Figure 68: Climate-adjusted annual space-heating demand determined as a weighted average value over the whole refurbished floor area and specific final energy saving, and CO2 emission reduction determined as a weighted average value over the whole refurbished floor area. (Irie & Ichinomiya, 2016)

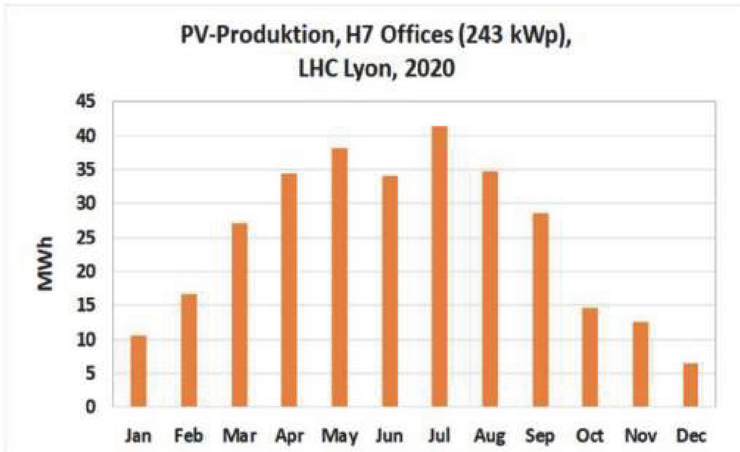


Figure 69: Monthly electricity production of the implemented roof-top PV panels selected by the LHCs in Lyon. (Irie & Ichinomiya, 2016)

5.3.5. Result discussion

The project successfully implemented 26 integrated smart solutions for low-energy districts in the Lighthouse Cities (LHCs) through collaborative co-creation processes. The implementation progress was closely monitored and evaluated using an integrated monitoring methodology (IMM). This involved the establishment of a robust monitoring infrastructure, automated data collection, seamless transfer to the city's data-management platform (DMP), and precise calculation of key performance indicators (KPIs). The evaluation provided valuable qualitative and quantitative insights, knowledge, experience, and lessons learned that significantly contributed to optimizing the implementation and deployment of energy solutions. Moreover, a comprehensive process evaluation approach was adopted to assess the implementation processes, identify success factors, and develop effective strategies to overcome barriers. The findings from this evaluation served as a solid foundation for scaling up and replicating the solutions throughout the cities. Notably, the evaluation uncovered qualitative indicators, process drivers and barriers, and valuable methodological lessons, which will greatly inform future projects and replications. (Hainoun et al., 2022b)

In the context of Lyon, the majority of the renovated structures were previously abandoned, resulting in substantial improvements in building efficiency and CO2 reduction. Among these structures, three were Multi-Ownership Buildings (MOBs), while two were rented municipal housing. Remarkably, the refurbishment process encountered no significant regulatory obstacles, which is a testament to the meticulous decision-making procedures employed by the involved companies. This accomplishment is indeed a resounding success. Building upon the achieved impacts measured by KPIs, the aforementioned process evaluation, and the invaluable experience gained from each LHC, the following primary recommendations can be drawn, with a strong emphasis on the development of low-energy district-building solutions:

- Emphasize the need for holistic refurbishment that takes into account the building envelope, local energy-supply infrastructure, and comprehensive building retrofitting.

- Foster effective communication and active involvement of relevant city stakeholders, particularly in larger projects that involve multiple stakeholders with different roles. Achieving well-structured and harmonized coordination among all actors is pivotal.

- Establish clear data flows, assigning responsibility to responsible entities and individuals for each demonstration site. This facilitates a focused response and swift rectification of any identified failures or faults in the collected data and employed meters/sensors.

- Recognize that certain KPIs related to building monitoring can only be fully understood about specific user behavior, such as rebound effects, higher room temperature, or tilted windows. Consequently, for future projects, it is advisable to conduct a qualitative analysis of consumer behavior to assess its impact on the monitored data and the resulting project outcomes.

The Lyon Confluence district, as part of a larger urban redevelopment project in Lyon, France, is dedicated to becoming a sustainable neighborhood. One notable aspect of this initiative involves the integration of photovoltaic (PV) technology into buildings, enabling the generation of electricity from sunlight. (Hainoun et al., 2022b)

The implementation of photovoltaic (PV) technology in multiple buildings within the Lyon Confluence district offers significant advantages over a single net zero energy building. It holds the potential to make a more substantial impact on reducing energy consumption and greenhouse gas emissions. This is primarily due to the district-level implementation, which enables the effective coordination and optimization of energy production and consumption across numerous buildings and users. Through the utilization of PV technology, the Lyon Confluence district can generate renewable energy for local use, thereby diminishing the dependence on non-renewable energy sources. Moreover, any surplus energy produced can be fed back into the grid, further reducing the reliance on non-renewable sources and contributing to the development of a resilient and decentralized energy system. However, it is crucial to recognize that the success of PV implementation in the Lyon Confluence district relies on several factors. These include the design and efficiency of the PV systems, the accessibility, and availability of energy storage systems, as well as the behavior of the district's users. Consequently, careful attention must be given to these aspects to ensure the optimal outcomes of the PV technology implementation. Overall, the integration of PV technology in the Lyon Confluence district represents a promising step toward attaining a more sustainable and resilient urban environment. In summary, this research aimed to explore energy reduction methods by focusing on building design and considering the district. The investigation commenced by analyzing the requirements for designing buildings with nearly net zero energy consumption. This analysis was supplemented by studying various case studies to gain a deeper understanding of the employed techniques in building design. Subsequently, the study emphasized the importance of considering factors like shape, orientation, thermal insulation, and other aspects during the concept design and design development stages. The research also examined and evaluated two neighborhoods in Turin, particularly their shapes, orientations, exposure to the sun and wind, functions, and, most significantly, their heating requirements. One district, San Salvario, demonstrated the application of bioclimatic methods and was of historical significance. By analyzing the existing energy requirements of different industries and their primary energy sources, the research identified heating as the dominant source of CO_2 emissions in the region. Further, the study evaluated the key elements mentioned earlier and determined the main challenges in the Lingotto district, including the reasons behind certain buildings having higher than necessary energy demands. Finally, the research discussed strategies and suitable technology applications to address these challenges. (Hainoun et al., 2022b)

Chapter 6

6. Conclusion

In summary, the objective of this research was to explore methods for reducing energy consumption in buildings and districts. The investigation commenced by identifying key elements for designing Net Zero energy buildings, highlighting the significance of early design decisions in optimizing energy usage. Through review and comparison of various case studies on passive and active strategies in achieving Net Zero energy buildings, it was concluded that relying solely on passive strategies related to the architectural and design aspects cannot single-handedly accomplish the goal. Similarly, the use of active strategies focusing on renewable energy and backup systems alone is insufficient. Achieving Net Zero energy buildings requires a comprehensive approach that combines both strategies, although economic challenges remain.

Furthermore, the study discussed strategies for energy-conscious districts. One strategy among many was outlined, considering various criteria, to create an energy-conscious district that contributes to lower energy demands, reduced CO_2 emissions from the built environment, and overall sustainability. A zero-energy district is achieved when all buildings within the district work together, maximizing energy efficiency through effective communication and collaboration. By optimizing the performance of multiple buildings instead of relying on a single building, it becomes easier to achieve higher levels of energy efficiency.

6.1. Answer to thesis questions

At the starting point, the research began with some main questions which can be referred to by the results acquired from the analysis.

1. **Why the topic of net zero energy building is so important?**

The topic of net-zero energy is important because it plays a significant role in addressing climate change and promoting sustainable development.

first of all, **Climate Change:** One of the main sources of greenhouse gas emissions is the construction industry. The building sector holds a significant responsibility in the energy and environmental landscape, accounting for a substantial portion of energy consumption and greenhouse gas emissions. Buildings can strongly lower their carbon footprint and contribute to climate change by becoming net-zero energy. Fossil fuels are a common source of energy used in buildings, especially for **power, heating, and cooling,** all of which produce greenhouse gases when burned. The goal of net-zero energy buildings, on the other hand, is to maximize energy production while limiting energy consumption, often using renewable energy sources.

Energy Efficiency: Energy efficiency is a top priority for net-zero energy buildings. With a focus on lowering energy usage, they are built with features like excellent **insulation, effective heating and cooling systems, LED lighting, and smart building management systems**. To solve global energy concerns and lessen reliance on scarce energy resources, these structures must maximize energy efficiency to minimize energy waste and reduce energy demand. NZEBs, characterized by high energy performance and low carbon emissions, aim to achieve a balance between energy efficiency measures and the use of renewable energy sources. achieving net-zero energy aligns with the principles of sustainable development. It promotes the responsible use of resources and reduces our dependence on non-renewable energy sources. Net-zero energy buildings, for instance, optimize energy efficiency through insulation, efficient appliances, and smart energy management systems. They also incorporate on-site renewable energy generation, such as solar panels, to meet their energy needs. This integration of sustainable design and renewable energy technologies leads to reduced environmental impacts and improved occupant comfort.

Overall, the pursuit of net-zero energy is vital for combating **climate change, reducing greenhouse gas emissions, and advancing sustainable development**. It represents a significant shift **towards cleaner and more sustainable energy systems, benefiting both present and future generations**.

2. What are the important criteria for achieving net zero energy building?

Here's a list of key innovation points and action items that professionals should consider when designing a net-zero energy building:

1. Energy Modeling and Analysis:

- Conduct detailed energy modeling to understand energy consumption patterns and optimize building design.
- Analyze energy loads for heating, cooling, lighting, appliances, and other equipment to determine the most efficient strategies.

2. Building Envelope and Insulation:

- To reduce heat gain and loss, design and create a well-insulated building envelope.
- Make use of high-performance windows with low solar heat gain coefficients and U-values.
- Use effective insulation materials, such as rigid foam panels or spray foam insulation.

3. Passive Solar Design:

- Make the most of natural daylighting by strategically placing and orienting windows.
- Use shading mechanisms, such as external louvers or overhangs, to lessen solar heat intake throughout the summer.
- Use thermal mass materials to store and release heat energy, such as brick or concrete.

4. Efficient HVAC Systems:

- Create and set up HVAC (heating, ventilation, and air conditioning) systems.
- Use radiant heating and cooling systems, geothermal systems, or high-efficiency heat pumps.

- Use zone controls and programmable thermostats to optimize energy use in various parts of the building.

5. Renewable Energy Integration:

- Install on-site renewable energy systems, such as solar photovoltaic panels or wind turbines, to generate electricity.
- Explore the feasibility of incorporating solar water heating or geothermal heat pumps for domestic hot water needs.
- Integrate energy storage systems, such as batteries, to store excess energy generated for later use.

6. Energy-Efficient Lighting and Appliances:

- Utilize LED lighting throughout the building for its energy efficiency and long lifespan.
- Install energy-efficient appliances and equipment, including ENERGY STAR-rated devices.
- Incorporate smart lighting and occupancy sensors to optimize energy use.

7. Building Automation and Controls:

- Implement advanced building management systems (BMS) for real-time monitoring and control of energy consumption.
- Utilize smart sensors and controls to optimize energy usage based on occupancy, daylight levels, and indoor environmental conditions.
- Integrate the BMS with renewable energy systems and HVAC systems to ensure efficient operation.

9. Life Cycle Assessment:

- Consider the life cycle impacts of building materials and products, choosing options with lower embodied energy and environmental footprint.
- Prioritize recycled or renewable materials, such as sustainably harvested wood or recycled steel.

- Optimize waste management strategies during construction and encourage recycling and reuse.

10. Continuous Monitoring and Commissioning:

- Establish a process for ongoing monitoring and commissioning of the building's energy systems to ensure optimal performance.
- Regularly review energy data, identify areas of improvement, and implement necessary adjustments.
- Engage occupants in energy conservation through awareness campaigns and energy-saving practices.

For experts interested in creating net-zero energy buildings, these action items offer a thorough place to start. It's crucial to keep in mind that every project is different, and extra considerations can be necessary depending on things like location, building type, and resource availability. To successfully reach net-zero energy targets, collaboration with experts, architects, engineers, and sustainable design professionals is essential.

3. How to build NZEB? What Are the main factors?

The first step in addressing this question is to understand in which step we have to consider which elements of design we have 2 steps:

- **Concept design**
- **Design development**

The phases of Net ZEB realization include preparation, **concept design, design development, technical design, construction, commissioning, operation, and monitoring**. The concept design phase focuses on energy-saving strategies such **as daylighting, solar protection, building thermal inertia, natural ventilation, building envelope insulation, and building-integrated solar energy technologies**. Decisions made during this phase greatly impact the feasibility of achieving net-zero energy. Subsequent stages refine the building design by integrating HVAC systems and RETs.

Overall, the concept design stage sets the foundation for achieving net-zero energy and should involve careful evaluation and decision-making regarding building elements, energy systems, and occupant comfort.

In summary, daylighting is crucial for reducing energy usage in office buildings. Architects should prioritize incorporating natural light in the design phase, considering building geometry and utilizing atriums for smaller buildings. Simulation tools aid in determining glazing space for desired daylight levels. Effective solar protection design is essential for achieving net-zero energy, with well-designed shading mechanisms and integration with lighting and climate control systems. Thermal mass components regulate indoor temperature fluctuations and should be considered early in the design process. Natural ventilation, influenced by building geometry and climate, reduces reliance on mechanical systems. Integration of solar energy technologies and proper building envelope design is crucial for net-zero energy buildings.

this thesis underscores the importance of **the design development phase** in achieving Net Zero Energy Buildings (Net ZEBs). It highlights the need to focus on renewable energy technologies, architectural ideas, and HVAC system design. Collaboration between engineers and architects is crucial for efficient design, and the selection of HVAC solutions should be based on energy calculations and load requirements. Building performance simulation tools and model resolution play significant roles in predicting and evaluating building performance, and careful consideration of the model resolution is necessary to balance accuracy and ease of interpretation. Additionally, the thesis emphasizes the significance of shape and configuration in achieving energy efficiency, the role of HVAC systems and building envelopes, the integration of building-integrated photovoltaics, and the importance of lighting and daylighting design. Overall, the thesis provides valuable insights for designing Net ZEBs and highlights the key considerations necessary for successful implementation.

Choosing the appropriate model resolution is essential for Net Zero Energy Building (Net ZEB) design, to sum up. While high-resolution models might not be required in the beginning, more accurate models are crucial for attaining confidence in energy performance. To integrate cutting-edge controls and guarantee accurate predictions, sophisticated technology models and interoperable tools are required. **Designers should use tools with capabilities like documentation, advice, and parametric analysis to make educated decisions early on**. They can effectively work towards net-zero energy and other building targets by doing this.

4. How can buildings communicate and work as a system in a district to reduce energy demands?

The first step in addressing this question is to understand how the energy requirements of each building are influenced by those of its nearby structures; it is crucial to comprehend the purposes and energy requirements of various structures. In this study, a method for contributing building blocks to energy demand was introduced. This method showed how each element can reduce the energy demand and reduce the need for fossil fuels. Since the primary energy is used only once among several buildings rather than several times for each structure, this strategy can greatly minimize the primary energy requirements for buildings. This strategy demonstrates a very effective method of communication between buildings in an area or district and how it might function as a system for energy recycling.

5. What is the advantage of NEZD INSTEAD OF NEZB?

Reducing urban carbon emissions is critical to mitigating the consequences of climate change. We noticed that Buildings must achieve the highest levels of efficiency, run on renewable energy sources, and adjust their loads in a way that enables large-scale deployment of renewable technologies. In recent years, zero-energy buildings have gained considerable traction in the market. Districts are the ideal platform to extend zero-energy building concepts to the urban scale. We have described some initial findings from efforts related to zero energy districts, including why a net zero energy district may be preferred over a net zero energy building when considering cost analysis, power production, and cost maintenance:

1. Cost Analysis:

- Shared infrastructure, such as energy distribution networks, energy storage systems, and renewable energy production facilities, can be used by net zero energy districts. Compared to establishing and maintaining separate systems for each building, this shared method can save money.

- Construction costs can be reduced through economies of scale by simultaneously developing several structures in a district. Cost-saving measures include bulk material procurement, faster building procedures, and coordinated planning and design.
- Less Redundancy: In a net zero energy district, redundant equipment, or systems, such as redundant HVAC systems or backup power generators, can be shared among buildings, lowering the overall cost of duplication.

2. Power Production:

- Aggregated Renewable Energy Generation: Net zero energy districts can gain from combining renewable energy generation resources, like solar panels or wind turbines, across numerous buildings. A bigger portion of the district's energy requirements can be supplied locally thanks to this aggregation, which raises the district's overall energy generation capability. Additionally, it opens the possibility of a variety of energy sources, thus boosting the security and stability of the energy supply.
- Strategic placement of renewable energy generation systems in regions with the greatest energy potential, maximizing their efficiency and output, is conceivable from a district-scale perspective. When opposed to individual buildings, this all-encompassing approach to energy production may lead to higher overall energy generation.

3. Cost Maintenance:

- Shared Maintenance Costs: In net zero energy districts, maintenance and operational expenses might be split across several buildings. This shared cost-burden distribution can result in cost savings for each building.
- Effective Management and Monitoring: Centralized monitoring, control, and optimization of energy usage across numerous buildings are made possible by district-level energy management systems. This centralized strategy boosts productivity, lowers maintenance expenses, and makes quick maintenance interventions possible.

4. Integration and Optimization:

- Synergistic Energy Systems: Net zero energy districts present a chance for district-level energy system integration and optimization. This entails coordinating the production of renewable energy, the storage of energy, and the distribution of energy among buildings. The district can maximize energy usage and minimize waste by coordinating energy flows, load balancing, and demand response systems.
- District-Level Energy Planning: Effective coordination of energy requirements, resources, and infrastructure is made possible by a comprehensive approach to energy planning at the district level. This can result in more effective energy system design and use, lowering both energy and monetary expenses.

5. Resilience and Redundancy:

  - Increased Energy Resilience: Areas with net zero energy use are more resistant to interruptions in the energy grid. Energy can be supplied from other buildings in the district if one building has an energy shortage or outage, minimizing the effects on operations and inhabitants. This connectivity improves energy security and lessens exposure to outside influences.
  - Distributed Energy Resources: Net zero energy districts can incorporate a variety of distributed energy resources, including microgrids and localized energy storage, which can enhance the overall resilience of the energy system, reduce transmission losses, and contribute to grid stability.

Through this study, we conclude that net zero energy districts offer advantages in terms of cost optimization, increased power production through aggregation, optimized maintenance through shared responsibilities, integrated and optimized energy systems, and enhanced resilience to disruptions. These benefits make net zero energy districts a compelling choice for achieving sustainability goals while considering economic viability and long-term operational efficiency.

6.2. Future design proposals

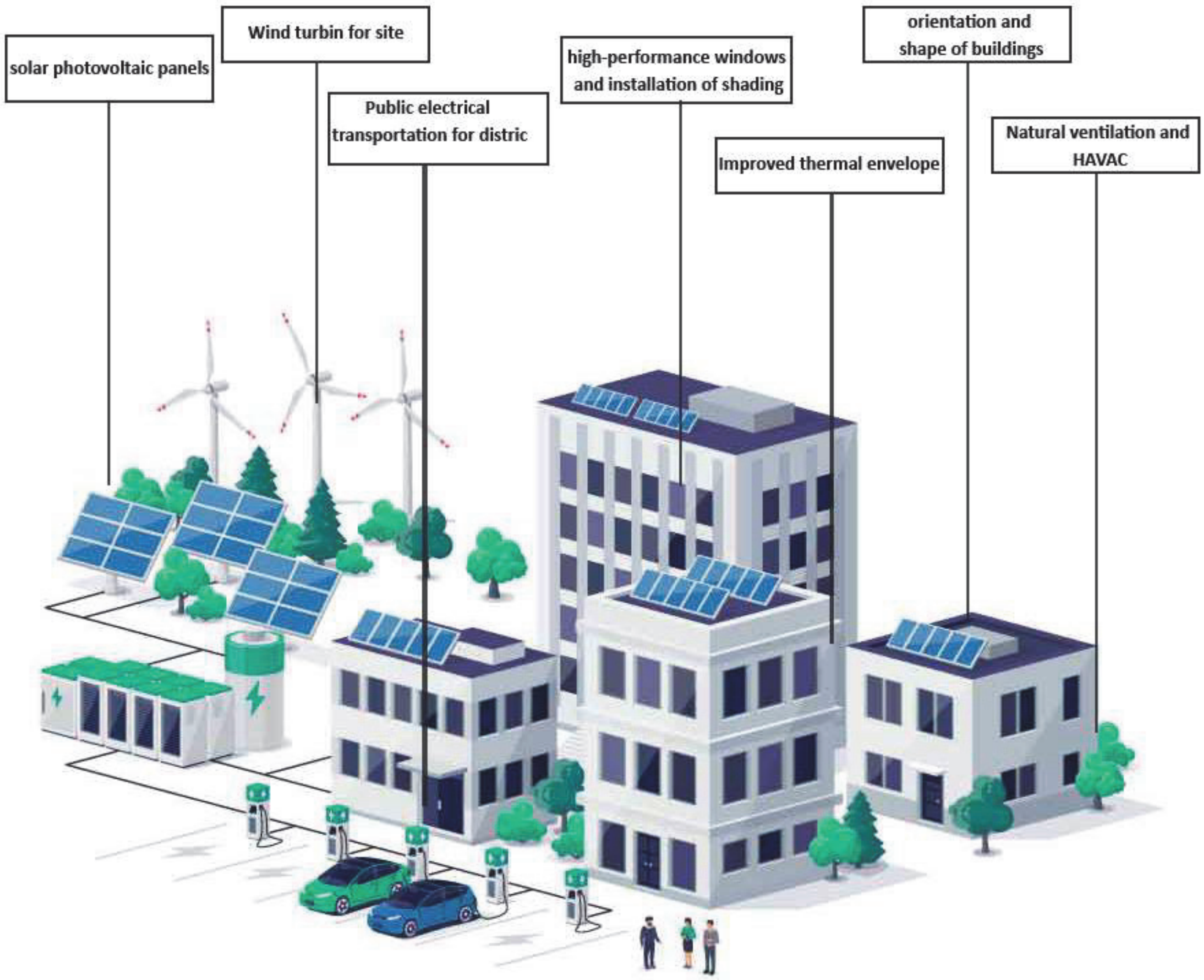


*Figure 70: Overall design elements. ((*6 Net Zero Energy Buildings FAQs*, n.d.)*

The thesis tried to point future designers and thinkers toward a new set of considerations. As we discussed building operations and electrical grids both need more adaptable and responsive in net-zero energy districts. With the improvement of technology and applications we lot of options. The concepts and technology of **smart sensing, smart controls, data analytics, machine learning, and energy mix diversification** will all how we operate our buildings. Net zero energy districts have emerged as a promising solution to mitigate; the construction industry is forced to shift its focus from single buildings to collective buildings. This proposal aims to explore future perspectives on achieving NEZD by focusing on data analysis technologies and engagement strategies that can be observed in the illustration above. it will help shape sustainable urban development strategies that prioritize energy efficiency, carbon neutrality, and community engagement with a focus on innovative technologies. We may look forward to technological advancement such as:

1. **Energy Monitoring and Metering:**

- Energy management systems: Examples include Energy CAP, Lucid, and eSight for collecting and analyzing energy consumption data from buildings and infrastructure within the district.

2. **Energy Modeling and Simulation:**

- Energy Plus: A widely used simulation tool for building energy analysis, allowing users to simulate and evaluate energy performance based on different building parameters.
- Design Builder: Software that combines energy modeling and building simulation capabilities to assess the energy efficiency of building designs and optimize energy systems.
- Open Studio: An open-source software development platform that integrates energy modeling and analysis capabilities, including simulation of building energy use and renewable energy integration.

3. **Renewable Energy Integration:**

- PVsyst: A software tool for simulating and analyzing the performance of solar photovoltaic (PV) systems, including shading analysis, energy yield prediction, and system optimization.
- WindPRO: Software specifically designed for wind energy analysis, providing insights into wind turbine performance, energy production estimates, and wind farm optimization.

6.3. Research outcome

Based on the conclusions we came to in this thesis, there are still certain limitations and critical opinions on the subject. Net zero energy districts and buildings offer solutions to address the challenge and problems of reduction of energy resources, deterioration of the environment, and need for sustainable development. Through energy efficient measures ZEBs seek to reduce energy consumption and renewable energy technologies remain to meet the energy needs. Thermal insulation, lighting advancement, and post-occupancy surveys to optimize indoor temperature ranges. Renewable energy technologies such as **photovoltaics, wind turbine, and solar thermal but there are still challenging issues regarding power infrastructure and integration and cost too.**

The findings of the case study conducted in Turin indicate that the most favorable scenario, **from a socio-economic perspective, involves a standard level of envelope retrofit combined with an EMM system fueled by biomass** (Beria et al., 2012). This study highlights the various benefits associated with these design choices, including energy and cost savings, as well as a substantial reduction in environmental impact and CO_2 emissions. By utilizing renewable sources to meet heating and electricity demands, these solutions align with the European decarbonization objective. Additionally, retrofit interventions contribute to job creation, employing a larger workforce compared to scenarios reliant on fossil fuels.

Professor Orlando's case study in Turin presents a framework for optimizing the placement of photovoltaic (PV) modules within the city district. The framework utilizes a Digital

Surface Model (DSM) to identify suitable areas for PV installation, considering factors such as roof slope, aspect, and height. By taking these parameters into account, the framework effectively identifies areas with optimal sun exposure and potential PV production. The results consistently demonstrate that the identified optimal placements outperform traditional placements in terms of power production, emphasizing the importance of selecting positions with minimal shading impact to maximize output. As we understand from this study switching to the net zero energy districts offers both opportunities and challenges at the same time while it provides options for us such as energy emission with low co2 and self-sufficiency and includes difficulties such as high-cost investment and maintenance and lack of standard need for reliable energy sources that is generally is expensive. To solve this challenge need managing energy storage, and reduce the use of fossil fuel vehicles as we talked before to improve electrical public transportation in districts or neighborhoods by providing the power needed for charging by PV solar panels in the district.

Be success of net zero energy buildings and districts need integration of human behavior and community activities as we see in season 5 in Confluence of Lyon it is important to prioritize human culture and renewable energy investment. At the community level of energy establishing energy communities and upgrading public transportation. While the cost associated is still challenging part of it is better to change our perspective from a single building to a group of building together in the district can solve some problem of cost issues. ZEBs and NZEDs have enormous promise for integrating renewable energy, enhancing energy efficiency, and promoting sustainable development. paying attention to details and design in concept design before the construction period These strategies can pave the path for a greener future by fusing community involvement, renewable energy technologies, and energy-efficient measures and socio-economic terms too. Nevertheless, continuing research, funding, and policy assistance are required to overcome obstacles, guarantee affordability, and maximize the benefit of NEZD AND NEZB for a sustainable future.

In conclusion, because renovation may not be the most practical course of action, paying attention to details and design before the construction period, as well as using the proper technology, can enhance the building's efficiency in the long run. A district should be thought of as a whole because the nearby buildings have a significant impact on one another and energy needs. This impact can be used to their advantage when the district acts as a system.

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