POLITECNICO DI TORINO

Collegio di Ingegneria Energetica

Corso di Laurea Magistrale in Ingegneria Energetica e Nucleare

Tesi di Laurea Magistrale

Building Renovation Tool:
energy efficiency scenarios of an office building located in Milan

Supervisor

Stefano Paolo Corgnati

Co-supervisors

Andrea Lanzini
Cristina Becchio
Simone Cannelli

Candidate

Stefania Lamparelli

Aprile 2018

A mia madre e a mio padre,

“Nulla si crea, nulla si distrugge, tutto si trasforma”

(Cit. Antoine-Laurent de Lavoisier)

Table of contents:

INTRODUCTION

In new and existing building higher energy efficiency is the key. In the energy Roadmap 2050, one of the main milestone is the concept of building renovation in term of energetic sustainability. The concept of NZEB: Nearly zero energy building should become the norm; the smart meters and technologies are good tools to contribute in creating responsible approaches in consumption, helping to avoid waste of energy. [1]

In the last few years, the attention on greenhouse gas and air pollution has considerably increased; as a matter of fact, the situation in many countries has started to be alarming and dangerous not only with serious consequences for the environment but also for people health.

To help the control and decreasing of the level of air pollution, a series of standards and reduction targets have been set. As far as it concerns the buildings, a key point is the control of energy consumption: it is essential to implement tools aimed to decrease the consumption in order to reach lower levels of emissions.

The Energy Performance Building Directive, EPBD, is born with the intention to promote and improve energy efficiency in the real estate sector and it represents the main legislative instrument in the European Union.

In Lombardia the decree n. 176 identifies the EPBD recast and sets the targets for a NZEB building.

The master thesis comes from the idea of creating a tool capable to perceive these rules and able to improve, through a specific set of energy efficiency measures, the energetic performances of the buildings. The tool creation was done in collaboration with **Engie**, a leading company in the European energy sector. In fact, the idea of a tool able to be versatile, innovative and effective about the buildings energy efficiency was born through a brainstorming with the B2B team of Engie Italia.

Building Renovation Tool can be useful to evaluate the different energy efficiency scenarios both from an energetic and economic point of view; in this way the users will be able to choose the best one related to their needs.

It is important to specify that the tool does not replace the user’s decision but rather supports him in the decision; it will be a user's task to read the outputs and decide how to interpret them, for example giving a different weights to the energetic parameters compared to the economic ones.

Furthermore, this tool has been suitable to calculate the energy consumption of a specific building situated in Milan; a series of energy efficiency scenarios will be presented and explained in order to understand how the tool works. To choose the best one, the economic analysis will be performed and the different scenarios will be compared both from an energetic and an economic point of view. Thanks to this application, the effectiveness of the tool has been demonstrated.

The innovation of this device regards the idea of considering the increase both in the asset and in the rent value of the building as a result of energy efficiency measures; this fact can impact the results of the economic analysis in a positive way and it can help to understand and quantify one of the multiple benefits of energy efficiency.

The articulation of the thesis is shown in the following summary:

- **CHAPTER 1:**

  In the chapter one, the main directives for the reduction of emissions and for the buildings efficiency are presented. Firstly, the goals of the **Roadmap 2050** are explained; only through more efficient, competitive and sustainable energetic system the emissions could be reduced by 80% within 2050. At this point, a series of decarbonisation scenarios and their impacts are presented. After an overview about the emissions reduction, the buildings energy efficiency is discussed; for this purpose, the EPBD Energy-Performance-Building-Directive and the concept of NZEB Nearly-Zero-Energy-Building are presented.

  The **Energy Performance Building Directive** sets the starting points for smart buildings in terms of energy efficiency, comfort and innovation. This directive meets the needs of renewing the building energy efficiency.

  The **NZEB** is defined as a building that have higher energy efficiency and low amount of energy needs which are almost fully covered by renewable sources. [2] The targets that a building have to respect in order to meet the NZEB requirements are shown in this chapter.

  Finally, the **multiple benefits** of energy efficiency are presented in order to deeply understand the power of energy efficiency. In fact, the concept, that only benefits which bring an energy efficiency measure are the consumption reduction and the decrease of greenhouse gas, is not completely correct. As a matter of fact, it undervalues the potential of the energy efficiency measures.

- **CHAPTER 2:**

  In the chapter two the **Building Renovation Tool** is presented. After an overview on the organisation and the sections of this, every block is shown and discussed; in this way, the chapter is like an instruction booklet that can be useful for the users to clearly understand the operation mode of the tool.

The tool is divided into five blocks; the first one, **Block A: Energy Modelling**, regards the stationary energy analysis of the building in the as-is situation. The **Block B: Energy Efficiency** is useful to evaluate the energy efficiency interventions; in fact, it is organized with a pre-set of energy efficiency measures. The users also have the possibility of combining several interventions together to create energy efficiency scenarios. The third block is the **Block C**: **Energy prices** in which the forward, best and worst energy prices scenarios are calculated; the economic analysis will be performed taking into account these different energy prices and, in this way, the users can understand the influence of energy prices on the economic parameters.

In the **Block D**: **Economic Analysis** the net present value, pay-back time and internal rate of return are calculated. After that, the different energy efficiency scenarios can be compared from an economic point of view.

In the end, there is the **Block E: Dashboard Report** in which the results of the previous blocks will be put together in order to provide an overview on the behaviour of the different energy efficiency scenarios; the dashboard report is useful to support the user to make the most appropriate choice relatively to his needs.

- **CHAPTER 3:**

  The chapter three is completely dedicated to the **case study** concerning an office building located in Milan. In this section, the tool was used to evaluate some energy efficiency measures on the examined building.

  Firstly, the as-is situation is discussed and the energy performances are calculated using the tool. The examined building is a C class and the NZEB check is negative. After this set of results, the energy efficiency measures are chosen and evaluated thanks to the Block B of the tool and, through the combination of these, four different scenarios were built to discover which was the best one. The energy prices are presented and then the economic analysis is performed for every different scenario. At the end, the dashboard reports are shown, and it is possible to choose the most profitable scenario.

Chapter 4 is reserved for the conclusions and the future perspectives of the thesis.

CHAPTER 1: Energy efficiency in building renovation

1.1 The European Strategy: Roadmap 2050

In 2011 the European Commission sets, in the Roadmap 2050, the goals to be achieved by 2050 in order to have an energetic system more efficient, more competitive and more sustainable. The major objective is to reduce the emission by 80% within 2050 compared to the 1990 level.
The key steps of this regulatory are:

- Carbon capture and sequestration
- Energy efficiency
- Renewable energy sources

The emission reduction can be technically and economically achieved by a deep decarbonisation of the energy system and it can be essentially attained in two ways strictly correlated: energy efficiency (especially in terms of building efficiency) and implementation of the renewable energy system.
In the future, due to the implementation of the renewable energy system, the building itself will produce more energy than the one needed; by 2050 this will allow to produce about 75% of the final energy consumption and about 97% of the electric one. [1]
"We need to be far more energy efficient. About two thirds of our energy should come from renewable sources. Electricity production needs to be almost emission-free, despite higher demand. Our energy system has not yet been designed to deal with such challenges. By 2050, it must be transformed. Only a new energy model will make our system secure, competitive and sustainable in the long-run"[1].
To obtain this energy system, the Roadmap 2050 explains it is important to take action quickly, otherwise, in case investments are postponed, the cost will further increase. As a matter of fact, the return for energy investments is quite long and not always so certain, quite common point in all innovation scenarios, and moreover, the volatility of oil and gas price does not help.
The foundations of this new energy system are explained in the Roadmap 2050. A series of decarbonisation scenarios are shown below:

- High energy efficiency: the first scenario in order to obtain a low carbon energy system is based on the concept of efficiency.
  Due to a high renovation rate of the existing buildings, the energy demand will decrease 41% by 2050 compared to 2005 peaks. [1]

[1] Roadmap 2050, European commission, Luxembourg: Publications Office of the European Union, 2012

- Diversified supply technologies: it is important to consider various sources of energy, the innovation process does not have to concentrate only on a limited range of technologies; on the contrary, the renovation of the energy system has to be global; no technologies are preferred compared to others.
- High renewable energy sources: this is a key point for the new energy system. In effect, the forecasts show that it is necessary a "very high share of RES in gross final energy consumption (75% in 2050) and a share of RES in electricity consumption reaching 97%."[2]
- Delayed CCS: this scenario provides an increase of the nuclear energy and the decarbonisation above all by carbon prices instead of technology push.
- Low nuclear: it is the contrary of the previous scenario.
  Assuming that the nuclear sector will not have substantial innovation, the best way to pursue is the penetration of CCS.

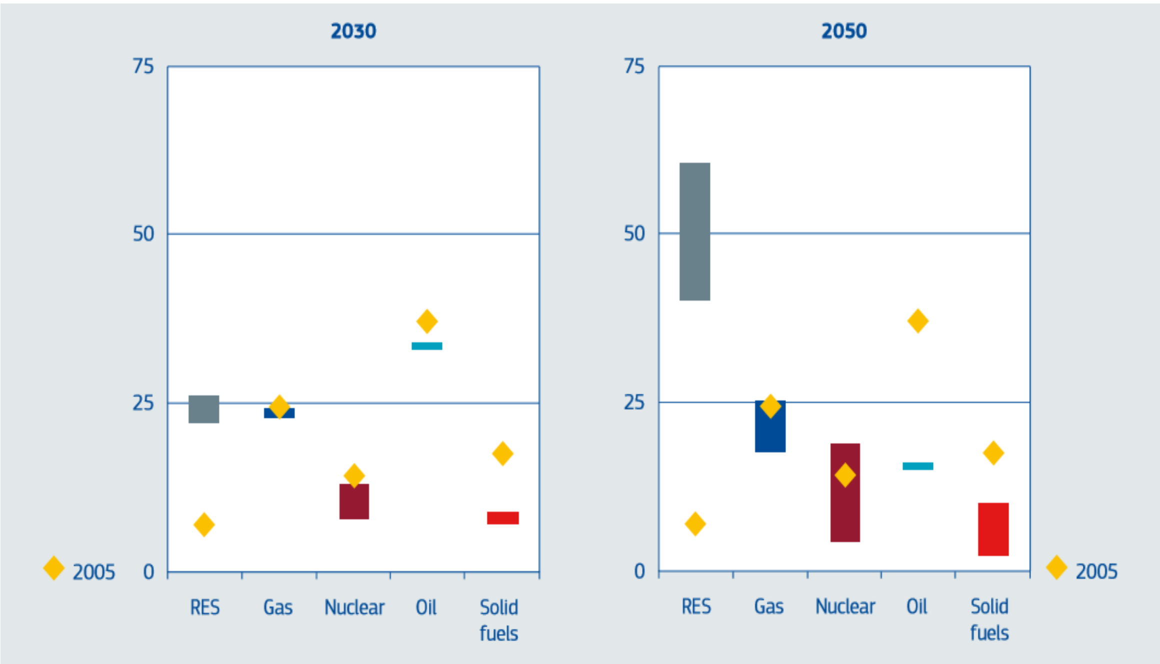


Figure 1-1: EU decarbonisation scenarios — 2030 and 2050 range of fuel shares in primary energy consumption compared to 2005 outcome (%) [1]

If these scenarios will be achieved, they can be deduced some conclusions.

The decarbonisation process is possible. As a matter of fact, assuming that in 2050 the energy cost could represent 14,6% of European GDP, the fulfilment of the scenarios above explained will lead to reduce the fossil fuel dependency up to 35-45%. [1]

The fossil fuel imports will decrease and consequently, the implementation of a low carbon energy system will give savings in terms of average capital costs.

[2] Roadmap 2050, European commission, Luxembourg: Publications Office of the European Union, 2012

“Investments in power plants and grids, in industrial energy equipment, heating and cooling systems (including district heating and cooling), smart meters, insulation material, more efficient and low-carbon vehicles, devices for exploiting local renewable energy sources (solar heat and photovoltaic), durable energy consuming goods, etc.”[3], all this allows the creation of major opportunities for European industry and focuses on the importance of research and innovation in order to develop more cost-competitive technologies.

In this context, electricity has a key role in all decarbonisation processes. According to the scenarios presented, electricity cost should decrease, on the contrary, the forecast shows that the price of electricity rises until 2050 and only after then it begins decreasing. This is due to the fact that in a high renewable energy scenario, the electricity prices rise in a first phase because of the high capital cost, the need for balancing capacity, storage and grid investments. [1]

A key point to obtain the results foreseen in Roadmap 2050 is renewable energy. It is important for the future to highlight the role of these types of energy sources, then, it is impossible to figure a low carbon energy system without the implementation of renewable energy. According to this point of view, the development in the renewable sector is essential.

As above mentioned, it is clear the central role of energy savings: “Primary energy demand drops in a range of 16–20 % by 2030 and 32–41 % by 2050 as compared to peaks in 2005–06. Achieving significant energy savings will require a stronger decoupling of economic growth.”[4]

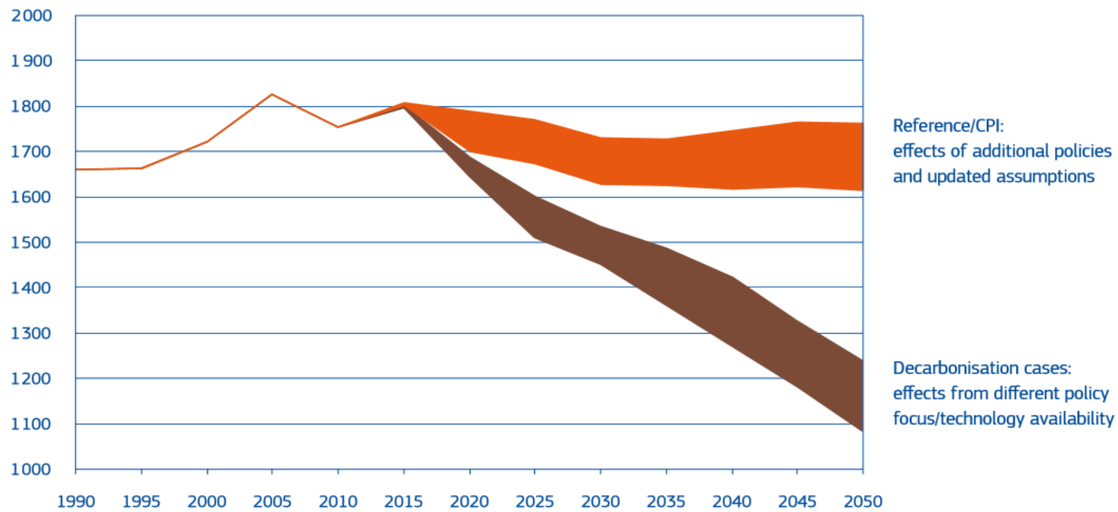


Figure 1-2: Gross energy consumption — range in current trend (REF/CPI) and decarbonisation scenarios (million toe) [1]

[3] Roadmap 2050, European commission, Luxembourg: Publications Office of the European Union, 2012

[4] Roadmap 2050, European commission, Luxembourg: Publications Office of the European Union, 2012

Energy savings in buildings are essential: building renovation in terms of energy efficiency, innovation, digitalization, comfort and distributed generation allows to achieve the goal of a low carbon energy system.

1.2 EPBD Energy Performance Building Directive

The **Energy Performance Building Directive** sets the bases for smart buildings in terms of energy efficiency, comfort and innovation. This directory meets the need of renewing the building energy efficiency. Talking about energy consumption, 40% of it comes from the building sector that it is continuously increasing. Then, it is necessary to establish some norms which regulate the energy in buildings; so, it can be possible to foresee a reduction in greenhouse gas emission and a decrease in energy dependency.

The **EPBD** is a European directory, every member state must comply with the guidelines of this norm. Finally, all European Countries are in a common strategy as far as it concerns energy buildings. This directory will regulate the energetic aspects of the building concerning the climatic and local conditions, when other aspects such as safety and accessibility are on charge of the single country.

To estimate the energy performances of the buildings, it is necessary to set a methodology taking into account the thermal behaviour, the heating, air-conditioned plant's efficiency and the use of renewable energy sources. Moreover, other parameters such as the shading, the energy capacity of buildings and the ability to take advantage of the natural light cannot be forgotten.

"Buildings have an impact on long-term energy consumption"[5], for this reason, it is suitable to intervene quickly and establish some rules concerning the new and existing buildings that are subjected to a large-scale renovation. [3]

---

[5] Official Journal of the European Union, DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast), 18.6.2010

In the following graph, it is represented the timeline of the **EPBD**:

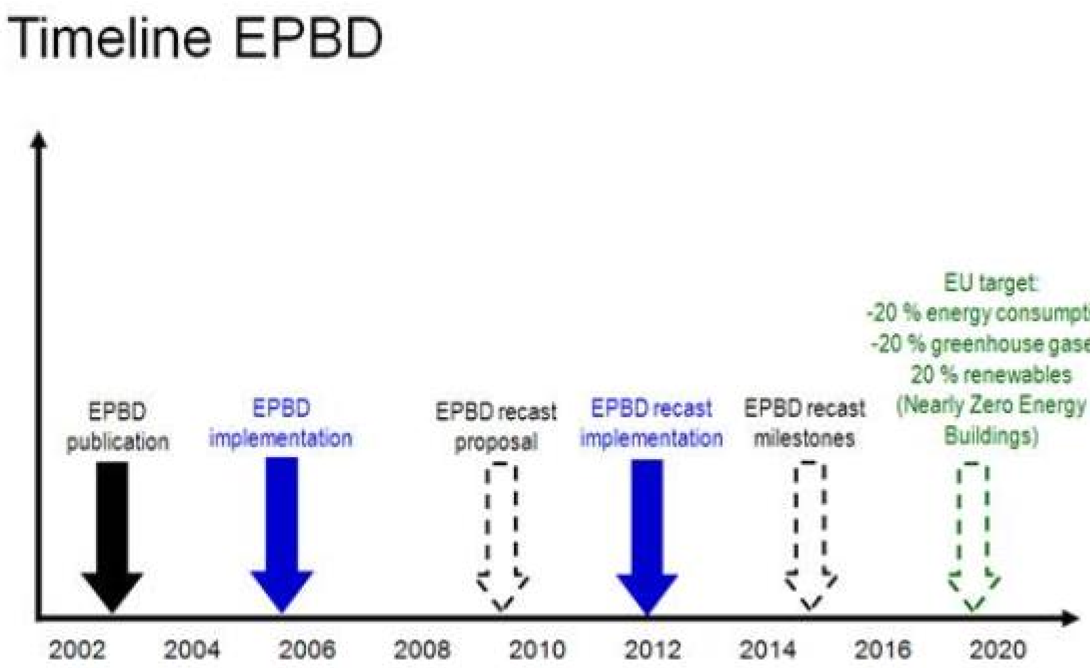


Figure 1-3: Timeline of the Energy Performance of Buildings Directive and its implementation [4]

Furthermore, it is promoted not only the construction of buildings in respect of the new minimum standards but also the construction of buildings that will be more efficient; thanks to this point of view it is possible to forecast an increase in the number of nearly-zero energy buildings.

Moreover, this directive outlines the financial instrument used to broadcast the energy efficiency.

The purpose of these instruments is to spread and stimulate the investment in energy efficiency.

This could encourage the development of the energy efficiency funds at national, regional and local level.

Member states should broadcast the most innovative technology, the use of renewable sources and the implementation of BMS-Building Management System.

In the article 1 of this directive, the prescribed requirements are explained; it is essential sharing among all the member states a general framework of the energy calculation methodology in order to be aligned.

In addition, it is highlighted the importance of adopting minimum requirements; these should be fixed with the aim of obtaining optimal cost levels or rather the energy performance which involves the lower cost during the economic lifecycle.

The minimum requirements should concern also the plant's performance; "The system requirements shall cover at least the following:

(a) heating systems;

(b) hot water systems;

(c) air-conditioning systems;

(d) large ventilation systems;

or a combination of such systems."[6]

Besides, there will be some parameters able to take into account the presence of control and management system; it is important to know and understand the importance of these last systems in the energy saving processes.

It is very convenient to analyse and evaluate all the alternatives during the project; analysing and choosing the better solution step by step, evaluating a trade-off of all the parameters: economic, energetic and environmental. This directive provides also the technologies more profitable to support the designers: cogeneration, heat pumps and energy from renewable sources.

Article 9 of the directive highlights the importance of NZEB: Nearly-Zero Energy Building. "By 31 December 2020, all new buildings are nearly zero- energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings."[7]

Every member state should set the minimum values of primary energy, under which a building can be considered NZEB.

In conclusion, the EPBD recast sets the principles for a smart and innovative view of energy efficiency in buildings; moreover, it highlights the importance of minimum requirements to be respected for all buildings and of a common methodology in order to evaluate the energetic performances of buildings.

1.3 The concept of NZEB: Nearly-Zero Energy Buildings

The concept of NZEB is mentioned in the EPBD Recast; it is important to provide guidelines of NZEB shared among all the member states. For this purpose, the REHVA journal had published the article:" How to define nearly net zero energy buildings nZEB" in May 2011.

In addition, a methodology usable by all the member state it is needed; this methodology should set the principles of the calculation, but obviously some differences from one country to another could occur, for example because of the local conditions.

The NZEB building was defined as a building that have higher energy efficiency and low amount of energy needs which are almost all covered by the renewable sources. "Following the cost-optimality

[6] Official Journal of the European Union, DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast), Article 8

[7] Official Journal of the European Union, DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast), Article 9

principle of the directive, nearly net zero energy building definition is proposed as national cost optimal energy use of > 0 kWh/(m² a) primary energy."[8]

At this point, it is necessary to clarify which type of energy flows have to be considered in the primary energy indicator.

The primary energy indicator is defined such as the summary of the differences between the delivered energy and the exported energy multiplied per their primary energy factor. The formula is shown below:

$$E = \sum (E_{del,i} - E_{exp,i}) \times f_i$$

Where E_{del} is the delivered energy, E_{exp} is the exported energy and f is the primary energy factor. [2]

The delivered energy accounts all the energy used in buildings such as energy for heating, energy for cooling, for ventilation and lighting. The primary energy factor represents the energy vectors used such as electricity or fuels.

"The performance level of "nearly" net zero energy use is decided at a national level and takes into account the followings:

- cost optimal and technically reasonably achievable level of primary energy use
- how many % of the primary energy is covered by renewable sources
- ambition level of the definition"[9]

It is fundamental to uniformly define which energy flows have to be taken into account in the calculation of the net delivered energy balance. For this purpose, it is important to specify the boundary conditions; the figure below shows what type of energy flows should be considered in the calculation and what are the boundary conditions of a typical building:

[8]REHVA journal, articles: "How to define nearly net zero energy buildings nZEB", May 2011

[9]REHVA journal, articles: "How to define nearly net zero energy buildings nZEB", May 2011

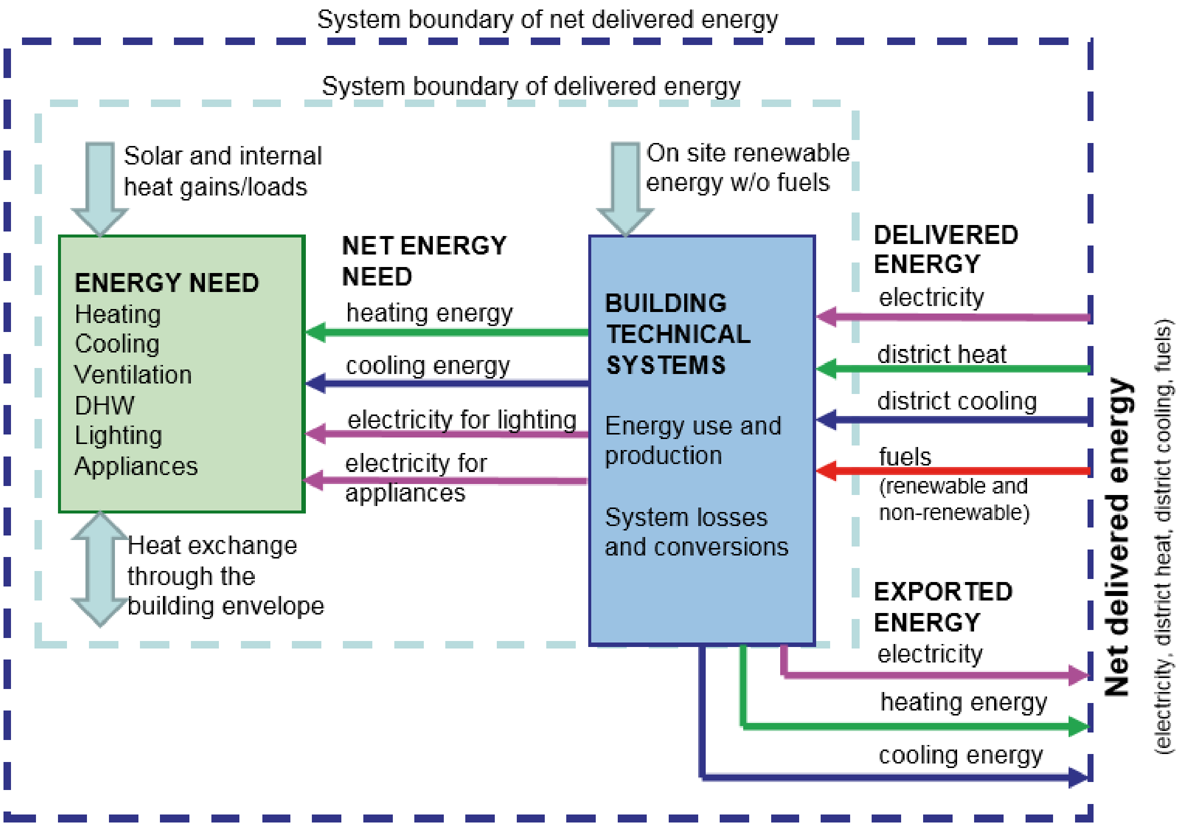


Figure 1-4: Boundary conditions of building used in order to calculate the net delivered energy [2]

Looking at the figure above, it can be possible to list the main steps of the calculation:

1. Estimation of the energy need for heating, cooling, ventilation, domestic hot water, lighting and appliances; this calculation considers the solar and internal heat gains and the heat exchange through the envelope.
2. Evaluation of the net energy need; the net energy need accounts all the system losses such as the control losses, the emission losses and the generation losses. While the previous point is focalized on the building's envelope characteristics, at this step the system losses take relevance. Moreover, the delivered energy takes into account also the on-site renewable energy, in order to evaluate the positive influence of these types of energy.
3. Calculation of the exported energy; the exported energy such as electricity from photovoltaic systems (or from hydroelectric system) and heating or cooling energy (for example from solar thermal system) will reduce the delivered energy.
4. Estimation of the net delivered energy; through the balance between the delivered energy and the exported energy it is possible to know how energy needs the building. In order to discover the net delivered energy it is necessary to multiply this balance for a primary energy factor.

It is important to highlight which types of on-site renewable energy should be taken into account at the step number two; only solar, wind, hydro energies have relevance in this calculation. While for the other types of renewable energy such as heat pumps there are some parameters used in order to show the positive influence, for example the COP (coefficient of performance) of the heat pumps.
Every member state can decide to employ others different parameters in order to evaluate the NZEB building in addition to the primary energy indicator.
Below, the definition and the parameters, that define an NZEB building, used in Italy are presented:
"Sono "edifici a energia quasi zero" tutti gli edifici, siano essi di nuova costruzione o esistenti, per cui siano contemporaneamente rispettati:

a. tutti i requisiti previsti dalla lettera b) del punto 6.13;
b. gli obblighi di integrazione delle fonti rinnovabili di cui alla lettera c) del punto 6.13;"[10]

The parameters are defined in the table below:

Parameter	Description
H'_T	Global transmission coefficient: it is an index of the envelope's dispersion
$A_{sol,est}/A_{sup,utile}$	It is the ratio between the summer solar area and the net area of the building; it is useful in order to evaluate the shading and the solar gain
$EP_{H,ND}$	Index of the energetic performance of building in terms of heating; it defines the behaviour of the building envelope and plants in the winter period
$EP_{C,ND}$	Index of the energetic performance of building in terms of air-conditioned; it define the behaviour of the building envelope and plants in the summer period
$EP_{gl,TOT}$	Index of the global energetic performance of building; it takes into account all the energy flows.
η_H	Efficiency of the heating system
η_C	Efficiency of the air-conditioned system
η_W	Efficiency of the domestic hot water system

Table 1-1: Description of the parameters used in order to determine if the building is an NZEB building [5]

Furthermore, another aspect to be considered in verifying if the building is NZEB is the presence of renewable energy. As a matter of fact, it is mandatory to cover about 50% of the energy used to domestic hot water with renewable sources and about 50% of the energy used to heating and cooling the building. Moreover, a system that produces electricity from renewable sources has to be installed. The power of this system is calculated with the formula below:

[10] Disposizioni in merito alla disciplina per l'efficienza energetica degli edifici e per il relativo attestato di prestazione energetica, a seguito della DGR 3868 del 17.7.2015

$$P = {}^{1}/_{K} * S$$

Where P is the power expressed in kW, K is a coefficient and it is equal to 50 m^2/kW and S is the area at the ground level. [5]

If the parameters and the conditions described above are respect the building can be considered an NZEB building.

1.4 Multiple benefits of energy efficiency

In order to evaluate the consequences and to choose an energy efficiency measures, it is necessary to understand what types of benefits it can bring.

The concept, that only benefits which bring an energy efficiency measure are the consumption reduction and the decrease of greenhouse gas, is not completely correct. As a matter of fact, it undervalues the potential of the energy efficiency measures. Therefore, other properties and consequences have to be taken into account. To explain that, the IEA International Energy Agency has published the report "Capturing the Multiple Benefits of Energy Efficiency" where a series of multiple benefits are examined and explained. If these benefits include the real value of energy efficiency measures, of course, this will positively affect the energy efficiency market and this will represent an incentive in the development of this market.

The major problem of the energy efficiency interventions is the payback period, in fact, in many cases this parameter is very high and it plays a central role in the choice of what types of energy efficiency measures implement. Nevertheless, choosing energy efficiency measures with a shorter time for the return of investments, it does not necessarily represent the better choice. The challenge is to be able to valorise not only the reduced energy demand but also other consequences, such as the health, wellness and the industrial productivity; so, the time for the return of investments will be shorter assuring a choice of the energy efficiency measures more aware and effective.

The major multiple benefits of energy efficiency are discussed here under:

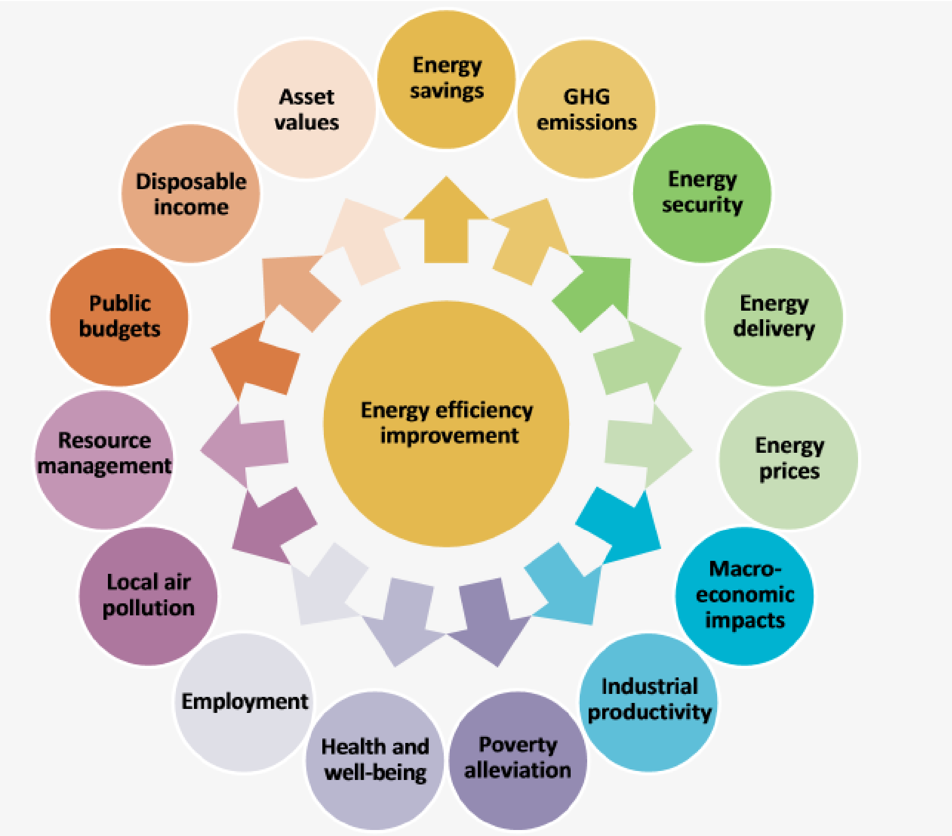


Figure 1-5: Multiple benefits of energy efficiency [6]

- Energy system security: if the energy efficiency begins to play an important role in the energy market, consequently it will occur a minor dependence on fossil fuels. This fact means that the fuel availability is more stable, the affordability grows and then the nations have a greater degree of independence compared to the trend of the fossil fuel markets. The supplying risk decreases and the security in the energy system grows up.
  Moreover, another important aspect is the energy prices; if the demand is lower thanks to the energy efficiency measures, as a consequence the prices of energy will tend to decrease.

- Economic development: first, there are the macroeconomic impacts: if the investments in the energy efficiency sectors continue to grow up, then the energy efficiency markets will become economies of scale. Thanks to the economies of scale the price can be reduced and it can create employment. Moreover, the investment in energy efficiency sector influences the trade balance. In fact, if the development and the innovation lead to new strategies in the production and in the energy savings, consequently the imported energy could decrease.
  A second economic impact concerns the industrial productivity. The energy efficiency measures have a lot of benefits in the industrial sector; other than the reduction in energy

consumption, they can reduce the operation and maintenance costs, improve the productivity and the capacity utilisation and decrease the pollution. All these benefits can be considered in "additional value ranging from 40% to 250% of the value of energy savings".[11]

- Social development: recent researches show that about 1.2 billion of people are without access to electricity. [6] If the energy efficiency becomes a "first fuel" and then the prices of electricity bill decrease, it will bring an increase in the access of energy also for poorer family. Moreover, another important social aspect concerns health and wellness. A significant number of studies highlights the link between energy efficiency and comfort meant as improvements in the health and well-being. In fact, through measures that concern insulation of a building, lighting system and improvement in heating and cooling system the indoor environment results more comfortable in terms of temperature, humidity and indoor pollution. These three last parameters have a significantly influence in terms of physical and mental health.

  In an office building, for instance, these parameters impact on people cognitive abilities; it is clear that if the employees work in an optimal environment in terms of view of lighting, temperature, humidity and indoor pollution, they work better improving their performances; therefore, their productivity will increase.

  Another benefit to be considered in the social development is the employment factor. The birth and the development of the energy efficiency sector create a large number of jobs, with a positive impact in social terms.

- Environmental sustainability: the energy sector plays a key role in the outdoor air pollution. Measures of energy efficiency concerning the production facilities and the transport sector are essential to limit the greenhouse gas emissions.

  Furthermore, the air pollution impacts significantly on people health; one need only consider "the total health costs associated with outdoor air pollution in China's urban areas in 2003 was estimated at between USD 25 billion and USD 83 billion"[12].

  On the other hand, decreasing the energy consumption through energy efficiency measures can reduce the need to find out new natural resources, consequently it brings a decrease of extraction wells and reduces the water waste. Moreover, it is clear that, thanks to a more rational use of energy, it becomes possible to reduce problems such as the ocean acidification, the ozone's hole and the emission of polluting particles.

---

[11] IEA, "Capturing the multiple benefits of energy efficiency", 2014
[12] IEA, "Capturing the multiple benefits of energy efficiency", 2014

- Increasing prosperity: energy efficiency can influence the public budgets in terms of tax revenues and government expenditures. In fact, if countries import the fossil fuels, by the energy efficiency measures they can reduce the energy consumption and then the fossil fuels to be imported, with a consequent positive effect in terms of government expenditures.
  On the other hand, if countries export the fossil fuels, by the reduction of energy consumption they have a greater quantity of fuels to trade and this gain can be converted in greater budget for the countries and lower taxes in the countries' energy sector.
  Another aspect concerning the increasing prosperity is the speech on the asset value of a building. Certainly, if the building performs better from an energetic point of view, the owner can rent or sell the building at higher value compared to a building that has poor energetic performances. A study of Eichholtz, Kok and Quigley shows that "every USD 1 saved in energy costs translates, on average, to acceptance of a 3.5% increase in rent and a 4.9% premium in market valuation"[13]. This positive aspect is explained in the Building Renovation tool, block D *(cf. chapter 2, paragraph 2.5: Block D Economic analysis)*.

In conclusion, the multiple benefits significantly influence the development in this sector and improve the results that the energy efficiencies scenarios produce. Moreover, it is not obvious to translate into economic terms the value of the multiple benefits; for this reason, it is essential to implement researches in order to completely understand the real potential of the energy efficiency.
In *chapter 2-paragraph 2.5*, there is an evaluation of the asset value of the building, which compares, from this point of view, the various energy efficiency scenarios involved.

[13] IEA, "Capturing the multiple benefits of energy efficiency", 2014

CHAPTER 2: Building renovation tool

2.1 Tool description and organisation

The **Building Renovation Tool** is created in order to simulate the energy performances of a building in terms of economic parameters and primary energy consumption. It can be useful for different typologies of buildings; in every section you find multiple choices and data input which make the tool adaptable.
The tool is split in two macro sections: "Section 1: Energy Performance ","Section 2: Energy efficiency + Business case"; furthermore, these two sections are split in some blocks.
The tool comes from the idea of building an instrument able to simulate the energy performances of buildings and at the same time evaluating the more appropriate energy efficiency scenario. The tool is able to extract data of following types: energetic results, then energy classification and NZEB check and economic results then net present value, internal rate of return and real estate evaluation.
Moreover, it is important to highlight that the aim of the tool is to be simply and quickly to use, also for users which have medium skills in the energetic field, the tool has to be easy using, for that reason, some parameters are calculated in a simplified way.
Furthermore, in order to evaluate the best energy efficiency scenarios which users can choose, in the block B there is a matrix that describes the "goodness" of the various scenarios in terms of energy demand reduction and NZEB check.

Building Renovation Tool is composed by the following blocks:

- Block A: Energy Modelling (Section 1)
- Block B: Energy Efficiency (Section 2)
- Block C: Energy prices Scenarios (Section 2)
- Block D: Economic Analysis (Section 2)
- Block E: Dashboard Report (Section 2)

The operative mode of the tool is:

1. Insert the data of the building in block A and then extract the results and evaluate the as-is situation.
2. Depending on the results obtained in the previous step, choose the energy efficiency scenarios that are more suitable, then examine the new results and evaluate what is the best.

3. Economic evaluation: it is also important an economic analysis of the different energy efficiency interventions. As a matter of fact, the best solution from the energetic point of view could become the worst from an economic point of view, then it is important to find a balance between these two aspects.

The tool is based on the national and regional regulatory concerning the energetic field.

The hierarchy of the tool is shown in the graph here under:

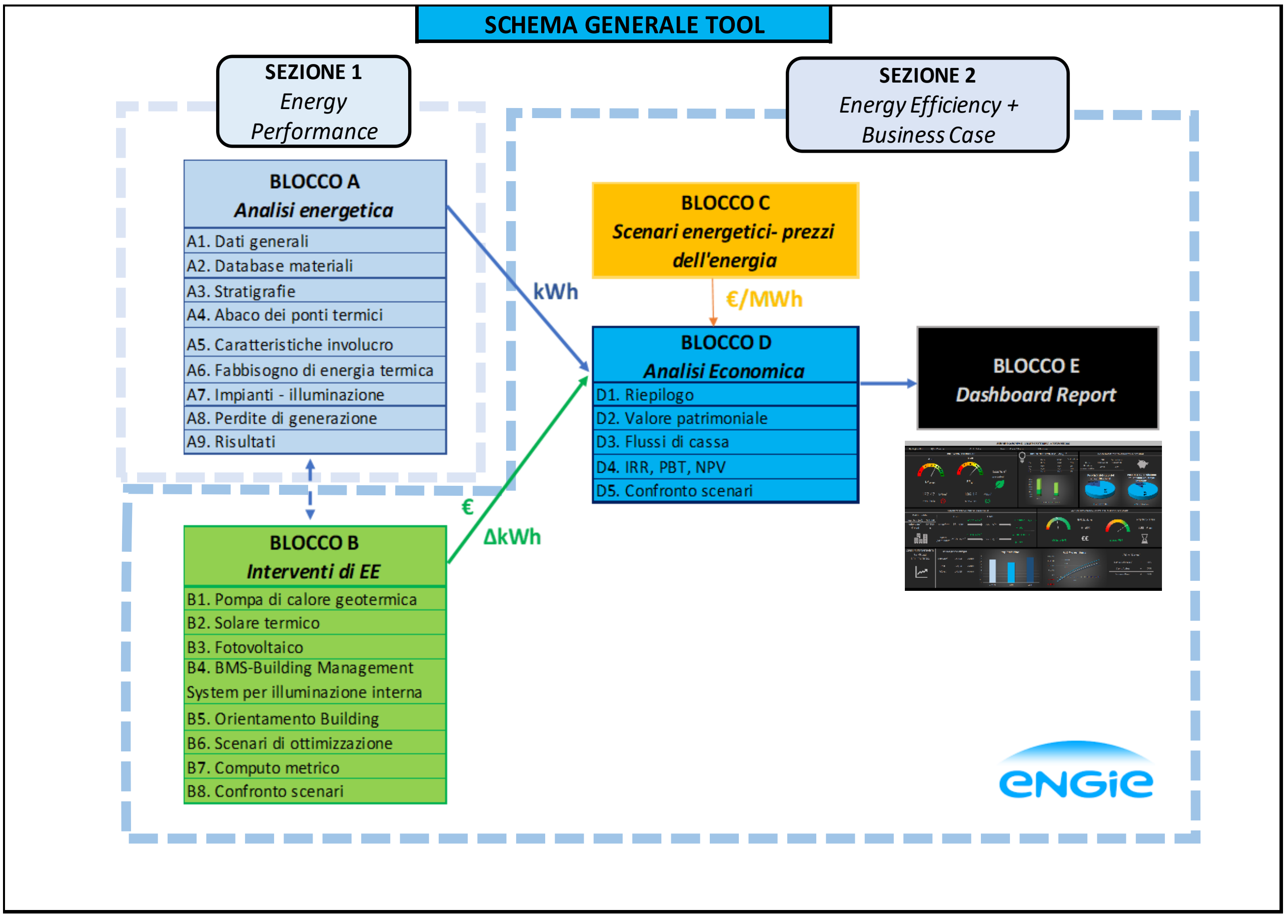


Figure 2-1: Tool description

2.2 Block A: Energy Modelling

The first block is the block which calculates the energetic parameters of the building. There are some cells in which the users can insert the data input, some cells are standard value and other are pre-set formulas. In order to clarify the meaning of the several types of cells, the legend here under:

#	Tipologia	Descrizione
1		Cella bianca: inserire i dati relativi all'edificio
2		Cella bianca con bordo giallo: selezionare la scelta più opportuna dal menù a tendina
4		Cella rosa: commenti e descrizione dei vari fogli
5		Cella azzurra/blu: formule o valori pre-impostati; NON MODIFICARE

Table 2-1: Legend of the cells

The block is split into nine sheets; the explanation of these sheets is shown in the graph below:

#	Nome del foglio	Descrizione
1	Dati generali	Inserire i dati generali dell'edificio in esame: indirizzio, dati climatici, utilizzo...
2	Database materiali	Database dei valori di conducibilità termica e resistenza dei principali materiali utilizzati in edilizia
3	Stratigrafie	Calcolo della trasmittanza termica delle strutture costituenti l'involucro opaco
4	Abaco dei ponti termici	Calcolo della trasmittanza termica lineica relativa ai ponti termici
5	Caratteristiche involucro	Calcolo del coefficiente globale di scambio termico dell'edificio- H_T
6	Fabbisogno di energia termica	Calcolo del fabbisogno di energia termica nel periodo invernale e estivo dell'edificio
7	Impianti - illuminazione	Calcolo delle perdite degli impianti di climatizzazione invernale, climatizzazione estiva, produzione ACS. Calcolo del fabbisogno di energia elettrica per l'illuminazione interna
8	Perdite di generazione	Calcolo delle perdite di generazione per macchine frigorifere e per diverse tipologie di impianti per riscaldamento e produzione ACS
9	Risultati	Calcolo dei parametri dell'edificio di riferimento, Calcolo della classe energetica, verifica edificio Nzeb

Table 2-2: Explanation of the Block A tool's sheets

The block A operates in sequence; first of all, the users have to insert the general data in the sheet number one. It is important to identify the major use of the examined building; for this purpose, there is a multiple-choice cell, the users can select the more appropriate voice and then, a series of values are set up on the basis of this choice. Moreover, the users can set up the address, the climatic zone, the minimum and maximum temperature and the parameters related to the size of the building. When the users have completed the first sheet, they can operate in two ways: if they know the property of the materials used in the stratigraphy of the walls, they can directly go to sheet number three and fill out the specific tables. On the contrary, if the properties are unknown, in sheet number two there is a material database from which the users can extract the energetic parameters related to a series of construction material. In this last case, the needed data to complete the tables in sheet number three are extracted from the material database. The stratigraphy sheet is necessary in order to discover the transmittance of the several walls, windows, attic and floors.

The following step is related to the presence of thermal bridges in the envelope of the building. If there are some thermal bridges, the users can go to sheet number four; this sheet is organized such as a database of the major types of thermal bridges, so the users can select the type more appropriate, complete the connected tables and thanks to pre-set up formulas, the transmittances of the thermal bridges are calculated. Though, if there aren't any thermal bridges, the users can go directly to sheet number five: envelope features.

In sheet five, the users have to select from a multiple-choice cells some characteristics of the wall: the type of walls and the orientation. This operation is useful to understand the temperature of the room which are not air-conditioned. In addition, in this sheet there are reports of the values of transmittance calculated in the previous sheets. This sheet (#5) gives the global heat transfer coefficient of the building (H_T). This parameter is used in sheet number six, where we calculate the energy needs of the building in winter and summer. Then the users can insert the values related to the monthly average irradiance on a vertical plane used in order to discover the solar contribution, the values related to the external temperature and the values related to the estimation of the transmission coefficient of ventilation.

At this point, they can see the behaviour of the envelope of the buildings in terms of dispersions of thermal energy.

As an explanation for the collocation of greater dispersions, a graph which shows the thermal behaviour of the envelope in the winter period was implemented *(cf. chapter 3, paragraph 3.1)*.

At this point, we examine the sheets related to the behaviour of the thermal plants.

Sheet number seven is concerned with the calculations of the emission, regulation, distribution and storage losses and with the calculation of the primary energy necessary for the internal lightening.

The users can select from several multiple-choice cells the parameters that fit better the examined building.

The results give the thermal needs that the power plants have to satisfy; after the extraction of these values, they are transferred to the following sheet: generation losses.

In order to calculate the primary energy, it is necessary to calculate the generation losses. For this reason, in sheet number eight the users have the possibility to select the type of the thermal plants and then are re-connected to external files able to calculate the generation efficiency.

Sheet number nine is the sheet that shows the results of the building.

In the first section, we can see the parameters that fit the reference building; the reference building is used in order to create the several range of the energetic classification. In this way, we can identify the approximate energetic class of the building. Moreover, there is the NZEB check.

The following flowchart summarize the operation mode of block A:

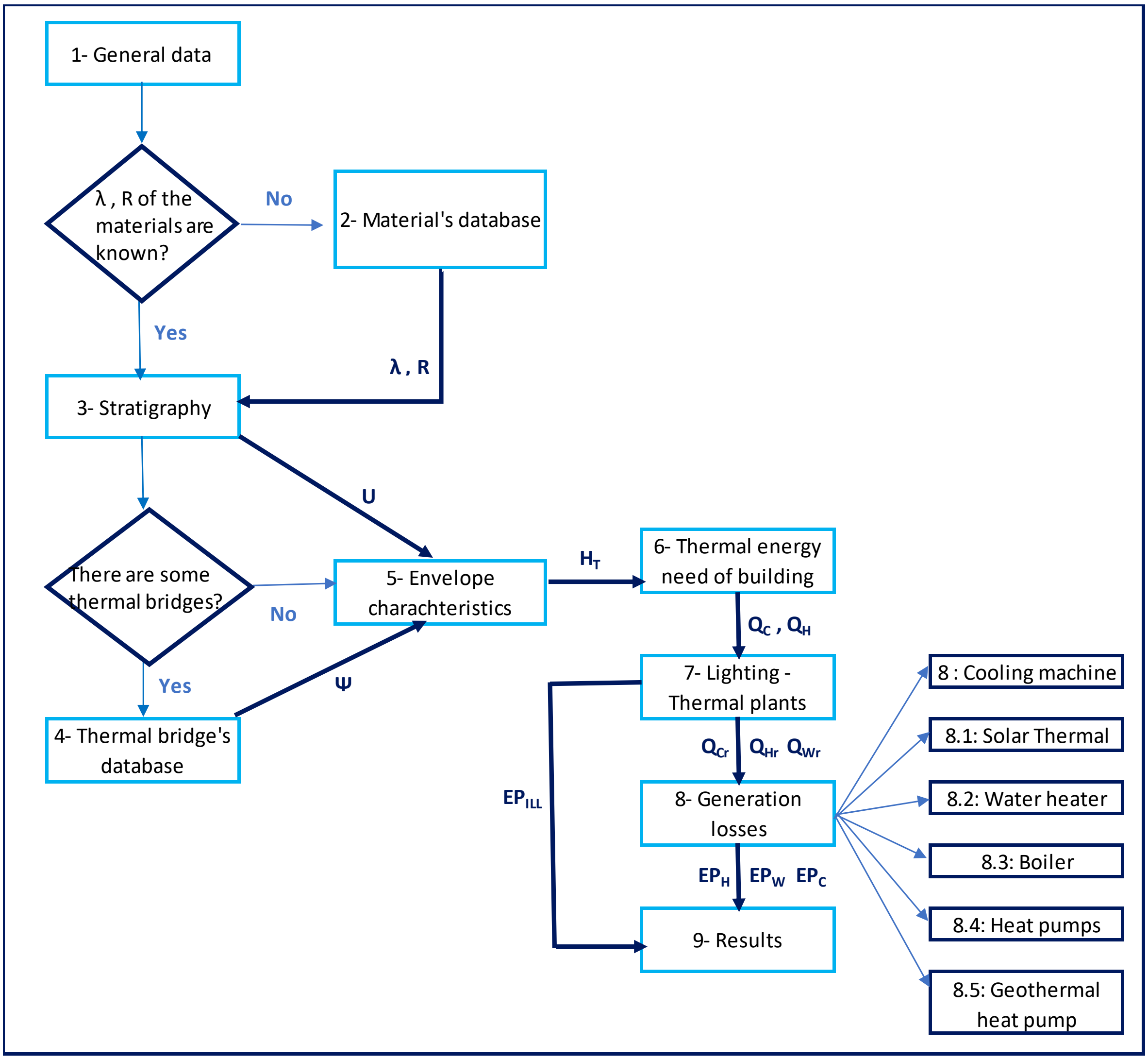


Figure 2-2: Flow chart of the Block A

Every section is built on the basis of the national framework; to clarify the regulations used in every sheet it is presented the table below:

# sheet	REFERENCE REGULATION
1	UNI/TS 11300-1 (2014)
2	-
3	UNI/TS 11300-1 (2014)
4	-
5	UNI/TS 11300-1 (2014)
6	UNI/TS 11300-1 (2014), UNI 10349 (2015)
7	UNI/TS 11300-2 (2014), UNI/TS 11300-3 (2010), UNI EN 15193 (2008), UNI EN 12464-1 (2004)
8	UNI/TS 11300-2 (2014), UNI/TS 11300-3 (2010), UNI/TS 11300-4 (2016)
9	Allegato B decreto n. 176 Lombardia, Disposizioni in merito alla disciplina per l'efficienza energetica degli edifici e per il relativo APE, a seguito della Dgr. 3868 del 17.7.2015

Table 2-3: Description of the regulations that are used in the block A

It is right and proper, at this point, explain in detail every sheet:

1. **General data**

The general parameters of the building have to be inserted by the users in this section.

The data input is split in four macro areas: identify data, geoclimatic context, building type and general dimension of the heated space.

The identify data concern all those data that identify the building. The users can insert: address, municipality, CAP and town.

The data to be inserted in the geoclimatic context area are those connected to the temperature data of the location. In this section the users can define: day degree, minimum temperature project, maximum temperature project, internal winter temperature, internal summer temperature, maximum solar irradiance, climatic zone and heating and cooling period. It is important to trace these data because will be useful in the following sheets of the block A.

Contesto geoclimatico	
GG	
T minima di progetto (°C)	
T massima estiva di progetto (°C)	
T interna invernale di progetto (°C)	
T interna estiva di progetto (°C)	
Irradianza solare massima estiva (W/m^2)	
Zona climatica	
Periodo di riscaldamento	
Periodo di raffrescamento	

Figure 2-3: Geoclimatic data section

The third macro area of this sheet concerns the choice of the building typology [7]. The users can select from a list the best one. The table here under shows the several choices the users can make:

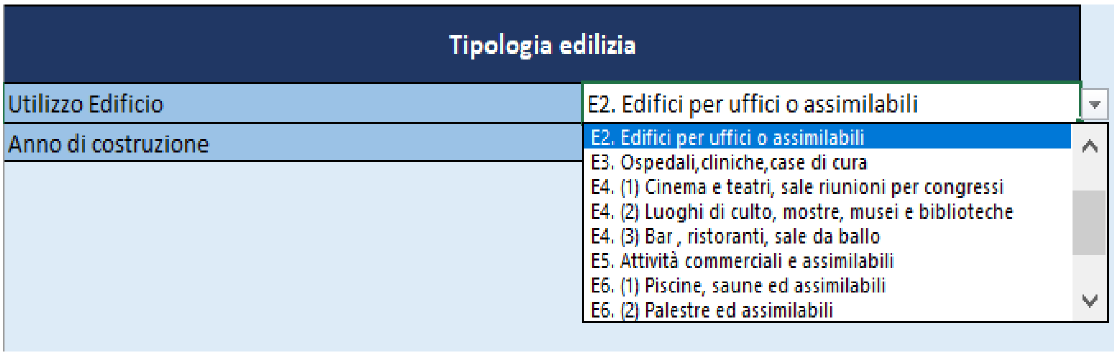


Figure 2-4: List of the several building typologies

The fourth section concerns the dimension of the air-conditioned room. The users can define the gross volume of the air-conditioned room, the usable area, the net dispersion surface and the number of floors. The ratio between surface and volume it is a pre-set formula, then the result appears when they complete the previous cells.

2. Database building materials

In the database materials there is a list of the most commonly used building materials.

They are split in categories: building’s panels, brickwork materials, flooring materials, insulating materials and plaster. For all these types of materials there is the reference value of the thermal conductivity (λ) [8].

In the same sheet, the users can also find the reference transmittance value of several window typology and framework.

Moreover, there are two tables that summarise the resistance of the air gap.

This database it is also useful if the users do not know the thermal capacity of the building as it has been defined a table that shows how to calculate this parameter.

3. Stratigraphy

In this section the users can build the stratigraphy of several walls; it is useful in order to discover the transmittance of the compound walls.

In other words, with the previous sheet we can measure the conductivity of the single layer of the wall; however, for calculating the transmittance of the n. layers composing the wall it is necessary to use the tables of the stratigraphy sheet.

The formula used to calculate the transmittance of the wall is [7]*:*

$$U = {}^{1}/_{R_1 + R_2 + \cdots + R_n} \left[\frac{W}{K * m^2}\right]$$

Where R_1, R_2 and R_n are the resistance of the single layer:

$$R = {}^{s}/_{1000 * \lambda} \quad \left[\frac{K \ * \ m^2}{W}\right]$$

S is the thickness of the single layer that is declared in millimetres.

The resistances are the ratio between the thickness of the layer and the conductivity; the conductivity can be obtained from the previous sheet (Database building materials) or can be directly inserted in the stratigraphy table if the users already are aware of this parameter. Though, it is important to insert the thickness of the layer.

Moreover, there are some layers that do not need the knowledge of conductivity because it is declared the resistance; these types of layers are, for example, internal and external inductance and the air gap.

Below, it is reported an example of the stratigraphy table to be completed by users:

Nome struttura	Parete esterna hall (ARC 067)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza interna			0,13
2	Rivestimento prefabbricato in CLS UHPC	1,500	13	0,008666667
3	Rivestimento prefabbricato in CLS UHPC	1,500	12	0,008
4	Lamina di alluminio	0,400	1	0,0025
5	Strato d'aria verticale		5	0,11
6	Isolante in lana di roccia	0,035	40	1,142857143
7	Strato d'aria verticale		5	0,11
8	Muratura in VIBRAPAC (20x20x50 cm)	0,881	200	0,227
9	Strato d'aria verticale		5	0,11
10	Isolante in lana di roccia	0,035	90	2,571428571
11	Strato d'aria verticale		5	0,11
12	Lastra in cemento fibrorinforzato	0,4	10	0,025
13	Adduttanza esterna			0,13
Trasmittanza (W/m^2K)		0,213426563		

Figure 2-5: Example of stratigraphy table; values of the examined building

4. Thermal bridges database

This database has been developed with the support of “Abaco dei ponti termici” published by Cened [9].

The users find in the first rows an index in which there are all types of thermal bridge, then, they can click on the suitable choice and they will be sent to the calculation table.

On the basis of the chosen thermal bridge, the users have to insert different parameters, for example, transmittance, thermal conductivity or both of them.

It is important to understand that the data input has to be inserted only in white cells because the others contain pre-set formulas.

The result of this section gives the linear thermal transmittance of the thermal bridge useful in sheet five.

In order to clarify these concepts, it is reported below an example of the thermal bridge table:

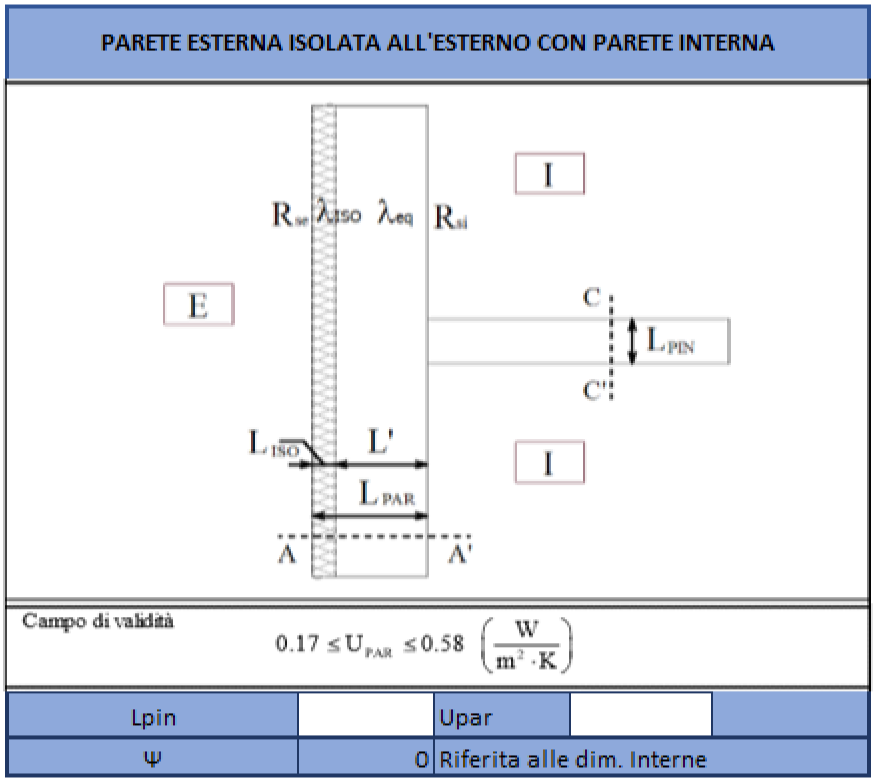


Figure 2-6: Example of thermal bridge's table

5. Envelope characteristics

The purpose of this sheet is to calculate the global heat transfer coefficient of the building envelope. The formula to obtain that is as follows [7]:

$$H_T = F_T * U_{struttura} * Superficie \quad [{}^{W}/_{K}]$$

The parameter F_T is a coefficient which considers the different temperature of the not air-conditioned surrounding space. If the surrounding space is the external environment this parameter assumes the value 1; instead, if the nearby space is, for example, a garage, this parameter assumes different values depending on its structure.

In order to calculate this parameter, the users have to be acquainted with some characteristics of the wall. There are a series of multiple choice cells in which they can select the most appropriate alternative. First of all, they can choose the type of wall: vertical wall, attic, lower floor or window; then, the users have to define the orientation of the different structure. To this purpose, two menus have been set: the first concerns the type of surrounding space and influence, the second multiple choice cell, on the other hand, concern the specific characteristic of the surrounding space.

In the graph below it is highlighted the behaviour of these multiple-choice cells:

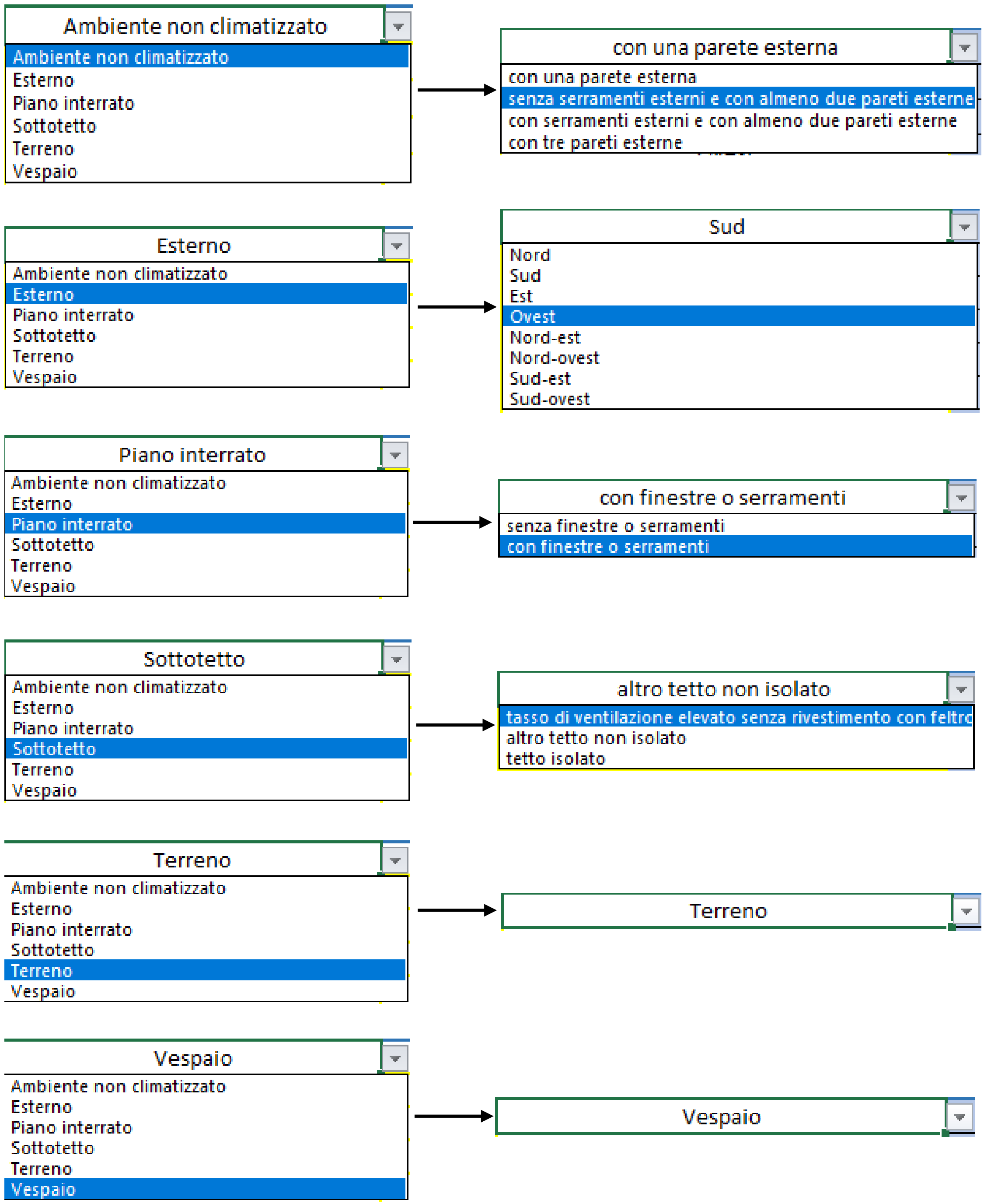


Figure 2-7: Second multiple choices on the basis of the first choice

Once these choices have been taken, the parameter F_T is automatically calculated.

The second parameter to be inserted in order to discover the H_T coefficient is the transmittance of the structure. In case of the presence of a thermal bridge, this parameter can be different from the transmittance U that they discover from the sheet “stratigraphy”, on the contrary, in case of the absence of a thermal bridge, this parameter is equal to U.

This different behaviour is explained by the following formula [7]:

$$U_{struttura} = {(U * Superficie + \ \Psi * Lunghezza\ ponte\ termico)}\Big/{Superficie} \quad [\frac{W}{K * m^2}]$$

Where the parameter Ψ comes from thermal bridge's sheet and "Lunghezza ponte termico" refers to the dimension of the thermal bridge expressed in meter. It hast to be inserted by the users. The third parameter is the surface of the structure that the users have to define in the third column. Then, the tool is able to calculate the global transmission coefficient of the building: H_T.

6. Thermal energy needed

In sheet number six, there is the calculation of the thermal energy necessary in winter and in summer. The formulas that are used differ depending on the thermal season [7].

$Q_{H,nd} = Q_T + Q_V - \eta_{gh} * (Q_{sol} + Q_{int})$ [kWh] in heating season

$Q_{C,nd} = Q_{sol} + Q_{int} - \eta_{gc} * (Q_T + Q_V)$ [kWh] in cooling season

The meanings of the parameters are listed in the table here under:

Parameter	Description	Formula
Q_T	Heat that is exchanged through the envelope of the building	$Q_T = \Delta t * \Delta\Theta * H_T \ [kWh]$
Δt	Number of kilo-hours per month	$\Delta t = 24 * \frac{n_{days}}{1000} \ [kh]$
$\Delta\Theta$	Temperature difference	$\Delta\Theta = T_{int} - T_{ext} \ [°C]$
Q_V	Heat that is exchanged thanks to the ventilation	$Q_V = \Delta t * \Delta\Theta * H_V \ [kWh]$
H_V	Global ventilation coefficient	$H_V = 0{,}34 * n_{air\ changes} * V_{net} \ [W/K]$ [10]
Q_{sol}	Solar supplies	$Q_{sol} = 0{,}2 * I_{sol} * n_{days} * A_{windows} [kWh]$ [10]
I_{sol}	Average monthly irradiance on a vertical plane	This parameter is calculated through the software PV gis [kWh/m^2]
Q_{int}	Internal supplies: people and equipment heat released	$Q_{int} = q_a * \Delta t * A_{conditioned} [kWh]$
q_a	Value of internal supplies	This is a pre-set value that depends on the typology of the building's use [W/m^2]
η_{gh}	Utilization factor of the winter free contributions	$\eta_{gh} = \frac{1 - {\gamma_h}^{a_h}}{1 - {\gamma_h}^{a_h+1}}$

η_{gc}	Utilization factor of the summer free contributions	$\eta_{gh} = \frac{1-\gamma_c{}^{-a_c}}{1-\gamma_c{}^{-a_c-1}}$
γ_h	Ratio between free contributions and losses in heating period	$\gamma_h = \frac{Q_{int}+Q_{sol}}{Q_T+Q_V}$
γ_c	Ratio between free contributions and losses in cooling period	$\gamma_h = \frac{Q_T+Q_V}{Q_{sol}+Q_{int}}$
a_h	Numerical reference parameter for winter season	$a_h = 1+\frac{\tau_h}{15}$
a_c	Numerical reference parameter for summer season	$a_c = 1+\frac{\tau_c}{15}$
τ_h	Reference time constant in winter period	$\tau_h = \frac{C_m * A_{tot}}{3,6 * H_{L,H}}$ [h]
τ_c	Reference time constant in summer period	$\tau_c = \frac{C_m * A_{tot}}{3,6 * H_{L,C}}$ [h]
C_m	Effective thermal capacity per unit of internal surface	- [KJ/m^{2}K]
$H_{L,H}$	-	$H_{L,H} = \frac{Q_{T,H}+Q_{V,H}}{\Delta\theta * \Delta t}$ [W/K]
$H_{L,C}$	-	$H_{L,C} = \frac{Q_{T,C}+Q_{V,C}}{\Delta\theta * \Delta t}$ [W/K]

Table 2-4: Description of the parameters used in order to calculate the thermal energy needed

7. Plants and lighting

In this sheet, we calculate the parameters concerning the emission, regulation, distribution and storage system losses. Moreover, there is also the calculation of the lighting primary energy and the thermal energy need for domestic hot water.

We detail the different sections of this sheet below

- Calculation of the lighting primary energy: the users have to select some features of the lighting system such as daylight factor, type of control system, building typology and type of presence sensors. Thanks to these inputs, the primary energy is calculated according to this formula [11]:

$$EP_{ill} = {}^{E_{ill}}/_{S} * f_p \quad \text{[kWh/m}^2\text{y]}$$

$$E_{ill} = \sum_{i=1}^{12} Will = \sum_{i=1}^{12}(W_{l,m} + {}^{n_{days,i-month}}/_{365} * W_p) \quad \text{[kWh/year]}$$

The meaning of the parameters that appear in the previous formulas are listed in the table below:

Parameter	Description	Formula
f_p	Conversion factor of the primary energy	$f_p = 1{,}95$
S	Usable area	This parameter is found in the sheet number one [m^2]
$W_{l,m}$	Monthly electricity required for lighting	$W_{l,m} = \frac{W_n * F_c * [(t_D * F_o * F_D) + (t_N * F_o)]}{1000}$ [kWh]
W_p	Parasitic electricity	$W_p = 6 * S$ [kWh]
W_n	Total installed power for lighting	$W_n = w_n * S \ [W]$
w_n	Installed power per unit of surface	The values of this parameter depend on the building typology [W/m^2]
F_c	Factor considering the presence of control system for the maintenance of constant lighting values	The value depends on the presence or absence of control system for the maintenance of constant lighting values
t_D	Time when natural light is available	The values of this parameter depend on the building's typology
F_o	Employment factor	This parameter is calculated according to the expected use of the building and the light control system
F_D	Factor correlating the use of total lighting power and the availability of daylight	The values of this factor depend on the availability of daylight
t_N	Time when there is no natural light available	The values of this parameter depend on the building's typology

Table 2-5 Description of the parameters used in order to calculate the lighting primary energy [12]

- Calculation of the thermal energy need for domestic hot water [11]: it is necessary to set up some parameters to estimate the domestic hot water demand.

  First of all, the users have to indicate the medium annual temperature of the external air and the kind of activity; as a result of these last choices the factors “a” and “Nu” are calculate. The "a" factor is the specific daily need according to the kind of activity and its unit of measure is litres per day. The “Nu” factor is a dimensionless parameter which value is linked to the building activity.

  Finally, it is possible to estimate the volume of water required per day:

  $$V_w = \frac{a * N_u}{1000} \text{ [m}^3\text{/day]}.$$

  In order to discover the thermal energy need for domestic hot water, we use the following formula:

  $$Q_{ACS} = \rho_w * c_w * V_w * \left(T_{erogazione} - T_{mean,annual}\right) * {}^{365}/_{1000} \quad \text{[kWh]}$$

  Where ρ_w and c_w are respectively the water density equal to 1000 kg/m^{3}and the specific heat capacity equal to 1,162*10^{-3} kWh/(kg*K).

  The parameter $T_{erogazione}$ is the water supply temperature that is fixed to 40°C.

- Calculation of the emission, distribution and storage system losses for the production of domestic hot water [11]:

  Concerning the emission system, in case of domestic hot water the efficiency of the system is set up to one. On the contrary, in case of distribution system, the users can select some parameters according to the features of this system such as the presence or absence of recirculation ring. Moreover, the users have to indicate also for the storage system if it is integrated in the heat generator or not.

  In this way, the efficiency of the several systems is shown and consequently also the thermal energy need that the heat generator has to supply is calculated according to this formula:

  $$Q_{w,gn\ out} = Q_{ACS} + Q_{l,er} + Q_{l,d} + Q_{l,s} \quad \text{[kWh]}$$

  Where $Q_{l,er}$, $Q_{l,d}$and $Q_{l,s}$ are respectively the thermal losses of the emission, distribution and storage system.

- Calculation of the emission, distribution, regulation and storage system losses for the winter air conditioning system [11] :

The first parameter that the users can discover is the effective thermal energy need. This parameter can differ from the thermal energy need that we have discovered in section six due to the domestic hot water losses.

The distribution losses are partially recovered, the storage losses are recovered only in the case that the storage tank is in an air-conditioned room. This fraction of the distribution and storage losses decreases the thermal energy need, in this way the effective thermal energy need is calculated according to the following formula:

$$Q_{H'} = Q_{H,nd} - (Q_{lrh,d} + Q_{lrh,s}) \text{ [kWh]}$$

Where $Q_{lrh,d}$ and $Q_{lrh,s}$ are respectively the recovered fraction of the distribution losses and the recovered fraction of the storage losses.

At this point, the users have to indicate the feature of the emission, regulation, distribution and storage system in order to discover their efficiency and consequently the thermal losses. Concerning the emission system, the users can select from a list the typology of the terminals such as panels embedded in the ceiling, fan coil, radiators etc.; moreover, they can indicate if there are radiant panels or not, if the answer is yes the users have to fill in some feature of the panels. In this way, the efficiency of the emission system is shown.

As far as it concerns the regulation system, the users have to select the typology of regulation, the feature of the system such as on-off system or proportional to 1°C etc., and the system typology or the type of the emission terminals.

The distribution losses are calculated with a simplified method; in this way, the users have to indicate only the insulation level of the pipes, the type of distribution and the number of floors.

The storage losses are calculated in the same way of the domestic hot water storage losses. The users have to indicate if the storage is internal to the heat generator, if not, they can fill in some features of the storage such as if it was in an air-conditioned room.

It is now possible to find out the thermal energy that the generator has to produce in order to heat the environment.

$$Q_{H,gn\,out} = Q_{H'} + Q_{l,e} + Q_{l,d} + Q_{l,r} + Q_{l,s} \text{ [kWh]}$$

Where $Q_{l,e}, Q_{l,d}, Q_{l,r}, Q_{l,s}$ are the several losses.

- Calculation of the emission, distribution, regulation and storage system losses for the summer air conditioning system [13]:

In order to discover the amount of thermal energy that the cooling machine has to supply in the environment, the users, as in the previous case, have to select the main feature of the emission, regulation, distribution and storage system.

Also in this case, the thermal energy need which the generator has to produce is the sum of the thermal energy need calculated in the section six and the different system losses.

$$Q_{C,gn\ out} = Q_{C,nd} + Q_{l,e} + Q_{l,d} + Q_{l,r} + Q_{l,s} \text{ [kWh]}$$

8. Generation losses

This sheet is split in four sections, each section concerning the different plants' typology according to their function.

- The first section concerns the generation losses related to the cooling machine. According to the UNI/TS 11300-3, the users have to indicate the nominal power of the machine and the energy efficiency ratio or rather the EER at different load factors (when the machine work at 100%, at 75%, at 50 % and at 25 %). In this way, it can be possible build the operating curve of the machine at partial loads. This curve is useful in order to discover the EER according to the load factor of the several months.

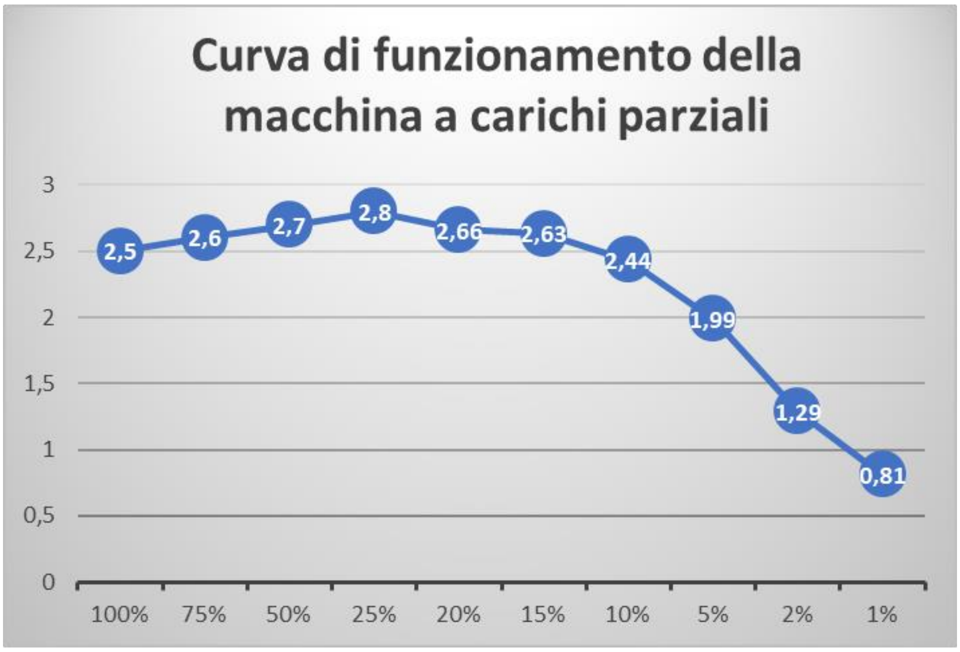


Figure 2-8: Example of the operating curve of the machine at partial loads

The load factor, F, is defined as the ratio between the thermal energy need that is explained in the previous section and the maximum thermal energy that the machine can produce in the same month [13].

$$F = \frac{Q_{c,gn\,out}}{Q_{max}} * 100 \text{ [-]}$$

The EER that the users find out looking at the graph is not the effective EER of the machine, as a matter of fact, it has to be multiplied by a corrective factor which considers the feature of the machine. For this reason, the users are required to select the type of the cooling machine and then, they have to indicate the different temperature according to the machine typology.

At this point, it is possible to find the monthly effective energy efficiency ratio [13]:

$$EER_x = EER(F)_x * \eta \text{ [-]}$$

Where x indicates the several months, EER(F) is the energy efficiency ratio calculated according to the load factor of the x month and η is the corrective factor.

It is now possible to obtain the thermal energy that the cooling machine must produce each month:

$$Q_c = {Q_{c,gn\,out}}/{EER} \text{ [kWh]}$$

In order to calculate the primary energy that is associated to the thermal energy the users have to select the type of energy carrier used such as electricity, natural gas, GPL etc.

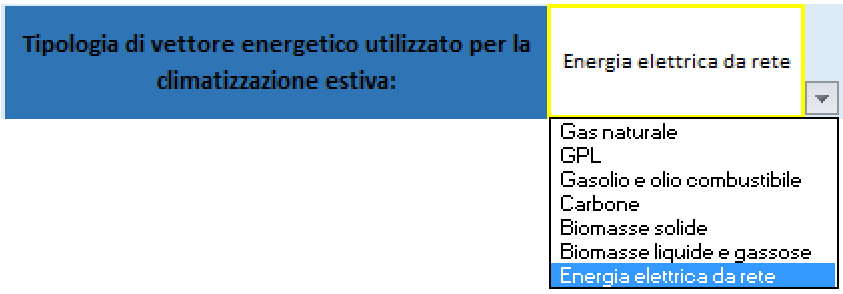


Figure 2-9: Typologies of energy vectors [14]

The primary energy associated to the summer air conditioning is evaluated according to the following formula [15]:

$$E_{P,C} = Q_C * f \text{ [kWh]}$$

Where f is the correction factor in primary energy depending on the choice of the energy carrier.

- In the second section, we find the calculation of the primary energy associated to the domestic hot water.

First of all, the users have to indicate if there is a solar plant.

è presente un impianto solare termico ?	si
Cliccare sulla cella adiacente per essere indirizzato al file di calcolo per gli impianti solari termici	8.1: Solare termico

Figure 2-10: Presence of solar thermal plant

If yes, then they are redirect to the "8.1: Solare termico" file and they have to insert the data input in order to discover the solar fraction or the amount of thermal energy need for domestic hot water that is covered by the solar plant.

Usually, the solar plant is undersized, then there will be a fraction of the thermal energy need that is not covered by the solar plant; in the cases of undersized solar plant or of no presence of solar plant, the users can select the type of plant that produce the resulting fraction, in case of solar plant, and the total thermal energy need for domestic hot water.

The users can choose from a list containing the main typology of plants to produce hot water. The plants that are implemented in this tool are: water heater, boiler, aerothermal heat pumps, geothermal heat pumps *(cfr. Chapter 2, paragraph 2.3: Block B Energy Efficiency)*.

Tipologia di impianto:
Selezionare la tipologia di impianto dal menù a tendina, cliccare sulla cella corrispodente alla tipologia di impianto scelta per essere reindirizzati al file di calcolo
8.2: Scalda acqua
8.3: Caldaia
8.4: Pompa di calore
8.5: Pompa di calore geotermica

Figure 2-11: Plant's typologies

For every choice, there is a file that the users can exploit in order to calculate the monthly efficiency according to the norm UNI-TS 11300-4.

Thanks to the monthly efficiency of the plants, it is possible to find out the effective thermal energy need to produce domestic hot water; then, selecting the type of energy carrier it will be discovered the primary energy associated to the DHW demand [15].

$$Q_w = \frac{Q_{w,gn\ out}}{\eta_{W,monthly}} \text{ [kWh]}$$

$$E_{p,w} = Q_w * f \text{ [kWh]}$$

- The third section concerns the losses of the thermal plants that produce the thermal energy need for winter air conditioning. As in the second section, there is the possibility to indicate if there is a solar thermal plant.

  Moreover, there is the same list of thermal plants; the only difference is the possibility to implement more than one plant.

è Presente più di un impianto dedicato alla climatizzazione invernale?		si
% di copertura fabbisogno impianto 1:		
% di copertura fabbisogno impianto 2:		

Figure 2-12: Possibility to implement more than one plant

  Especially in the case of buildings with high values of thermal energy need for winter air conditioning, it is convenient to install more than one system.

  If the users select as the choice more than one plant, then they have to indicate the coverage percentage of the plant one and plant two. In this way, the thermal energy need is parcelled between the two plants.

  The primary energy associated to winter air-conditioning is calculated according to the following formula [15]:

$$E_{p,H} = \frac{Q_H}{\eta_{H,monthly}} * f \text{ [kWh]}$$

- In the fourth section, we analyse the possibility to insert a photovoltaic plant. To achieve this result, the users have to specify the main features of the system such as the type of panels, the collection area net of the frame and the solar monthly irradiation.

  This last parameter is calculated with the support of the open source software PVGIS [16].

  When the users have entered all the necessary data, the tool calculates the monthly energy produced by the photovoltaic system. At this point, the users can choose where to use the energy produced by the photovoltaic plant; for example, if there is a heat pump, the photovoltaic energy can decrease the consumption of electricity.

  The default option of the tool splits the energy produced by the photovoltaic plant into summer and winter period; in summer period, it decreases the consumption of the cooling machine and in winter period it decreases the consumption of the thermal plant. For this reason, the users have to be careful and in case of thermal plants that use not electricity as energy carrier but for example natural gas or any other energy carrier the photovoltaic energy cannot decrease the consumption of these thermal plants, but it will have to decrease, for example, the lighting consumption.

9. Results

Results sheet is composed of four sections:

- The first concerns the reference building, useful in order to find out the ranges of the energy classes. In fact, in the act "Disposizioni in merito alla disciplina per l'efficienza energetica degli edifici e per il relativo attestato di prestazione energetica, a seguito della DGR 3868 del 17.7.2015" we find the guidelines for the energetic classification. Class ranges are established on the basis of the non-renewable primary energy needs of the reference building. The reference building is a building that has the same shape (area, volume, ratio S/V) of the real building but has pre-set value [17] in terms of:

  -wall transmittance

  -window transmittance

  -attic transmittance

  -floor transmittance

  -efficiency of the distribution system

  -efficiency of the generation plants

  -efficiency of the lighting plants

  In the table below the ranges of the energy classes are shown:

	Classe A4	≤ 0,40 $EP_{gl,nren,rif}$
0,40 $EP_{gl,nren,rif}$ <	**Classe A3**	≤ 0,60 $EP_{gl,nren,rif}$
0,60 $EP_{gl,nren,rif}$ <	**Classe A2**	≤ 0,80 $EP_{gl,nren,rif}$
0,80 $EP_{gl,nren,rif}$ <	**Classe A1**	≤ 1,00 $EP_{gl,nren,rif}$
1,00 $EP_{gl,nren,rif}$ <	**Classe B**	≤ 1,20 $EP_{gl,nren,rif}$
1,20 $EP_{gl,nren,rif}$ <	**Classe C**	≤ 1,50 $EP_{gl,nren,rif}$
1,50 $EP_{gl,nren,rif}$ <	**Classe D**	≤ 2,00 $EP_{gl,nren,rif}$
2,00 $EP_{gl,nren,rif}$ <	**Classe E**	≤ 2,60 $EP_{gl,nren,rif}$
2,60 $EP_{gl,nren,rif}$ <	**Classe F**	≤ 3,50 $EP_{gl,nren,rif}$
	Classe G	> 3,50 $EP_{gl,nren,rif}$

Figure 2-13: Energetic classification [5]

- In the second section, there is the energy class calculation of the real building.

  To obtain that, the many indexes referred to the several types of services are calculated according to the following formulas [15]:

$$EP_C = \frac{E_{p,c}}{S} \, {kWh}/{m^2 * year}$$

$$EP_W = \frac{E_{p,w}}{S} \, {kWh}/{m^2 * year}$$

$$EP_H = \frac{E_{p,H}}{S} \, {kWh}/{m^2 * year}$$

$$EP_{ILL} = \frac{E_{p,ill}}{S} \, {kWh}/{m^2 * year}$$

  Then, it is possible to calculate the global primary energy associated to the building:

$$EP_{gl,tot} = EP_C + EP_W + EP_H + EP_{ILL} \quad {kWh}/{m^2 * year}$$

  In case of the reference building or of the real building, some indexes are left out in order to simplify the calculation. These indexes are the following: the primary energy associated to the ventilation service and the primary energy associated to the transport service.

  Once the global primary energy of the building has been calculated, it is possible to discover the energy class. In order to represent intuitively the class, a dashboard graph is implemented.

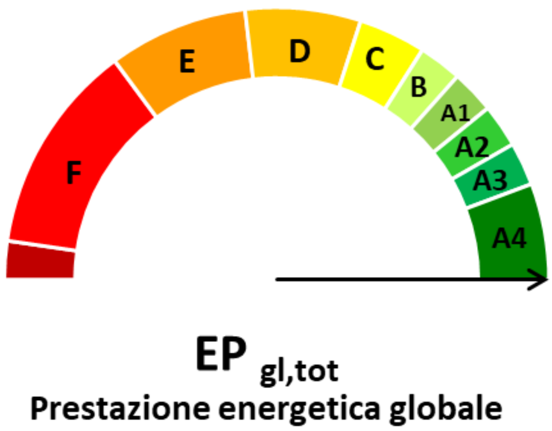


Figure 2-14: Dashboard graph

- In the third section, the users can find the parameters that the building has to respect in order to be a near-zero energy building. These parameters are described in the paragraph "*1.3 The concept of NZEB: Nearly-Zero Energy Buildings*".
  In this tool, the values of these parameters refer to a building situated in the climatic zone E; if the users have to simulate the energy performances of a building situated in other climatic zones they have to change these values according to the regulations.
- In the fourth section, the users can discover if the building is an NZEB building; to explain this issue more clearly a table shown here under represents the different needed requirements.

RISULTATI	
L'edificio rispetta i requisiti sul coeff. Medio globale di scambio termico?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione invernale?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione estiva?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la produzione di ACS?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione invernale?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione estiva?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la produzione di ACS?	NO
L'edificio rispetta i requisiti sull'indice di prestazione energetica?	SI
L'edificio rispetta gli obblighi sull'integrazione con fonti rinnovabili?	NO
L'edificio rispetta gli obblighi sulla potenza elettrica da fotovoltaico?	SI

L'edificio non è Nzeb

Figure 2-15: NZEB check table

If all requirements are respected the building is NZEB and in this case, automatically under the table will appear the wording "L'edificio è NZEB"; on the contrary, will appear "L'edificio non è NZEB".

At this point, the users are able to understand the energetic behaviour of the building and looking at the various parameter and/or energetic index they can choose the more appropriate energy efficiency scenario; in order to do that they can redirect to the block B.

At the end of the sheet nine there is a command button that is useful to create the file that will be used by the block B. Then, before closing the block A, the users have to click on this button and the "Block A-to be" is automatically created.

2.3 Block B: Energy Efficiency

The block B has been conceived to optimize the energetic parameters of the examined building; in this section the users can select one or more energy efficiency interventions.

The energy efficiency measures that are considered are the following:

-Geothermal heat pump

-Solar thermal plant

-Photovoltaic plant

-BMS Building Management System

-Building orientation

Moreover, the users can combine more than one energy efficiency interventions in order to create an energy efficiency scenario. In this way, not only the different impacts of the single energy efficiency intervention but also the ones of a set of measures can be compared .

Another important aspect of this block is related to the cost of investment of the different interventions; in fact, the results provided by block B are the consumption reduction, expressed in kWh/m^2, the new energetic class of the building, the NZEB check after an energy efficiency scenario and the initial investment cost.

The block B operates with a series of external files; every energy efficiency measures are implemented in separate files.

Moreover, in order to calculate the consumption reduction, the new energetic class and the NZEB check, the block B works with a backup file called "BlockA_to-be" that is the copy of the block A created thanks to the bottom in its sheet nine. In this way, depending on the type of intervention chosen, the new parameters are calculated keeping the other characteristics of the building fixed. This is possible by the implementation of different macro or rather short programmes that are used to automate some tasks.

In this way the block A remains unaffected and the energy efficiency interventions are implemented in the copy of the block A; every time that an energy efficiency measure is chosen, the programme is able to open the backup file, to change the appropriate values, to calculate the new consumption and then to close the backup file without any saving operation. So, it is possible to evaluate several energy efficiency measures independently because the backup file does not keep the memory of the previous intervention.

In every sheet of the block B there are instructions that the users have to follow for avoiding mistakes.

The following flowchart summarize the operation mode of block B:

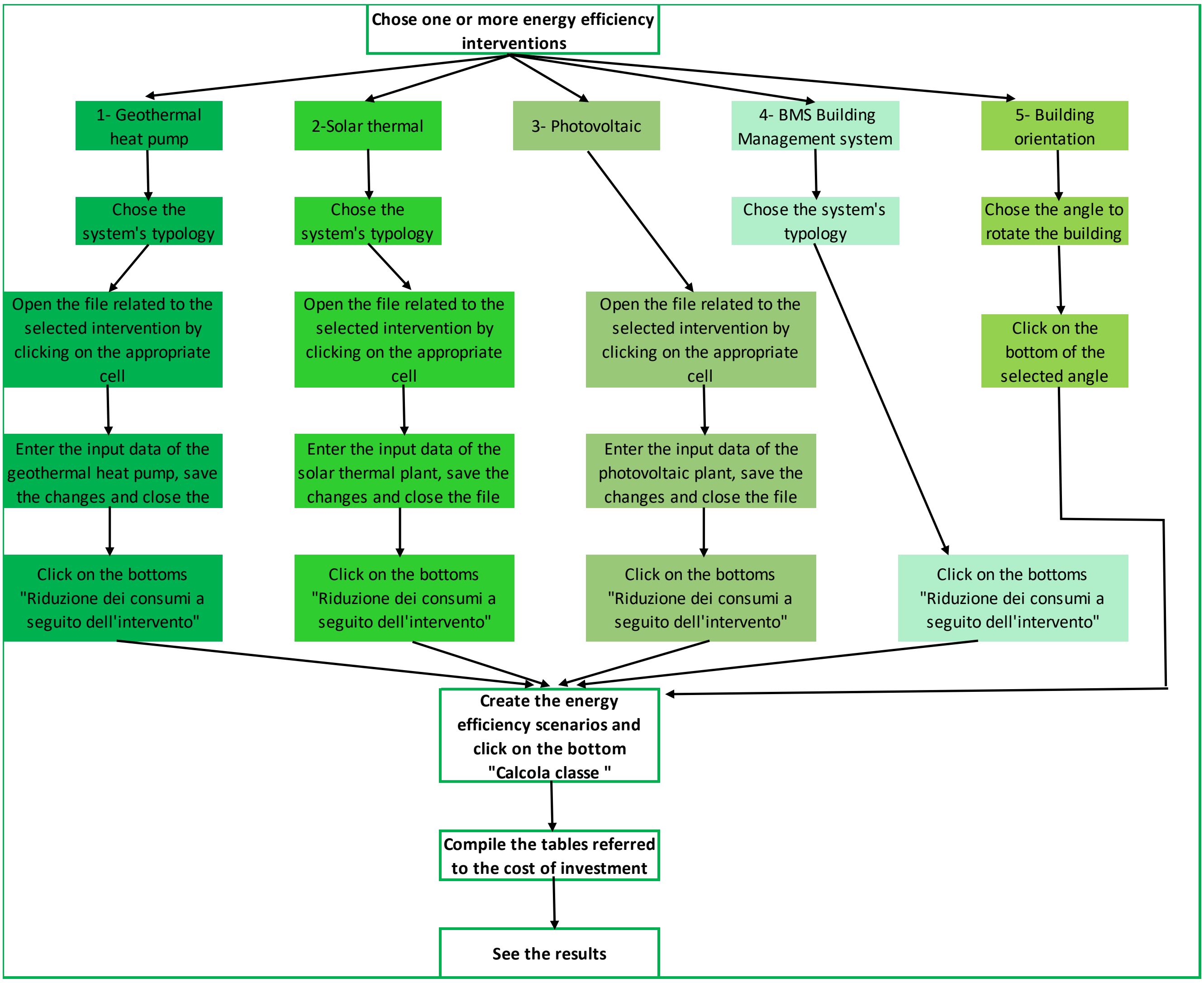


Figure 2-16: Mode of operation of the block B

The block is split into seven sheets; the explanation of these sheets is shown in the graph below:

#	Descrizione fogli:	
1	**Pompa di calore geotermica**	Valutazioni sulla riduzione dei consumi
2	**Solare Termico**	Valutazione sulla riduzione dei consumi
3	**Fotovoltaico**	Valutazione sulla riduzione dei consumi
4	**BMS-Building Management System per illuminazione interna**	Valutazione sulla riduzione dei consumi
5	**Orientamento building**	Valutazione sulla riduzione dei consumi
6	**Scenari di ottimizzazione**	Combinazioni dei vari interventi di EE
7	**Computo metrico**	Valutazione degli investimenti per i vari scenari
8	**Confronto scenari**	Confronto dei vari scenari

Table 2-6: Explanation of the Block B tool's sheets

It is right and proper at this point explain in detail every sheet:

1. **Geothermal heat pump:** the first energy efficiency intervention is the installation of a geothermal heat pump.

   First of all, the users have to indicate the type of system; for this purpose, there is a multiple-choice cell with three options: only heating system, heating and domestic hot water system and heating and air-conditioning system.

   After this choice a table, that compares the consumption and the energy classes before and after this intervention, appears.

Riduzione dei consumi a seguito dell'intervento:	
Consumi to be:	0,00 kWh/m^2
Consumi as is:	0,00 kWh/m^2
Classe energetica to be:	A4
Classe energetica as is:	A4
Δconsumi:	0,00 kWh/m^2

Table 2-7: Table that compares the consumption as-is and to-be

In order to calculate the consumption reduction, the users have to fill the geothermal heat pump file with the features of the selected heat pump; to do that they have to click on the proper cell and then they are redirected to the geothermal heat pump file.

This file is divided in six sheets; the first of these is the data input sheet. The users have to indicate the features of the heat pump such as the power generation and the COP (coefficient of performance) at different temperatures. Moreover, other parameters such as the load factor, the climatic load factor, the thermal power, the COP at full load and the COP at partial load have to be put for different reference temperatures.

In the figures below, the data input tables are shown [18]:

Dati P.D.C a pieno carico		Φg	Φg	Φg	COP	COP	COP
		T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C
		35,00	45,00	55,00	35,00	45,00	55,00
	-5,00						
	0,00						
	5,00						
	10,00						

Figure 2-17: Data input of the heat pump at full load

Dati da fornire per determinazione COP_{PL} T mandata 35°C					
	$T_{designh}$	A (T_{bival})	B	C	D
Te	-10	-5	0	5	10
PLR					
DC					
CR					
P					
COP (carico parziale)					
COP' (pieno carico)					
f_{COP}					

Figure 2-18: Data input table

This first sheet also shows a table for the thermal energy needs of the building; these last parameters are extrapolated by the block A.

In the second sheet there is the calculation of the ground temperatures based on the ground features and the depth [19]. The users have to complete this sheet in order to find out and to understand how the temperature varies depending on the depth.

The third sheet shows two tables that summarize the thermal energy needs for winter air-conditioning and the thermal energy needs for domestic hot water; in this sheet the users have to indicate the type of system and then if the heat pump is used only for the heating system or for both domestic hot water and heating system.

Fourth and fifth sheet present the output of this file or rather the calculation of the monthly COP in case of heating system (sheet #4) and domestic hot water system (sheet #5).

In the last sheet, there is the calculation of the COP interpolated with the return water temperature, useful in the monthly COP calculation [18].

The table below summarizes the features of the geothermal heat pump's file:

#	Sheet's name	Description
1	Data input	The users have to put the data input of the selected geothermal heat pumps, the days of the heating season and the project temperature. There are two tables that summarize the consumption both for heating and DHW [18].
2	Ground Temperature	The users have to put the depth of the heat exchangers and the features of the ground. There is a table that shows the ground temperature variations in the months according to the typology of ground and the depth [19].
3	Energy need	In this sheet the only parameter that the users must insert is the type of system. There is a table in which the return temperature of

		the heat pump is calculated.
4	PDC	The users do not enter any data. In this sheet there is the calculation of the monthly COP for a heat pump used to heating system. It is the first output of this file [18].
5	PDC DHW	The users do not enter any data. In this sheet there is the calculation of the monthly COP for a heat pump used to DHW system. It is the second output of this file [18].
6	PDC support	The users do not enter any data. In this sheet there is the calculation of the COP interpolated with the return water temperature [18]

Table 2-8: Geothermal heat pump file description

After completing this file, the users have to close and save it. Then they can click on the bottom **"Riduzione dei consume a seguito dell'intervento"** in order to discover the positive impact of the geothermal heat pump installation.

2. **Solar thermal plant:** this sheet evaluates the convenience of a solar thermal plant.
   Such as in the geothermal heat pump sheet the users have to select the system's typology and open the file connected to solar thermal plants.
   The features that the users must indicate are those that concern the collector typology and the auxiliary heater [18].
   Moreover, it is necessary insert the solar irradiance values on the collector plane (W/m^2); these values can be extrapolated from the opensource software PVgis [16].
   After entering all the data, the file is able to calculate the fraction of the thermal energy needs that the solar plant can cover.
   In order to clarify the behaviour of the solar plant a graph is implemented at the end of the file. The graph is shown below:

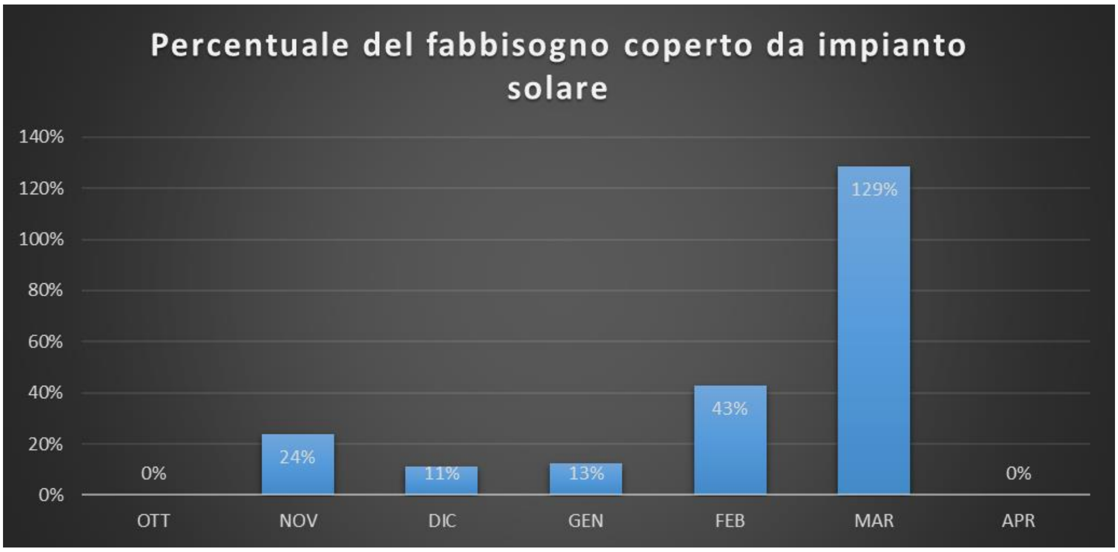


Figure 2-19: Percentage of the thermal need that the solar plant can cover

After that, such in the case of the geothermal heat pump, the users must save and close the file and then click on the bottom to discover the consumption reduction and the new energetic class of the building.

3. **Photovoltaic:** the third energy efficiency measure that is considered is the installation of a photovoltaic plant. The users can open the file that concern photovoltaic plant by clicking on the specific cell; then they have to fulfil the features of the selected panels.

   A multiple-choice cell is used to choose the typology of photovoltaic; the different options are shown in the figure below [18]:

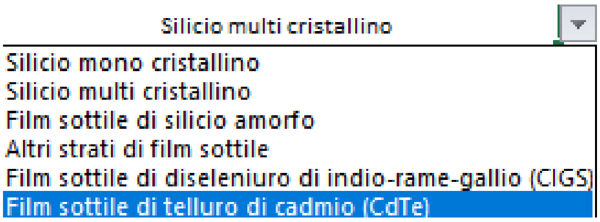


Figure 2-20: Photovoltaic panels typologies

Moreover, they have to put also the collection area of the photovoltaic system and the values of the monthly solar irradiance on the collector's plane.

At this point, the file is able to calculate the monthly energy that the photovoltaic plant can produce.

The consumption reduction and the new energy class are calculated, as in the other sheets, by clicking on the specific bottom.

4. **BMS – Building Management System:** in this sheet some BMS systems for the interior lighting control are considered.
   By using these systems, the interior lighting primary energy can be drastically reduced and, especially in tertiary building, this has a significant impact on the global primary energy.
   The users can choose, from a list, three different typologies of BMS systems:
   -Presence sensors
   -Photosensors
   -Presence sensors and photosensors
   Based on this choice the consumption reduction and the new energy class are calculated automatically [12].

5. **Building orientation:** this is a particular energy efficiency intervention that is useful only in the case of project evaluations. Building orientation means that the users can rotate the building and then change the orientation of the various walls. Obviously, these evaluations can only be done before the construction of the building and then in a preliminary project phase. It is clear that the orientation of the walls influences a lot the energetic consumption; if the building has a great number of windows south oriented, the solar supplies are greater with respect to a building that have the same windows but north oriented. Then this behaviour will be a benefit in winter period because higher solar supplies mean lower energetic consumption for heating, but it will be a drawback in summer period because it means higher energetic consumption for air-conditioning.
   The purpose of this sheet is to find a meeting point between the two performances. The users have to modify the standard building according to the orientation and the planimetry of the examined building. To do that in this sheet there is a specific window in which the users can modify a pre-set rectangle.
   The drawing does not influence the results, but it is useful to understand how the building rotate if the users select, for example, 270 degrees or 45 degrees.
   Moreover, to clarify how the orientation changes according to the degree chosen there is a table that explain the variation of the cardinal points.

The table and the window in which the users can draw the building are shown below:

Rotazione	Orientamenti pareti
45°	S-->S-O, S-O-->O, O-->N-O, N-O-->N, N-->N-E, N-E-->E, E-->S-E, S-E-->S
90°	S-->O, S-O-->N-O, O-->N, N-O-->N-E, N-->E, N-E-->S-E, E-->S, S-E-->S-O
135°	S-->N-O, S-O-->N, O-->N-E, N-O-->E, N-->S-E, N-E-->S, E-->S-O, S-E-->O
180°	S-->N, S-O-->N-E, O-->E, N-O-->S-E, N-->S, N-E-->S-O, E-->O, S-E-->N-O
225°	S-->N-E, S-O-->E, O-->S-E, N-O-->S, N-->S-O, N-E-->O, E-->N-O, S-E-->N
270°	S-->E, S-O-->S-E, O-->S, N-O-->S-O, N-->O, N-E-->N-O, E-->N, S-E-->N-E
315°	S-->S-E, S-O-->S, O-->S-O, N-O-->O, N-->N-O, N-E-->N, E-->N-E, S-E-->E

Table 2-9: Wall orientation according to the degrees of rotation

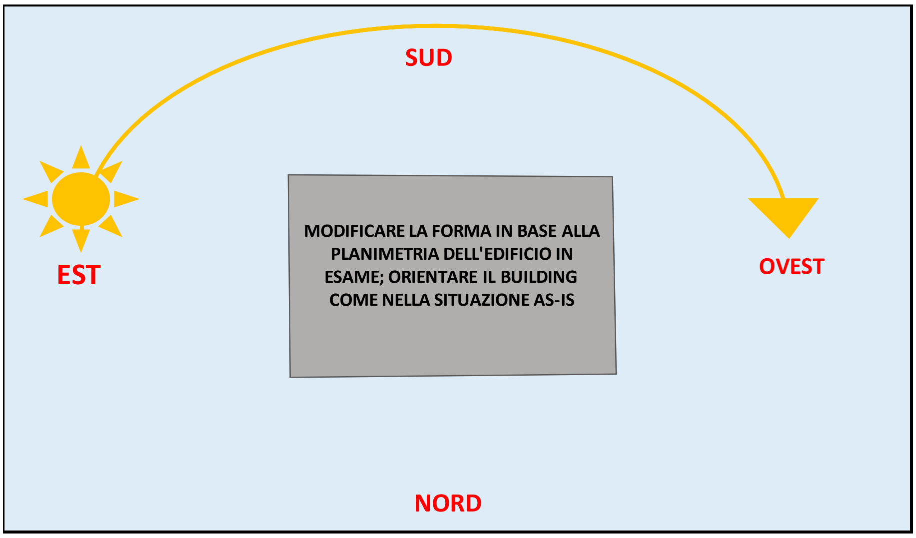


Figure 2-21: Window to draw and orient the building as-is

Thanks to the implementation of some VBA macro the users can discover the change of the energetic consumption according to the orientation.

The programmes are able to open the backup file, find the orientation of the different walls and windows and, according to the selected rotation degrees, change these orientations; after that the thermal energy need in winter and in summer are evaluated.

The example below clarifies this process.

The user wants to discover the change of the energetic consumption in case the building is rotated of 45 degrees then he clicks on the bottom “Rotazione: 45°”; the macro referred to 45 degrees start. The “BlockA_to-be” is opened, in the sheet “Caratteristiche edificio” the macro is able to control how the walls and windows are oriented. To rotate the building of 45 degrees the macro changes north with north-east, south with south-west, west with north-west etc. After that the new thermal energy needs in winter and in summer are copied and transposed in the specific table of the block B referred to a rotation of 45 degrees *(cf. Table 2-10)*.

The macro closes the backup file without save and then rotate the shape of the building in the specific window *(cf. Figure 2-21).*

ROTAZIONE: 45°			
Tipo:	**TO-BE**	**AS-IS**	**Riduzione/aumento:**
Consumi invernali	0,0	0,0	**0,0**
Consumi estivi	0,0	0,0	**0,0**
Energia primaria	0,0	0,0	**0,0**

Table 2-10: Table that compares the consumption before and after the rotation of 45 degrees

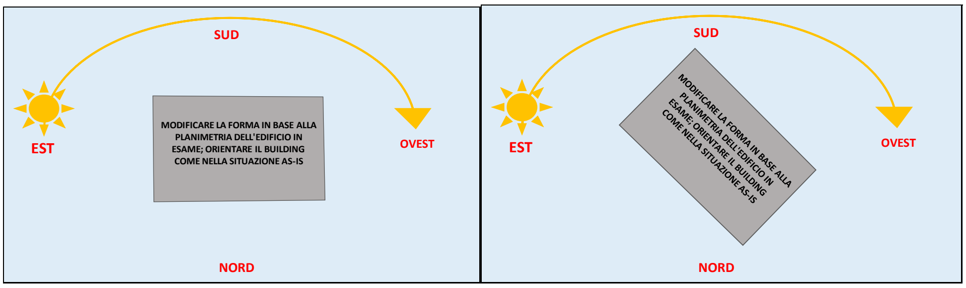


Figure 2-22: Building shape rotation

6. **Energy Optimization scenarios:** in sheet #6 the users have the possibility to create scenarios by combining different energy efficiency measures.
   In order to do that there are some multiple-choice cells in which are represent the interventions above described.
   After they have chosen different combinations the consumption reduction and the new energetic class are automatically calculated by clicking on the bottom "Calcola classe".

SCENARIO 1		
Tipologia di interventi		Riduzione consumi (kWh/m^2)
BMS illuminazione	Fotosensori	0
Solare termico	Per climatizzazione invernale	0
Fotovoltaico		0
Pompa di calore geotermica	Per climatizzazione invernale e ACS	0
TOTALE:		**0**

Table 2-11: Table of energy efficiency scenario n° 1

7. **Scenarios' initial investment:** in this sheet the users have to complete the financial cost for the scenarios chosen. There are pre-set tables in which they can insert the description of supplies or activity, the quantity and the prices. In this way the initial investment, expressed in €, for a specific scenario is calculated.

8. **Scenarios' comparison:** the positive impacts of the different scenarios chosen, in terms of consumption reduction, energetic class and NZEB check, is summarized in this sheet. There is a table that takes into account all these positive effects and also the initial investments; these results are the output of the block B that are useful for the block D or rather the economic analysis.

Scenario:	Riduzione consumi (kWh/m^2):	Classe energetica as-is:	Classe energetica to-be:	Verifica nZEB:	Costo inerventi (€) :
Scenario 1	0	A4	A4	NO	€ 0,00
Scenario 2	0	A4	A4	NO	€ 0,00
Scenario 3	0	A4	A4	NO	€ 0,00
Scenario 4	0	A4	A4	NO	€ 0,00
Scenario 5	0	A4	A4	NO	€ 0,00

Table 2-12: Scenario comparison table

2.4 Block C: Energy price background

In the following paragraphs the calculation of the electricity prices is discussed and explained.

2.4.1 The liberalization of the energy market in Italy

The purpose of these chapter is to understand and highlight the role of the energy price when ones evaluate an energy efficiency scenario.

It is right and proper, at this point, explain how the energy price is calculated in Italy.

In 1999 the Italian energy market was liberalized; before this date the market was managed by a single national entity, ENEL.

The liberalization of the market allowed to create competition between the energy producing companies; this competition translates into an increase of the efficiency of the productive plants in order to reduce the marginal cost for the production [20].

Through the decree called "Decreto Bersani", issued on 16th March 1999, it is established that the production, importation, exportation, purchase and sale activities are completely free. Instead the transmission and dispatching activities are reserved to the country.

Production is a liberalized activity and the electricity generated can be self-consumed, sold through bilateral contracts, sold to the network as surplus or sold via the power exchange, which started operating in April 2004.

The transmission consists in the transport of electricity on the high voltage lines (35 kV <V <150 kV) and very high voltage lines (V> 150 kV), whose management has been entrusted to the Terna company. The distribution activity is inherent to the transport and supply of electricity on medium voltage lines (1 kV <V <35 kV) and low voltage lines (V <1 kV) and is entrusted by MISE ("Ministero dello Sviluppo Economico") to distributors through thirty years concessions.

GME ("Gestore Mercati Energetici") is the society entrusted with the management of the power exchange. The power exchange is a system that concerns offers for sale and purchase of the electric energy. In compliance with other commodities, in the power exchange no real products or consumer goods are sold; the promise of producing a certain amount of energy in a specific hour of a specific day is sold [20].

Through the power exchange the PUN ("Prezzo Unico Nazionale") is evaluated; this price is expressed in €/MWh and it is equal to the weighted average consumption price. The estimation of this price takes into account the market trend of the day before (MGP- "Mercato del Giorno Prima").

These data can be consulted on the GME website.

2.4.2 MGP "Mercato del Giorno Prima" & PUN "Prezzo Unico Nazionale"

The MGP ("Mercato del Giorno Prima") is a market for the wholesale electricity exchange.

Time blocks of electric energy are traded for the day after; in this way prices, quantities exchanged, insertion and withdrawal schedules are established for the day after. In this market there are selling offers and purchase offers.

The selling offers express the availability to sell a certain quantity of energy at a specific unit price.

The purchase offers express the availability to acquire a certain quantity of energy at a specific unit price. The purchase offers, which are accepted, are valued at PUN "Prezzo Unico Nazionale". This price is a weighted average consumption price and it is evaluated every day for every hour through a market algorithm [21].

In fact, the market algorithm accepts the offers in order to maximize the value of trade in compliance with the transit limit.

The transit limit are physical limits for energy transit between two zones; the zones are portions of transmission lines that are established by electrical system. These limits are defined by a model that take into account the balance between consumption and electric generation. These limits are signaled by Terna every day at the MGP.

Thanks to the market algorithm, all the selling offers are sorted by increasing price in an aggregate bid curve; in the same way all the purchase offers are sorted by decreasing price in an aggregate demand curve. The intersection between the two curves defines: the total quantity exchanged, the price of balance, the accepted offers and the schedules of the insertion and withdrawal; those are obtained such as the sum of the accepted offers, in the same hour, at the same point of offer [21]. The points of offer can be single generation or consumption unit or aggregates of production or consumption units.

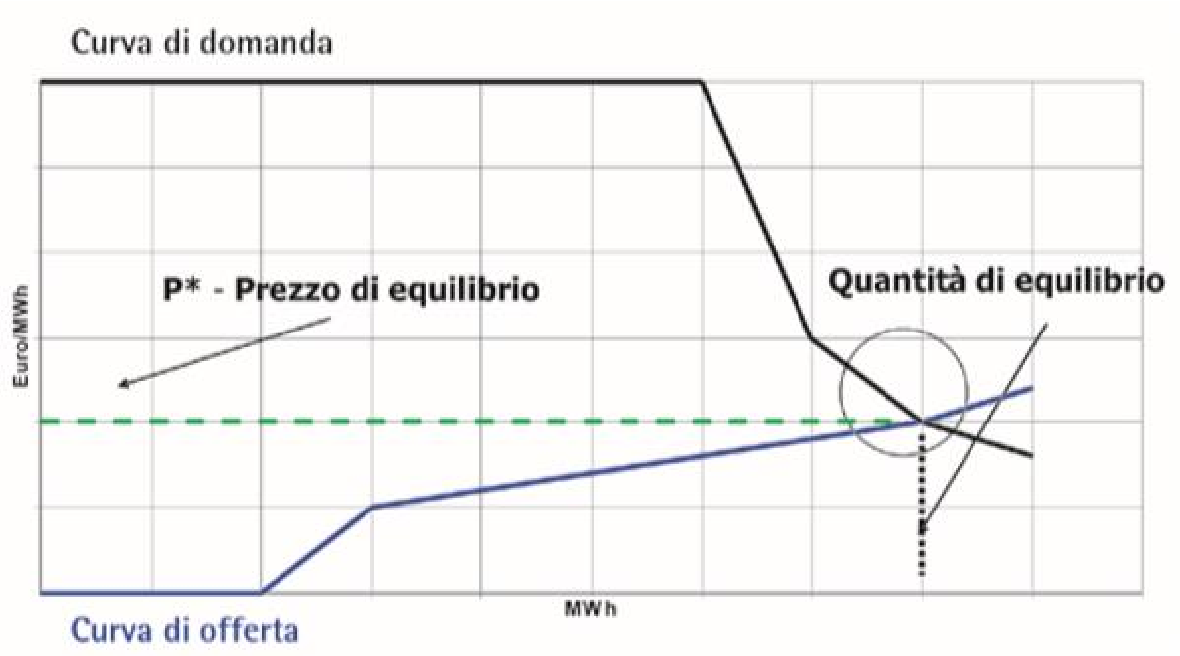


Figure 2-23: Demand and supply curves [21]

It is right and proper, at this point, explain in detail how the PUN is calculated.

If the energy flows on the network deriving from the insertion and withdrawal schedules don not infringe any transit limits the balance price is equal in all the zones and it is equal to P*.

The accepted offers are those with no lower purchase price with respect to P* and with no higher selling price with respect to P*.

If at least one limit is infringed, the algorithm splits the market into two zones: an export zone that includes all the zones that are upstream of the limit and an import zone that includes all the zones that are downstream of the limit. After that the algorithm repeat the process in the two zones.

The output is a balance price that is referred to a certain zone: Pz. If further limits are infringed the algorithm repeat the market splitting.The average of the zonal consumption weighted Pz is the PUN "Prezzo Unico Nazionale" [21].

The accepted offers and the PUN can be consulted in the GME website:

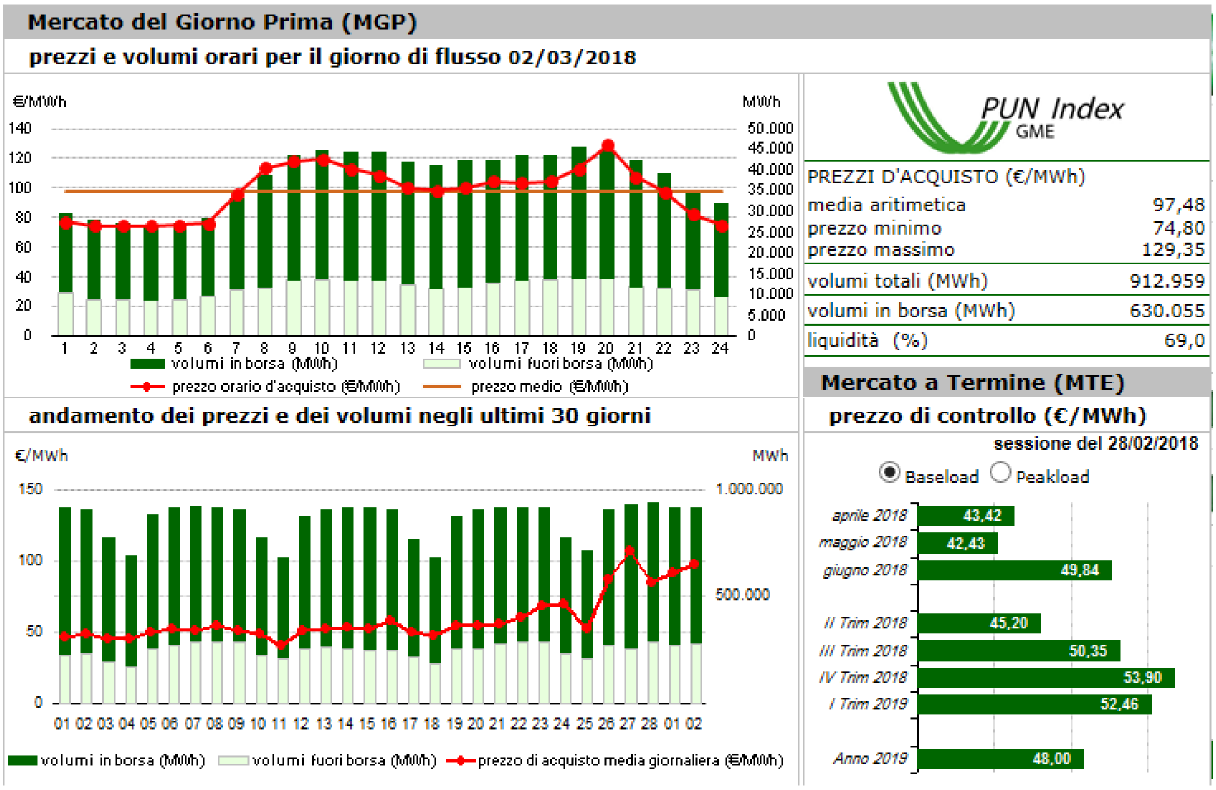


Figure 2-24: MGP & PUN [22]

The PUN can be sold in two different ways [23]:

- "PUN in fasce": in this case there are only three different prices that are referred to the consumed kilowatt-hour in three time slots; the first time slots is F1 or rather the peak hours range and this occurs from Monday to Friday from 8 am to 7 pm.
  The second time slot is F2 or rather the intermediate hours and this occurs from Monday to Friday from 7 am to 8 am and from 7 pm to 11 pm.
  The last slot is the off-peak hours, and this occurs from Monday to Friday from 11 pm to 7 am and on Sunday.
  Then, if the users chose this option they pay the energy with three different fixed prices according to the time slots.
- "PUN orario": the consumer pays only one price for all kilowatt-hour consumed during the month. This price is a personalized price; in fact, it is obtained by the consumption hourly curve of the utilities.
  The consumption hourly curve is a curve in which there are listed the consumption hour per hour on a monthly based.
  In this way the average price is the hourly PUN multiplied by the real consumption of the utilities.

In the following paragraphs and in the block C of the tool a "PUN orario" offer is considered.

2.4.3 The purchase price of energy

To obtain the final price of energy, or rather the purchase price, for the PUN more quantities must be added. These quantities regard the price for transmission, dispatching, system charges etc.

The purchase price is calculated by adding up four quantities: the fixed quote, the power quote, the variable quote and the price for excise.

The quantities above mentioned are explained in the following lines:

1. **Fixed quote:** the fixed quote, expressed in €/y, considers the price of marketing and sales (PCV), the dispatching component (DISPbt), the price for transport and counter management and the system charges.

   The PCV covers the fixed costs of commercial management of customers that are supported by the operators of the free market.

   The dispatching component returns to the customers, who are entitled to the enhanced protection service, the difference between the revenue from the PCV component and the commercial management costs incurred by the suppliers of the enhanced protection service.

   The price for transport and counter management includes three terms: DIS, MIS and UC6 where DIS and MIS are the costs for dispatching and measure and UC6 is related to the charges for the improvement of service continuity.

   The system charges instead include two terms: Asos and Arim; Asos is related to the general costs concerning the support of renewable energy and cogeneration; Arim includes all the other system charges such as financing of territorial compensation measures for sites hosting nuclear power plants and nuclear fuel cycle plants and financing of research and development activities of general interest for the electricity system. [24]

2. **Power quote:** the power quote, expressed in €/(kWh*y), is the amount to be paid in proportion to the amount committed, even in the absence of energy consumption. It is referred to the maximum power, value established for every month related to the type of voltage: low voltage utilities, medium and high voltage utilities. Moreover, it takes into account also the price for transport and counter management and the system charges referred to the power in kW.

3. **Variable quote:** the variable quote is the sum of three contributions: energy matter, transport and counter management and system charges, each weighted on the basis of the monthly consumption of the utilities.

   The price for energy matter includes the PUN, the price for dispatching (PD) and the equalization component (PPE); also in this case all these are weighted on the monthly consumption.

4. **Price for excise:** this price is correlated with the consumption of the utilities; there are some pre-set values on the basis of the kWh that are consumed.

The purchase price of energy is the sum of the contributions above mentioned; to clarify the role of the several quantities, a graph below shows the percentage composition of the energy price:

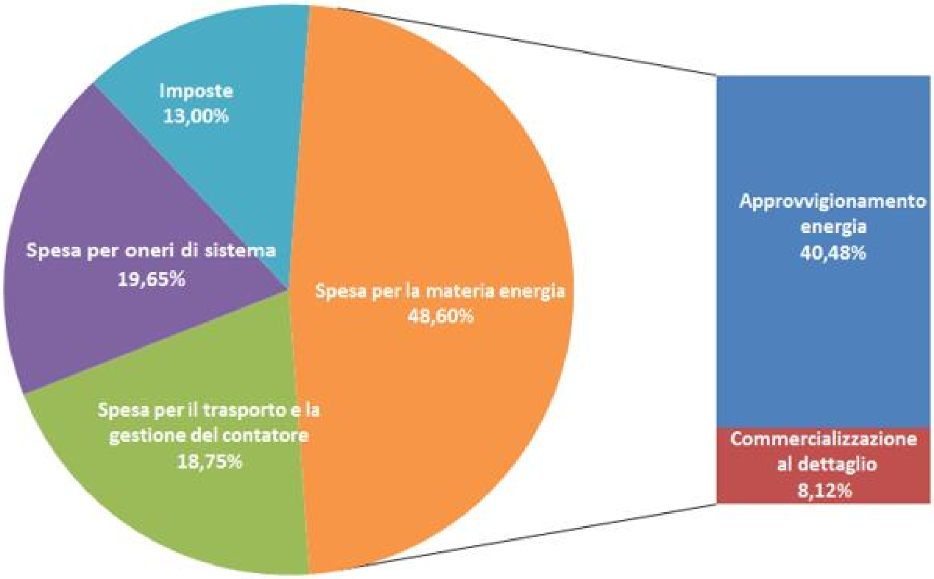


Figure 2-25: Percentage composition of the energy price [25]

2.4.4 Block C: Energy prices Scenarios

The positive impact, in an economic point of view, of an energy efficiency scenario strongly depends on the energy price. For this reason, in the block C of the tool there are three different scenarios of the energy prices: forward, best and worst.

The forward scenario is built considering the forward from 2018 to 2024 of the PUN.

There are many sheets where it is calculated the average weighted on the consumption of the PUN for each month and for each year.

In these sheets the users have to insert the hourly consumption of the examined building and automatically the tool is able to calculate the monthly PUN.

The hypothesis is that the hourly consumption of the building will not change in the future years; but it is a good approximation especially when tertiary building, whose function is always the same, are considered.

In order to understand how the PUN varies in the same months over the years there are some graph; an example is reported below:

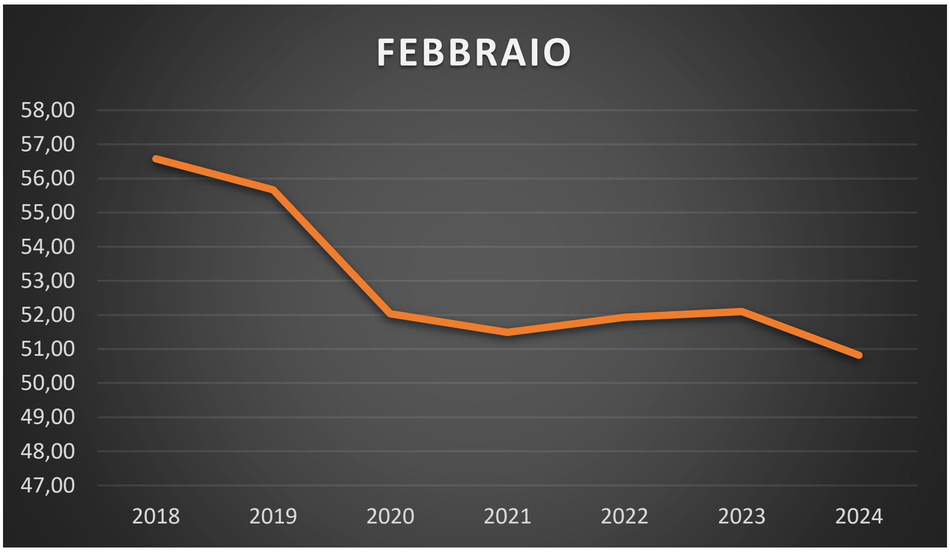


Figure 2-26: PUN values from 2018 to 2024 in February

In the last sheet of the block C there is the calculation of the final price of electricity; this is also based on the hourly consumption of the building.

The tool is able to calculate a yearly average PUN price that is the average of the PUN weighted on the consumption of each hour of each month.

These results are summarized in the sheet called "Scenari dei prezzi dell'energia"; a table in which there are the PUN price and the final price is shown and there is also a graph that shows how the PUN varies during the years.

Anno	PE MEDIO ANNUALE €/MWh	P.TOT MEDIO ANNUALE €/MWh
2018	**52,07842628**	**157,2814224**
2019	**49,30670323**	**154,2214402**
2020	**47,53117584**	**152,3258841**
2021	**47,30556263**	**152,012181**
2022	**47,71406764**	**152,4631705**
2023	**47,99600681**	**152,7744313**
2024	**46,4081496**	**151,021437**
2025	45,55582299	150,0804684
2026	44,86120402	149,311301
2027	44,16658505	148,5421336
2028	43,47196609	147,7729662
2029	42,77734712	147,0037987
2030	42,08272815	146,2346313

Table 2-13: Table of the PUN and of the final price of electricity

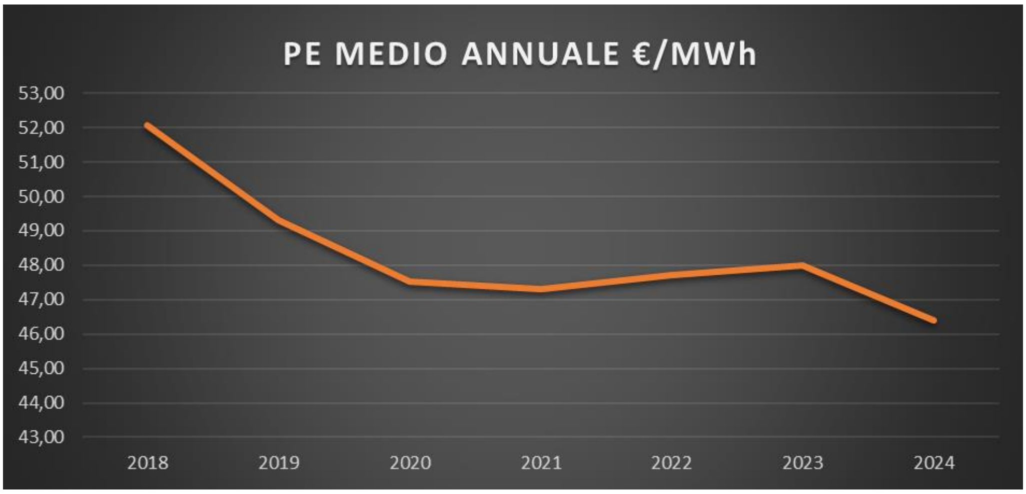


Figure 2-27: PUN variations during the years

As it can be seen in the table above, the electricity prices are calculated until 2030 even if the PUN forward are known only until 2024; the prices after 2024 have been estimated thank to a linear interpolation of the previous ones.

In addition to the forward scenario also the best and worst scenario are defined.

The best scenario is the one in which the energy prices reach the maximum values. Thanks to the historical values of the PUN from 2010 to 2017, it is possible to hypothesize that in 2018 the PUN is equal to the maximum values of the PUN in the years. For the other years the price was built making a difference between the forward valued of 2018 and the best values of 2018; for each year after 2018 the price is the sum of the difference and values of forward PUN.

In the same way the worst scenario was built. In this case the difference between the values of the forward PUN in 2018 and the minimum values of the PUN in the years 2010 to 2017 is subtracted.

The outputs of this block are the €/MWh for every year and in the three cases.

2.5 Block D: Economic analysis

In the block D there is the economic analysis of the different scenarios that the users have choose in the block B.

The input data of this block are the consumption reduction, the new energetic class of the building, the NZEB check, the investment, that are all outputs of the block B, and the energy price that is the output of the block C.

The block is organized in some sheets; the first sheet it is a summary of the results of the several scenarios. There is a table in which all the outputs of the previous blocks are shown.

Moreover, there are also three table that refer to the forward energy prices, best energy prices and worst energy prices.

In the second sheet there is an assessment of how the real estate and the rent of the building change as a result of the energy efficiency interventions.

In order to make an accurate evaluation the users have to insert the typical values of rent and sale of a building located in the same zone of the examined building.

These values can be find through the "Agenzia delle Entrate" website [26]. In this way the increase in value is weighted on the rent or sale value of a building in the same zone.

Moreover, it is important to consider the historical values; in this way it can be possible to make predictions on how the rent and sale values vary in future years.

To clarify this concept, it is reported below the study of these values considering the building that will be examined in the following chapters.

Figure 2-28: Historical real estate values of an office building located in Bicocca zone of Milan [26]

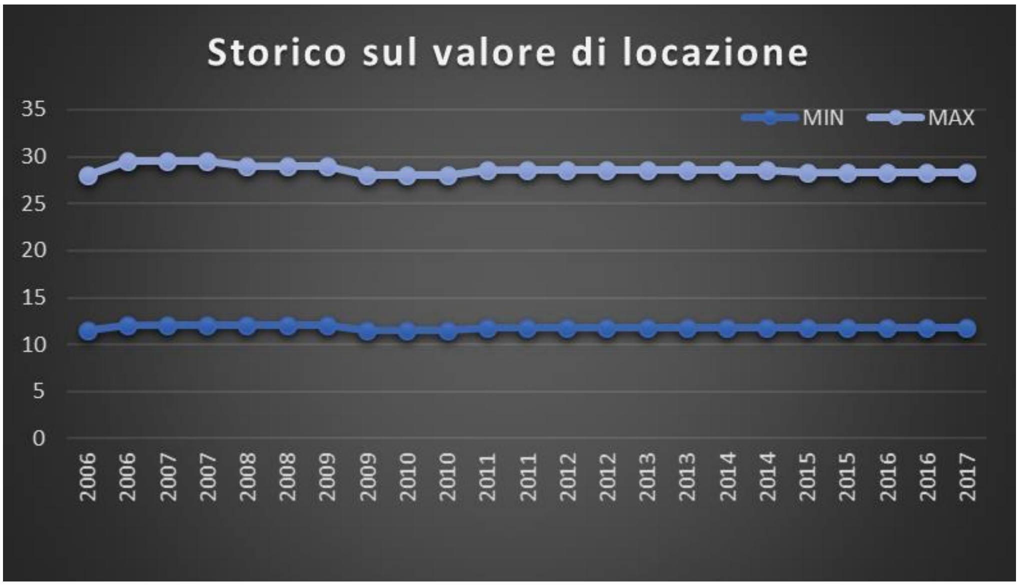


Figure 2-29: Historical rent values of an office building located in Bicocca zone of Milan [26]

Semestre		Valore mercato (€/mq)		Valori locazioni (€/mq)	
		MIN	MAX	MIN	MAX
1	2006	2200	3200	11,5	16,5
2	2006	2300	3350	12	17,5
1	2007	2300	3350	12	17,5
2	2007	2300	3350	12	17,5
1	2008	2300	3300	12	17
2	2008	2300	3300	12	17
1	2009	2300	3300	12	17
2	2009	2250	3200	11,5	16,5
1	2010	2250	3200	11,5	16,5
2	2010	2250	3200	11,5	16,5
1	2011	2250	3200	11,8	16,8
2	2011	2250	3200	11,8	16,8
1	2012	2250	3200	11,8	16,8
2	2012	2250	3200	11,8	16,8
1	2013	2250	3200	11,8	16,8
2	2013	2250	3200	11,8	16,8
1	2014	2250	3100	11,8	16,8
2	2014	2250	3100	11,8	16,8
1	2015	2250	3000	11,8	16,5
2	2015	2250	3000	11,8	16,5
1	2016	2250	3000	11,8	16,5
2	2016	2250	3000	11,8	16,5
1	2017	2250	3000	11,8	16,5
2	2017	2241	2999	12	16
1	**2018**	**2238**	**2968**	**12**	**16**
2	**2018**	**2238**	**2968**	**12**	**16**
1	**2019**	**2235**	**2936**	**12**	**16**
2	**2019**	**2235**	**2936**	**12**	**16**
1	**2020**	**2231**	**2905**	**12**	**16**
2	**2020**	**2231**	**2905**	**12**	**16**
1	**2021**	**2228**	**2873**	**12**	**16**
2	**2021**	**2228**	**2873**	**12**	**16**
1	**2022**	**2224**	**2841**	**12**	**16**
2	**2022**	**2224**	**2841**	**12**	**16**
1	**2023**	**2221**	**2810**	**12**	**16**
2	**2023**	**2221**	**2810**	**12**	**16**
1	**2024**	**2218**	**2778**	**12**	**16**
2	**2024**	**2218**	**2778**	**12**	**16**

Table 2-14: Table of the historical e predicted values [26]

As it can be seen from the graph above, both the real estate and the rent values do not vary considerably during the years; then, it is possible, with good approximation, to predict the values of the future years thanks to a linear approximation of the previous ones.

Once these values have been established, it is possible to evaluate the consequences of the energy efficiency interventions.
In order to exploit the positive impacts of the energy efficiency scenarios, an increase proportional to the upgrade of the energy class is considered.
As stated in the Multiple Benefits of energy efficiency paper "recent evidence suggest that individuals and businesses are willing to pay a rent and/or sales premium for property with better energy performance"[14]. In order to quantify this premium, the differentiation coefficients according to the energy class proposed by "Borsino immobiliare" are considered [27]. Thanks to these data it is possible to estimate both the rent and the real estate values increase.

In the third and fourth sheets, the calculation of the cash flows in the two cases are reported: firstly, considering only the positive impact of the consumption reduction, whereas, in the second case considering also the increase of the rent values.
As mentioned above, all the cash flows are evaluated in three ways with respect to the energy price. Then, for example, for the scenario #1 there will be three cash flows related to the consumption reduction: cash flow in the forward case, cash flow in the best case and cash flow in the worst case; moreover, there will be the same cash flows but considering the increase of the rent values. Thus, for every scenario there will be six cash flows.

To evaluate, from an economic point of view, the energy efficiency scenarios, some parameters have been chosen. These parameters are: Net Present Value (NPV), Pay Back Time (PBT) and Internal Rate of Return (IRR).
The net present value is given by the algebraic sum of the investment cost (I) with the net cash flows (B_t) over the whole lifetime of the project that are discounted at a certain nominal rate (i) [28]:

$$NPV = -I + \sum_{t=1}^{n} \frac{B_t}{(1+i)^t}$$

An investment project is accepted once the NPV is greater or equal to zero. Among the various projects having a comparable initial investment cost, the one with the higher NPV should be chosen.
The payback time describes the opportunity to choose the investment with the shortest period of return of the invested capital.
It measures the time when negative cash flows equal the positive cash flows [28].

$$-I + \sum_{t=1}^{PBT} \frac{B_t}{(1+i)^t} = 0$$

[14] IEA, "Capturing the multiple benefits of energy efficiency", 2014

The internal rate of return is the value of the nominal discount rate that makes the discounted cash flows equal to the investment cost. The users should choose the project with the highest IRR and, to accept an investment project, this parameter should be greater than the nominal discount rate (i).

In order to calculate these parameters, there are pre-set tables. An example is shown below:

Anni	1	2	3	4	5	6	7	8	9	10
Minore consumo	93.382 €	91.566 €	90.440 €	90.254 €	90.522 €	90.706 €	89.666 €	89.107 €	88.650 €	88.194 €
Maggiori affitti	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €	10.896 €
Incentivi (TEE,...)	- €	- €	- €	- €	- €	- €	- €	- €	- €	- €
EBITDA	**104.279 €**	**102.462 €**	**101.336 €**	**101.150 €**	**101.418 €**	**101.603 €**	**100.562 €**	**100.003 €**	**99.546 €**	**99.090 €**
ammortamento	26.548 €	26.548 €	26.548 €	26.548 €	11.510 €	11.510 €	11.510 €	11.510 €	11.510 €	11.510 €
EBIT	**77.730 €**	**75.914 €**	**74.788 €**	**74.602 €**	**89.908 €**	**90.092 €**	**89.052 €**	**88.493 €**	**88.036 €**	**87.580 €**
Tasse	21.920 €	21.408 €	21.090 €	21.038 €	25.354 €	25.406 €	25.113 €	24.955 €	24.826 €	24.697 €
Recupero fiscale	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €	3.000 €
FCF	- 89.881 €	57.506 €	56.698 €	56.564 €	67.554 €	67.686 €	66.939 €	66.538 €	66.210 €	65.882 €
DCF	**-€ 95.227**	**€ 47.526**	**€ 42.598**	**€ 38.634**	**€ 41.946**	**€ 38.207**	**€ 34.350**	**€ 31.040**	**€ 28.080**	**€ 25.400**
CDCF	**-€ 95.227**	**-€ 47.702**	**-€ 5.104**	**€ 33.530**	**€ 75.476**	**€ 113.683**	**€ 148.033**	**€ 179.074**	**€ 207.153**	**€ 232.554**
IRR										**65%**
PBT	**3,13**	**Anni**								
NPV	**-€ 86.570**	**-€ 43.365**	**-€ 4.640**	**€ 30.482**	**€ 68.614**	**€ 103.348**	**€ 134.576**	**€ 162.794**	**€ 188.321**	**€ 211.413**

Table 2-15: Table of the economic parameters

As it can be seen from the graph, in the first row there are the years, the second and the third rows regard the positive cash flows (one concerns the consumption reduction and the other the rent values increase, respectively); the fourth row is related to the incentives (energy efficiency certificates, white certificates etc.).

After these three terms have been evaluated, the EBITDA, Earnings Before Interests Taxes Depreciations and Amortizations, is obtained as the sum of the previous ones.

In the fifth row the users have to evaluate the amortization of the energy efficiency measures in order to compute the EBIT, Earnings Before Interest and Taxes, that is the difference between the EBITDA and the amortization. After that the taxes are calculated. These are the sum of the IRES, corresponding to the income tax on capital companies that is equal to 24%, and the IRAP that is equal to 4,2%. The taxation is calculated on the EBIT.

The following row regards the tax deductions.

At this point, the users can find out the results: the real earnings; the FCF, or rather free cash flows, are equal to the previous results except for the first year in which it is assumed that the investment is paid without any funding. For this reason, the FCF of the first year is equal to the real earning minus the investment.

The DCF are the discounted cash flows or rather the FCF that take into account the actualization and then the nominal discount rate. The CDCF are the cumulative discounted cash flows that are the sum of the DCF of the same year and the DCF of all the previous years. The CDCF are useful to discover the payback time; in fact, the year in which the CDCF becomes positive corresponds to the payback time.

There are a series of sheets similar to the sheet above described in order to evaluate more than one scenario. Every sheet refers to a different scenario.

The last sheet called “Confronto scenari” summarizes the economic behaviour of the scenarios. There are three typologies of graphs: the first compares the scenarios from the NPV point of view, the second shows the different PBT and finally, the third table, compares the IRR after ten years.
By looking at these graphs the users can understand and choose the best scenario.

2.6 Block E: Dashboard Report

The Block E is an overview of all the previous results; there is a report for each energy efficiency scenario. Every report is divided into the five following sections:

1. Energy performance: the first section compares the energy performance before and after the energy efficiency interventions; in order to do so, two dashboard graphs are implemented; moreover, the NZEB check is also reported through the inclusion of some smiles. Nearby the graphs, a writing that explains the energy performance appears. Some assumptions have been done to produce this writing. If the to-be global primary energy is among the A1 and A3 classes, the performances are considered excellent; instead, if the to-be global primary energy is among the D and A1 classes the performances are medium; otherwise the performances are considered bad.

2. Consumptions reduction: in this section the to-be primary energy indexes, referring to the different services, are compared to the same indexes of the as-is situation; the percentage reduction is shown, and a bar graph is implemented to clarify for which service the consumption has been lowered the most.

3. Investment cost vs consumptions reduction: this section is useful when more than one energy efficiency intervention is considered. In fact, through pie charts, the investment cost and consumptions reduction of the different interventions are compared. This can help the users to understand which of the interventions chosen is the most profitable; for example, if the investment cost of the intervention 1 is double with respect to the investment cost of the intervention 2 but the consumptions reduction of the intervention 1 is similar to the intervention 2, this means that the intervention 2 is the most profitable. Then, the users will be able to decide whether to discard the intervention 2 or not.

4. Increase of the real estate of the building: the increase in both the real estate and the rent values is shown in this section. Firstly, the data concerning the geometry of the building are shown followed by the comparison of rent and real estate values. Moreover, also the percentage increase, the € gained per year from the building's rent and the € gained if the building was sold are reported.

5. Economic analysis considering the forward energy prices: the internal rate of return and pay-back time are shown; to clarify the behaviour of these two parameters two dashboard graphs are implemented. Moreover, as in the case of the energy performance, a writing based on their values, appears; the assumptions made in the case of the internal rate of return are the following: if the IRR is lower than 10% it is considered a bad value, if it is between 10% and 40% it is considered a medium value, otherwise the IRR is excellent. The assumptions made for the pay-back time parameter take into account the fact that energy efficiency measures usually have medium or high values; for this reason, if the PBT is lower than eight years it is considered low and hence excellent; if it is between eight years and fifteen years it is considered medium, otherwise it is high and therefore a bad PBT.

6. Economic analysis vs energy prices: in this section the energy price influence on the economic parameters is shown. Firstly, an overview of the energy prices in the three scenarios is presented; after that, there are two graphs that show the variations of the pay-back time and the net present value depending on the energy prices. In the end, a table, in which the different internal rates of return are compared, is shown.

CHAPTER 3: Case study

3.1 Description of the as-is building

The case study chosen to test the tool is an office building located in Milan. The aim of this paragraph is to describe the building in the as-is situation.

When the study started, the building was under construction, so both the description and the energy efficiency measures were evaluated on the project. Then, from now on, when talking about the as-is building or to-be building, the project of the as-is or to-be building is considered in this paper.

The examined building is an important renovation of an existing structure; it is located in the Milan Ponale zone.

The building, before the renovation interventions, looked like this:

Figure 3-1: Building before renovation

The project of the renovation included the total rebuilding of the facades and the replacement of all the existing plants and terminals. The structural skeleton of the existing building is the only thing that remained. Moreover, thanks to the renovation, an additional floor was added.

The rendering of the building after the renovation is shown in the *Figure 3-2*:

Figure 3-2: Render of the building renovation

The main features of the building after the renovation are presented in the following lines:

1. **General data**:

   The examined building is located in Milan and, more in particular, the address is: Via chiese 72/74.

   Regarding the geoclimatic context, there are 2404 day degrees and the climatic zone is the E zone; moreover, the internal temperature in winter is set up to 20°C, whereas the summer one is equal to 26°C. Minimum and maximum external temperatures are set up to -5 °C and 31,9 °C, respectively.

   The heating period, according to the project, runs from 2nd November to 3rd March; instead, the air-conditioning period goes from 4th March to 28th October.

   The examined structure is an office building and so falls into the category:" E2. Edifici per uffici o assimilabili".

   The net dimension of the air-conditioning environment is about 9720 m^2 and the net dispersing surface is equal to 13968 m^2.

2. **Envelope characteristics:**

   The facades are predominantly glazed via a double-chambered glass with a cavity of argon gas; the glasses are selective glasses with U_g=0,5 W/m^2K. The transmittance of the whole window, taking into account also the frame transmittance, is U_w=1 W/m^2K; the window's frame is of A4 class, the most efficient one. The values of the windows' transmittance are below the limits envisaged in Lombardy for NZEB building.

A screening system for the glazing is provided, made up of blinds in transparent surfaces.

The stratigraphy and the transmittances of the opaque walls with the greatest impacts are shown below:

Nome struttura	Parete nuovi vani scale-uffici (ARC 046)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza interna			0,13
2	Lastra di cartongesso	0,250	13	0,052
3	Lastra di cartongesso	0,250	12	0,048
4	Lamina di alluminio	0,400	1	0,0025
5	Strato d'aria verticale		5	0,11
6	Isolante in lana di roccia	0,035	90	2,571428571
7	Strato d'aria verticale		5	0,11
8	Lastra di cartongesso	0,250	12	0,048
9	Lastra di cartongesso	0,250	13	0,052
10	Adduttanza esterna			0,13
Trasmittanza (W/m^2K)		0,307320821		

Table 3-1:Wall's Stratigraphy

Nome struttura	Muri a secco interno-esterno (ARC 043)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza interna			0,13
2	Lastra di cartongesso	0,250	13	0,052
3	Lastra di cartongesso	0,250	12	0,048
4	Lamina di alluminio	0,400	1	0,0025
5	Strato d'aria verticale		5	0,11
6	Isolante in lana di roccia	0,035	90	2,571428571
7	Strato d'aria verticale		5	0,11
8	Camera d'aria e sottostruttura	2,000	10	0,005
9	Muratura in VIBRAPAC (15x20x50 cm)	0,781	150	0,192
10	Strato d'aria verticale		5	0,11
11	Isolante in lana di roccia	0,035	90	2,571428571
12	Strato d'aria verticale		5	0,11
13	Lastra in cemento fibrorinforzato	0,400	12	0,03
14	Lastra in cemento fibrorinforzato	0,400	13	0,0325
15	Adduttanza esterna			0,04
Trasmittanza (W/m^2K)		0,164		

Table 3-2:Wall's Stratigraphy

Nome struttura	Parete bagno-cavedio (ARC 051)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza interna			0,13
2	Rivestimento in piastrelle di gres porcellanato incollate	1,000	10	0,01
3	Lastra di cartongesso	0,250	13	0,052
4	Lastra di cartongesso	0,250	12	0,048
5	Lamina di alluminio	0,400	1	0,0025
6	Strato d'aria verticale		5	0,11
7	Isolante in lana di roccia	0,035	90	2,571428571
8	Strato d'aria verticale		5	0,11
9	Lastra di cartongesso	0,250	12	0,048
10	Lastra di cartongesso	0,250	13	0,052
11	Adduttanza esterna			0,13
Trasmittanza (W/m^2K)		0,306379254		

Table 3-3:Wall's Stratigraphy

Nome struttura	Controparete bagno-vano ascensori (ARC 052)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza interna			0,13
2	Rivestimento in piastrelle di gres porcellanato incollate	1,000	10	0,01
3	Lastra di cartongesso	0,250	13	0,052
4	Lastra di cartongesso	0,250	12	0,048
5	Lamina di alluminio	0,400	1	0,0025
6	Strato d'aria verticale		5	0,11
7	Isolante in lana di roccia	0,035	90	2,571428571
8	Strato d'aria verticale		5	0,11
9	Muratura in calcestruzzo vano ascensore	1,410	200	0,141843972
10	Adduttanza esterna			0,13
Trasmittanza (W/m^2K)		0,302501151		

Table 3-4:Wall's Stratigraphy

The stratigraphy of the lower floors are shown in the following graphs:

Nome struttura	Soletta piano terra-ingressi (ARC 003)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,17
2	Finitura in piastrelle di gres incollate	1	10	0,01
3	Collante per piastrelle	0,400	10	0,025
4	Cappetta di regolarizzazione (massetto)	1,410	20	0,014184397
5	Sottofondo alleggerito	0,100	60	0,6
6	Soletta in predalles	0,444	150	0,3375
7	Intonaco intumescente	0,700	20	0,028571429
8	Isolante in lana di roccia	0,035	100	2,857142857
9	Lastra di cartongesso	0,250	12	0,048
10	Adduttanza inferiore			0,17
Trasmittanza (W/m^2K)		0,234719817		

Table 3-5: Lower floor's stratigraphy

Nome struttura	Soletta piano uffici/pilotis (ARC 005)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,17
2	Finitura autoposante	1,000	10	0,01
3	Pavimento sopraelevato in pannelli di solfato di calcio	0,800	40	0,05
4	Sottostruttura con traversini	52,000	20	0,000384615
5	Spazio vuoto pavimento sopraelevato	10,000	100	0,01
6	Trattamento antipolvere	0,700	10	0,014285714
7	Soletta in predalles	0,444	120	0,27
8	Intonaco intumescente	0,700	20	0,028571429
9	Isolante in lana di roccia	0,035	120	3,428571429
10	Spazio vuoto controsoffitto	10,000	90	0,009
11	Lastra di cartongesso	0,250	12	0,048
12	Adduttanza inferiore			0,04
Trasmittanza (W/m^2K)		0,245169355		

Table 3-6: Lower floor's stratigraphy

The stratigraphy of the upper floors are shown below:

Nome struttura	Soletta uffici (ARC 006)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,13
2	Finitura autoposante	1,000	10	0,01
3	Pavimento sopraelevato in pannelli di solfato di calcio	0,800	40	0,05
4	Sottostruttura con traversini	52,000	20	0,000384615
5	Spazio vuoto pavimento sopraelevato	10,000	80	0,008
6	Trattamento antipolvere	0,700	10	0,014285714
7	Soletta in predalles	0,444	320	0,72
8	Intonaco intumescente	0,700	20	0,028571429
9	Spazio vuoto controsoffitto	10,000	155	0,0155
10	Controsoffitto radiante tipo Barcolair	10,000	45	0,0045
11	Adduttanza inferiore			0,13
Trasmittanza (W/m^2K)		0,899894188		

Table 3-7: Upper floor's stratigraphy

Nome struttura	Soletta terrazzi P5/P6 (ARC 018)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,04
2	Pvimento in gres da esterno	1,000	20	0,02
3	Mapelastic	0,400	5	0,0125
4	Massetto di pendenza	1,410	40	0,028368794
5	Telo in polietilene microforato	0,500	1	0,002
6	Isolante STIFERITE CLASS B	0,026	80	3,076923077
7	Telo in polietilene microforato	0,500	1	0,002
8	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
9	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
10	Cappa in CLS	1,410	60	0,042553191
11	Blocco da solaio di laterizio	0,743	260	0,35
12	Spazio vuoto controsoffitto	10,000	175	0,0175
13	Controsoffitto radiante tipo Barcolair	10,000	45	0,0045
14	Adduttanza inferiore			0,1
Trasmittanza (W/m^2K)		0,269371511		

Table 3-8: Upper floor's stratigraphy

Nome struttura	Soletta copertura (ARC 020)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,04
2	Pavimento in quadrotte di CLS	1,500	40	0,026666667
3	Spazio vuoto pavimento sopraelevato	10,000	23	0,0023
4	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
5	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
6	Isolante STIFERITE CLASS B	0,026	100	3,846153846
7	Barriera al vaporePOLYGLASS PLANA P	0,500	4	0,008
8	Massetto di pendenza	1,410	50	0,035460993
9	Cappa in CLS	1,410	60	0,042553191
10	Blocco da solaio di laterizio	0,743	260	0,35
11	Spazio vuoto controsoffitto	10,000	175	0,0175
12	Controsoffitto radiante tipo Barcolair	10,000	45	0,0045
13	Adduttanza inferiore			0,1
Trasmittanza (W/m^2K)		0,222760079		

Table 3-9: Upper floor's stratigraphy

Nome struttura	Soletta copertura/basamento impianti (ARC 033)			
N.	Descrizione strato	λ (W/m*K)	s (mm)	R (m^2K/W)
1	Adduttanza superiore			0,04
2	Cordolo in CLS armato	1,410	150	0,106382979
3	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
4	Guaina bituminosa POLYGLASS FLEXO S6	0,500	4	0,008
5	Isolante STIFERITE CLASS B	0,026	100	3,846153846
6	Barriera al vaporePOLYGLASS PLANA P	0,500	4	0,008
7	Massetto di pendenza	1,410	50	0,035460993
8	Cappa in CLS	1,410	60	0,042553191
9	Blocco da solaio di laterizio	0,743	260	0,35
10	Spazio vuoto controsoffitto	10,000	175	0,0175
11	Controsoffitto radiante tipo Barcolair	10,000	45	0,0045
12	Adduttanza inferiore			0,1
Trasmittanza (W/m^2K)		0,218983648		

Table 3-10: Upper floor's stratigraphy

As it can be seen from the transmittance values, it is difficult to hypothesise energy efficiency measures on the envelope since, walls, windows and floors present very low transmittance values and, hence, they are already very efficient from the trasmissions point of view.

After having completed the sheet "5-Caratteristiche involucro", the value of the transmission coefficient has been found equal to 6106,49 W/K.

3. **Thermal energy needs:**

In order to discover the thermal energy needs both in summer and in winter it is necessary to evaluate some parameters. Firstly, the average monthly irradiance on a vertical plane has been inserted in the specific table [16]; as the building is an office building the internal supplies are equal to 6 W/m^2 [7].

The number of air changes has been entered resulting in a ventilation coefficient equal to 2861 W/K.

At this point, the average monthly external temperature (Θ_e) [29] and the number of kilo-hours per month (Δt) have been inserted.

Finally, the tool is able to calculate the thermal energy needs; the tables below show the thermal energy needs both in winter and in summer for the examined building:

Fabbisogno di energia termica per la climatizzazione invernale							
	OTT	NOV	DIC	GEN	FEB	MAR	APR	TOTALE
Θ_e (°C)	14,1	7,5	3,5	4,0	7,1	10,6	13,4	-
Δt (kh)	0,0	0,7	0,7	0,7	0,7	0,1	0,0	-
ΔΘ (K)	5,9	12,5	16,5	16,0	12,9	9,4	6,6	-
H_T (W/K)	6106,5	6106,5	6106,5	6106,5	6106,5	6106,5	6106,5	-
H_V(W/K)	2861,5	2861,5	2861,5	2861,5	2861,5	2861,5	2861,5	-
Q_{int}(kWh)	0,0	40589,4	43388,7	43388,7	39189,7	4198,9	0,0	**170755,3**
Q_{sol} (kWh)	0,0	24711,7	24257,8	24254,4	35238,8	4684,7	0,0	**113147,5**
Q_T (kWh)	0,0	53126,5	74963,3	72691,7	52936,0	4132,9	0,0	**257850,4**
Q_V (kWh)	0,0	24894,8	35127,4	34063,0	24805,5	1936,6	0,0	**120827,4**
γ_H	0,0	0,8	0,6	0,6	1,0	1,5	0,0	0,9
$\eta_{G,H}$	1,0	0,8	0,9	0,9	0,8	0,6	1,0	0,8
$Q_{H,ND}$ (kWh)	0,0	22957,5	47674,4	44756,1	18475,2	607,4	0,0	**134470,6**

Table 3-11:Winter thermal energy need

Fabbisogno di energia termica per la climatizzazione estiva								
	MAR	APR	MAG	GIU	LUG	AGO	SETT	OTT	TOTALE
Θ_e (°C)	10,60	13,40	19,40	22,80	24,50	24,30	19,80	14,10	-
Δt (kh)	0,67	0,72	0,74	0,72	0,74	0,74	0,72	0,67	-
ΔΘ (K)	15,40	12,60	6,60	3,20	1,50	1,70	6,20	11,90	-
H_T (W/K)	6106,49	6106,49	6106,49	6106,49	6106,49	6106,49	6106,49	6106,49	-
H_V(W/K)	2861,47	2861,47	2861,47	2861,47	2861,47	2861,47	2861,47	2861,47	-
Q_{int}(kWh)	39189,75	41989,02	43388,65	41989,02	43388,65	43388,65	41989,02	39189,75	**334512,51**
Q_{sol} (kWh)	43723,77	43908,10	48355,24	48600,44	52101,73	49901,52	47105,70	33109,05	**366805,54**
Q_T (kWh)	63194,88	55398,11	29985,33	14069,36	6814,85	7723,49	27259,39	48832,41	**253277,82**
Q_V (kWh)	29612,80	25959,28	14050,97	6592,83	3193,40	3619,19	12773,61	22882,62	**118684,71**
γ_C	0,89	1,06	2,08	4,38	9,54	8,22	2,23	1,01	-
$\eta_{G,C}$	0,73	0,80	0,96	1,00	1,00	1,00	0,97	0,78	-
$Q_{C,ND}$ (kWh)	14814,28	20787,44	49477,31	70012,84	85485,20	81953,25	50397,77	16161,79	**389089,86**

Table 3-12: Summer thermal energy need

As it can be seen from the previous tables, the summer thermal energy need is more than twice of the winter one; this often happens when tertiary buildings are considered.

Considering the winter period, to highlight where the most impactful transmission losses are located, there is a graph; the latter allows users to understand if it is useful or not to hypothesize efficiency measures on the envelope. Below, the graph representing the dispersions for the examined building is shown:

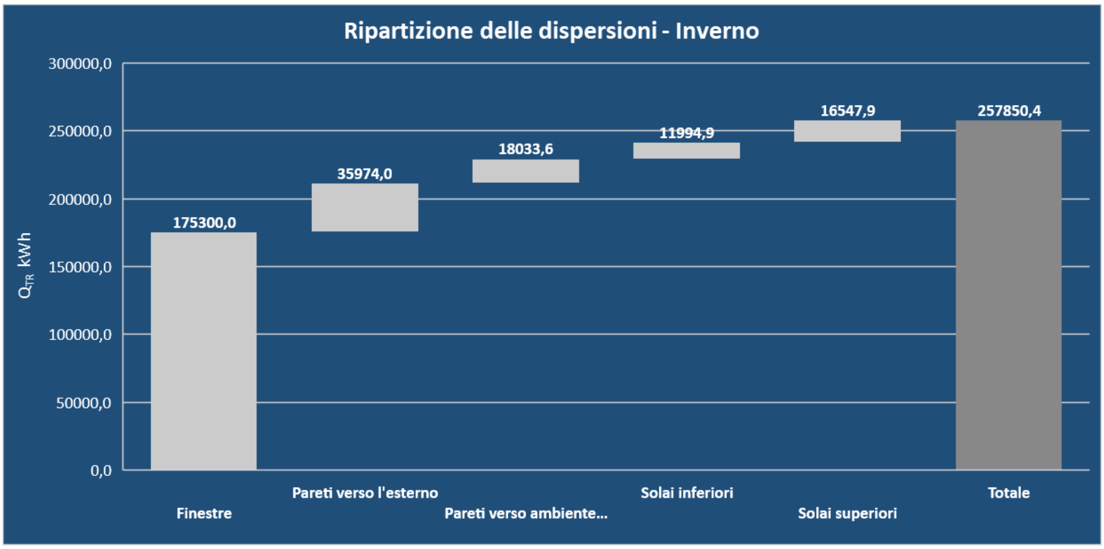


Figure 3-3: Collocation of the greater dispersions

Looking at this graph, one can understand that the greatest dispersions occur across the windows whereas, dispersions through other walls are insignificant. So, if energy efficiency measures are assumed, surely, they will refer to windows.

In the examined building the windows have optimal parameters from the dispersion point of view; for this reason, it is not convenient to hypothesize energy efficiency improvements on the windows and then on the envelope.

4. Plants and lighting:

The internal lighting system is entrusted to LED lamps. The LED technology is the best one on the market from the point of view of both consumption and efficiency; for this reason, no re-lamping interventions will be hypothesized.

Since it is a building with a high number of windows, a high daylight factor has been chosen. Moreover, the legislation for the interior lighting establishes a value of 500 lux for an office building; for this reason, “zona ad alto livello di illuminamento” was chosen.

Concerning the building management system for the interior lighting, only presence sensors are installed.

Thanks to the data above described, the internal lighting section of the tool has been completed and the primary energy has been calculated, resulting equal to 83,34 kWh/m^2 per year.

In the second section of this sheet, there is the domestic hot water (DHW) need calculation. Firstly, the typology of building was inserted; thanks to this choice, the volume of hot water in litres per day and the DHW need (Q_{ACS}) have been calculated.

The results of these parameters are represented in the following table:

Calcolo del fabbisogno di ACS:						
$T_{erogazione}$ (°C)	$T_{media\ annuale\ aria\ esterna}$ (°C)	Tipo di attività	Fattore a	Fattore N_u	V_w (l/g)	Q_{ACS} (kWh)
40	14,3	Uffici	0,2	9719,68	1943,94	21189,18

Table 3-13: Thermal energy need for DHW [11]

At this point, the supply, distribution and storage losses of the domestic hot water system are evaluated.

The supply losses are negligible and equal to zero kWh.

The distribution losses depend on the system typology. Having no data on the system type, it was assumed that there isn't any recirculation ring; thanks to this assumption the distribution losses are calculated and are equal to 1695 kWh per year.

Moreover, knowing that the storage is inside the generator, the storage losses are negligible and equal to zero kWh as well.

Then, the thermal energy that the generator has to supply is equal to the thermal energy need for DHW plus the losses that, in this case, are the distribution losses.

The third section concerns the supply, regulation, distribution and storage losses of the heating system.

In order to determine the supply losses, the terminals typology has been inserted; in the examined building there are radiant ceiling panels that are a particular low-temperature terminals typology. The regulation of this building is a single environment regulation with a gap proportional to 0,5 °C. The distribution losses are evaluated taking into account the insulation level of the pipes. Not having data related to this, a B level of insulation has been assumed; this level corresponds to a good approximation since the building, which is under construction, is expected to have a good insulation level. Moreover, also the distribution typology must be inserted: this is a horizontal distribution that must serve six floors.

As in the case of DHW, the storage is internal to the generator; then the storage losses are equal to zero kWh.

Thanks to these approximations and calculations, it is now possible to discover the monthly thermal energy need that the generator must provide to the heating system.

In the following table, there is the calculation of several losses of the heating system.

	OTT	NOV	DIC	GEN	FEB	MAR	APR	TOT
$Q_{H,ND}$ (kWh)	0,0	22957,5	47674,4	44756,1	18475,2	607,4	0,0	134470,6
$Q_{H'}$ (kWh)	0,0	22957,5	47674,4	44756,1	18475,2	607,4	0,0	134470,6
$Q_{l,e}$ (kWh)	0,0	27604,9	57325,4	53816,3	22215,3	730,4	0,0	161692,4
$Q_{l,rg}$ (kWh)	0,0	2106,8	4375,0	4107,2	1695,4	55,7	0,0	12340,1
$Q_{l,d}$ (kWh)	0,0	2152,9	4470,7	4197,0	1732,5	57,0	0,0	12610,1
$Q_{l,s}$ (kWh)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
$Q_{H,gn,out,m}$ (kWh)	0,0	54822,0	113845,6	106876,6	44118,5	1450,6	0,0	321113,2

Table 3-14:Supply, distribution, regulation and storage losses of the heating system

As in the case of the heating system, also the supply, distribution, regulation and storage losses for air-conditioning system must be evaluated. The terminals and distribution typologies are equal to those of the heating system; the only difference is the regulation typology that is proportional to 1°C in this case. The storage losses are again equal to zero kWh because the storage is inside the cooling machine.

Below the same table of the heating system is reported but referred to the air-conditioning system:

	MAR	APR	MAG	GIU	LUG	AGO	SET	OTT
$Q_{C,ND}$ (kWh)	14814,3	20787,4	49477,3	70012,8	85485,2	81953,3	50397,8	16161,8
$Q_{l,e}$ (kWh)	302,3	424,2	1009,7	1428,8	1744,6	1672,5	1028,5	329,8
$Q_{l,rg}$ (kWh)	467,5	656,0	1561,5	2209,5	2697,8	2586,4	1590,5	510,1
$Q_{l,d}$ (kWh)	157,4	220,9	525,7	744,0	908,4	870,8	535,5	171,7
$Q_{l,s}$ (kWh)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Q_{cr} (kWh)	15741,5	22088,6	52574,2	74395,2	90836,0	87083,0	53552,3	17173,4

Table 3-15: Supply, distribution, regulation and storage losses of the cooling system

5. **Generation losses:**

In this paragraph the types of thermal plants are discussed.

Heating and cooling are entrusted to a reversible heat pump that works with external air thus, corresponding to an air-water reversible heat pump. The nominal cooling power and the nominal thermal power are known thanks to the data provided in the project; also the COP and the EER are established. Having these data available, an air-water reversible heat pump has been chosen from the database of "Climaveneta" [30]. This will be useful in order to compile the data input of the heat pump file.

Starting from the cooling behaviour, the EER for different load factors have been inserted. Moreover, the nominal power equal to 600 kW and the system typology, air-water, have been set up. On the basis of the typology, other parameters must be inserted; more in particular, the monthly outlet water temperature, that is equal to 7°C for all months, and the external dry bulb air temperatures are added.

Thanks to these data, the load factor F and the EER of the cooling machine are calculated for each month. The results are presented in the table below:

	March	April	May	June	July	August	September	October
F (%)	3,9 %	5,1 %	11,8 %	17,2 %	20,3 %	19,5 %	12,4 %	4,3 %
EER	1,73	2,19	2,30	2,20	2,22	2,18	2,40	2,02

Table 3-16: F and EER for the cooling machine

As it can be seen form the table, the load factor is always very low, this involves low EER values. Moreover, by looking at these values it can be possible to hypothesize that the cooling machine is over dimensioned; for this reason, one of the energy efficiency interventions should regard the sizing and the replacement of the cooling machine.

For what concerns the heating system, the same heat pump is used. In order to evaluate the performances, the heat pump's file must be compiled. The data input are those of the SpinChiller3-WSAN-XSC3 MF-220.4-4T that is an air-water reversible heat pump with the same nominal power and with similar COP and EER values.

In the following graphs the data input of the chosen heat pump are presented:

	Φg	Φg	Φg	COP	COP	COP
	T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C
	35,00	45,00	55,00	35,00	45,00	55,00
-7,00	428,00	416,00		2,88	2,29	
2,00	562,00	542,00		3,64	2,91	
7,00	702,00	677,00	655,00	4,43	3,58	2,79
12,00	810,00	772,00	744,00	4,99	4,00	3,12

Table 3-17: Data of the heat pump at full load [30]

	$T_{designh}$	A (T_{bival})	B	C	D
Te	-10	-7	2	7	12
PLR		0,88	0,54	0,35	0,15
DC		428,00	248,00	168,00	165,00
CR		1,00	0,46	0,24	0,09
P	484,00	428,00	261,00	168,00	74,50
COP (carico parziale)		2,88	4,57	5,08	5,08
COP' (pieno carico)		2,88	3,64	4,43	4,99
f_{COP}		1,00	1,26	1,14	1,02

Table 3-18: Data of the heat pump [30]

The heat pump's file is able to calculate the monthly COP of the selected heat pump; in the table below the results of the COP are shown:

	November	December	January	February	March
COP	4,9	3,8	3,4	3,6	4,7

Table 3-19: Monthly COP of the selected heat pump

As it can be seen from the previous table, the heat pump has more acceptable performance values with respect to those of the summer period. Anyway, the COP could reach higher values so that it is possible to hypothesize an energy efficiency intervention on the heat pump.

Concerning the production of domestic hot water, there is an absorption heat pump; the COP of this plant is about 4,8 for each month corresponding to an excellent value. For this reason, it is inconvenient to replace this heat pump.

In the tables below, the total consumption, expressed in kWh, for both summer and winter air-conditioning and DHW are shown:

	March	April	May	June	July	August	Sept	Oct
Q_C	9086	10065	22858	33760	40897	39992	22313	8496

Table 3-20: Summer consumption

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Q_W	403	403	403	403	403	403	403	403	403	403	403	403

Table 3-21: DHW consumption

	November	December	January	February	March
Q_H	11169	30173	31155	12419	309

Table 3-22: Winter consumption

At this point, it is possible to discover the primary energy associated to these consumptions; To do so, the energy carrier used must be declared; being all electric heat pumps, the energy carrier will be electricity with a coefficient equal to 1,95 [14].

Moreover, there is a photovoltaic plant in the examined building; to consider the electricity produced by this plant the section that concerns the photovoltaic plant has been compiled. The panels typology is a thin layer of amorphous silicon and the total collection area of the plant is equal to 227 square meters. Furthermore, there is no mechanical ventilation.
The solar incident irradiance on the panels was estimated thanks to the Pvgis software [16].

After these data have been entered, the tool is able to calculate the monthly electricity that the plant can produce; the resulting values are reported in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
$E_{el,PV,}$	535	829	1335	1449	1773	1859	2059	1802	1411	918	561	492

Table 3-23: Photovoltaic electricity production

As it can be seen from the table, the production compared to the consumptions is very low; for this reason, one of the possible energy efficiency interventions should be the extension of the photovoltaic plant and/or the change of panel's typology.

The electricity produced by the photovoltaic panels will reduce the consumption of the electric reversible heat pump both in summer and in winter periods.

6. Results:

Thanks to the knowledge of the examined building it is possible to "construct" the reference building. Firstly, the reference values of transmittance are inserted in the examined building; in this way the global transmission coefficient is calculated, and it is equal to 7674 W/K. By looking at this parameter, it is possible to understand that it is useless to hypothesize energy efficiency interventions on the envelope, as previously mentioned, because the global transmission coefficient of the examined building is lower than this value.

After that, the distribution typology of the reference building has been chosen; it should be remembered that the type of distribution of the reference building must be the same as the building examined corresponding, in this case, to a hydronic distribution.

The tool is able to fit the building with the reference parameters [17] concerning the generation and the energy carriers; thus, at this point, it is possible to discover the primary energy (kWh/m^2) consumed by the reference building:

$EP_{H,nren}$	27
$EP_{C,nren}$	33
$EP_{W,nren}$	3
EP_{ILL}	50
$EP_{gl,tot,rif}$	113

Table 3-24: Primary energy of the reference building

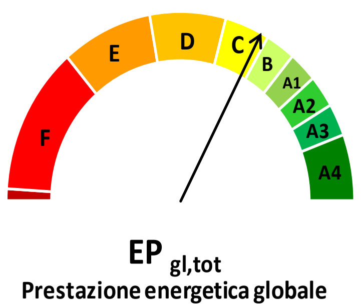
Thanks to the global primary energy of the reference building, it is possible to discover the ranges of the energetic classification; this ranges are shown in the figure below:

Classificazione	min	max
A4	0,00	45,00
A3	46,00	68,00
A2	69,00	91,00
A1	92,00	113,00
B	114,00	136,00
C	137,00	170,00
D	171,00	227,00
E	228,00	295,00
F	296,00	397,00
G	397,00	

Table 3-25: Energy classes

The tool is able to compare these values with the global primary energy of the examined building so that it is possible to discover the energy class.

The primary energy for each service, the global primary energy and the energy class of the examined building are reported in the following figure:



EP_W	EP_H	EP_C	EP_{ILL}	$EP_{gl,tot}$
0,97	16,33	36,84	83,34	137,47
L'edificio è di classe energetica :				C

Figure 3-4: Energy class of the examined building

The building is a C class, so it will be possible to optimize it.

The NZEB check is reported below:

L'edificio rispetta i requisiti sul coeff. Medio globale di scambio termico?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione estiva?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione estiva?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'indice di prestazione energetica?	NO
L'edificio rispetta gli obblighi sull'integrazione con fonti rinnovabili?	SI
L'edificio rispetta gli obblighi sulla potenza elettrica da fotovoltaico?	NO

L'edificio non è Nzeb

Table 3-26: NZEB check

The building is NZEB only if all the conditions are respected; for this reason, the examined building is not NZEB.

The conditions that are not respected are those concerning the efficiency of the summer generation system, the global primary energy and the photovoltaic power.

In fact, as previous mentioned, the reversible heat pump works badly in the summer period with low values of EER; it could be convenient to change this heat pump in order to meet this condition.

Moreover, the global index of energy performance is higher than the reference value; this fact can be explained by looking at the primary energy of the single service. The DHW index EP_W is lower compared to the same index of the reference building; this means that there isn't any issue with the heat pump producing hot water. The index referred to the heating system EP_H is lower compared to the same index of the reference building; also in this case there is no problem. Instead, the index that concerns the air-conditioning system E_C is higher; this means that the heat pump can be optimized to achieve a better performance in the summer period. By looking at the lighting index E_{ill}, one can notice that it is much higher; surely an energy efficiency intervention that considers the optimization of the building management system for interior lighting should be proposed.

Another condition that the examined building does not respect is the one that regards the photovoltaic power. The legislation sets a rule for this power; the building is NZEB if the photovoltaic power is greater or equal to the power calculated with the following formula:

$$P = \frac{1}{50} * A_g \quad \text{kW}$$

where A_g is the area at ground level. For the examined building this reference power is equal to 44,5 kW and the peak power of the existing photovoltaic plant is equal to 13,6 kW, a much lower value. For this reason, an increase of the photovoltaic power should be considered in the energy efficiency interventions.

3.2 Energy efficiency measures

In this chapter the energy efficiency measures chosen for the examined building are described. To evaluate the positive impacts of these interventions the block B was used.

3.2.1 Geothermal heat pump

The first energy efficiency measure that has been considered is the installation of a geothermal heat pump; as mentioned above, the efficiency of the reversible heat pump in the summer period is low and also the load factor. Then, first of all, the size of the heat pump was calculated; in order to do that the heating consumption was considered. After that, it was necessary to check if the power was good also for the summer period. To do so the load factor, when the heat pump works like a cooling machine, must be lower than 100% otherwise the power must be increased.

The size of the heat pump is calculated according to this formula:

$$P = \left(H_T * \left(T_{int} - T_{prog}\right) + H_v * \left(T_{int} - T_{prog}\right)\right) * 1{,}2 \quad \text{W}$$

Where H_T is the global transmission coefficient of the building that in this case is 6106,49 W/K, T_{int} is the internal temperature which is set at 20°C, the T_{prog} is the minimum project temperature that is set at -5°C and H_V in the global ventilation coefficient calculated considering a number of air exchanges equals to 0,5 vol/h. In this way, the heat pump is sized with respect to the worst case represented by the minimum external temperature and the maximum dispersions.

The obtained power is 313 kW, about half of that of the project.

After that, this power has been inserted in the calculation of the cooling machine's load factor; it is possible to notice that the load factor is never higher than 100%: this means that the selected heat pump is able to produce the thermal energy need both in summer and in winter.

At this point, it is possible to choose a reversible geothermal heat pump that is capable to produce this power. The selected heat pump is the ElfoEnergy Ground Medium MF 90.2 that has a nominal thermal power of 314 kW with a COP of 4,42 and a nominal cooling power of 271 kW with an EER of 4,52. This heat pump was chosen thanks to the “Climaveneta” database [30]; moreover, the latter allows to compile the data input of the geothermal heat pump file too.

In the tables below the data input of the selected heat pump are shown:

	Φg	Φg	Φg	COP	COP	COP
	T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C	T. mand°C
	35,00	45,00	55,00	35,00	45,00	55,00
-5,00	208,02	209,84	200,75	3,99	3,23	2,45
0,00	254,22	252,24	237,04	4,52	3,68	2,78
5,00	301,54	296,00	274,35	5,05	4,14	3,12
10,00	344,41	334,33	307,60	5,58	4,56	3,45

Table 3-27: Data input of the heat pump at full load [30]

	$T_{designh}$	A (T_{bival})	B	C	D
Te	-10	-7	2	7	12
PLR		0,88	0,54	0,35	0,15
DC		318,88	194,10	148,23	148,23
CR		1,00	0,61	0,39	0,17
P	360,47	318,88	194,10	124,78	55,46
COP (carico parziale)		5,14	5,38	5,11	5,05
COP' (pieno carico)		5,14	5,14	5,14	5,14
f_{COP}		1,00	1,05	0,99	0,98

Table 3-28: Data input of the heat pump [30]

At this point the sizing of the geothermal pipes has been done. Since it is a very delicate issue, two different methodologies have been adopted and then the values have been compared.

The first methodology is the ASHRAE method [31]; an online spreadsheet that simulates the ASHRAE method was used. Some input parameters have been entered in order to discover the total meters of pipes. These parameters are the following:

- Maximum hourly ground peak load, q_h: is “obtained from a knowledge of the building peaks loads and of the heat pump coefficient of performance (COP) at the expected return fluid temperature from the GHX.”[15]

  This parameter is equal to 198681 W for the examined building.

- Average monthly ground loads, q_m: is “evaluated during the months when q_h occurs.”[16]

[15] ASHRAE Transactions, Volume 122, Part 1

This parameter is equal to 35312,6 W for the examined building.

- Yearly average ground load, q_y: “is the net result of heat rejection and collection into the ground”[17] and it is equal to 21705 W.
- Thermal conductivity of the ground [19]: this parameter has been calculated thanks to the sheet “Temperatura del terreno” of the geothermal heat pump file. In fact, by choosing the ground typology, this value is automatically calculated. Regarding the ground typology some assumptions have been done since no reliable data were specified in the project; wet sand was chosen showing a thermal conductivity equal to 2,4 W/mK.

- Thermal diffusivity of the ground [19]: this parameter is also calculated automatically by inserting the ground type and is equal to 1,0E-0,6 m^2/s. To insert this value in the spreadsheet it has been converted into m^2/day resulting in 0,086 m^2/day.

- Undisturbed ground temperature: this temperature is equal to 14°C and it is obtained by some trials on the depth in the sheet “Temperatura del terreno” of the geothermal heat pump file. If the temperature remains constant in each month, this corresponds to the value looked for.

- Fluid properties: these parameters are pre-set values from the spreadsheet.

- Borehole characteristics: also these values are assumed equal to the pre-entered values of the sheet.

The output of the spreadsheet is the total length of the pipes and it is shown below:

Final results				
total borefield length	L	m		3464,2

Figure 3-5: Total bore field length

[16] ASHRAE Transactions, Volume 122, Part 1
[17] ASHRAE Transactions, Volume 122, Part 1

The other methodology analyzed is a simplified method [32] divided into three phases:

1. **Calculation of the electrical power:**

$$W_{el} = \frac{P_{th}}{COP} \quad \text{kW}$$

Where, in this case, the nominal thermal power is equal to 314 kW and the COP is 4,42; then the W_{el} is equal to 71 kW.

2. **Calculation of the heat that must be extracted from the ground:**

$$Q_{ter} = P_{th} - W_{el} = 243\ kW$$

3. **Calculation of the total pipes length:**

In order to estimate the total length of the geothermal pipes, the heat exchanger coefficient of the ground must be declared. This coefficient is derived from the "Idraulica-Impianti a pompe di calore geotermiche, CALEFFI".

The ground typology chosen, as in the previous case, is wet sand and then the heat exchanger coefficient is about 70 W/m; the value of this coefficient is enclosed in the table below:

Rese termicbe specificbe per sonde geotermicbe

Tipo sottosuolo	Conducibilità termica (W/mK)	Potenza estraibile (W/m) 1800 ore	Potenza estraibile (W/m) 2400 ore
Valori guida generali:			
Sottosuolo povero (sedimento secco)	<1,5	25	20
Rocce e terreni sciolti saturi d'acqua	1,5-3,0	60	50
Rocce ad alta conduttività termica	> 3,0	84	70
Tipologia roccia/terreno:			
Ghiaia, sabbia, asciutta	0,4	< 25	< 20
Ghiaia, sabbia, saturi d'acqua	1,8-2,4	65-80	55-65
Argilla, terriccio, umido	1,7	35-50	30-40
Calcare (massiccio)	2,8	55-70	45-60
Arenaria	2,3	65-80	55-65
Magmatite siliceea (ad esempio, granito)	3,4	65-85	55-70
Magmatite basica (ad esempio, basalto)	1,7	40-65	35-55
Gneiss	2,9	70-85	60-70

Figure 3-6:heat exchanger coefficients [32]

At this point, it is possible to find out the total pipes length:

$$L = {Q_{ter}}/{70\ W/m} = 3471\ m$$

As it can be seen from the results, the difference between the two outcomes is very low (7 m) and then it is negligible since there is a deviation equal to:

$$E = 1 - {3464}/{3471} = 1\%$$

Thanks to these results, the estimation of the pipes length can be considered a good approximation.

The result that has been chosen in order to establish the pipes depth, the number of pipes and the pipes typology is 3471 m; in this way if an error has been made it is an oversizing error.

The pipes depth has been chosen equal to 50 m; this value has been determined by looking at the undisturbed ground temperature and thanks to some researches; the studies show that the typical depths varies from 40 m to 250 m. [33]

The pipes typology is double U pipes; so that the number of pipes is:

$$N°_{pipes} = \frac{L}{50 * 4} = 17$$

Where 50 is the pipes depth and the number 4 derived from the pipes typology (double U).

Furthermore, the cooling performance of the selected heat pump must be inserted in the sheet #9 of the Block A to-be. The partial load factors, the nominal power and the typology of the heat pump have been defined.

At this point, it is possible to select the system typology in the block B and then evaluate the new performance and the consumptions reduction. In the *Table 3-29* the new parameters of the building are shown:

Riduzione dei consumi a seguito dell'intervento:		
Consumi to be:	109,74	kWh/m²
Consumi as is:	137,47	kWh/m²
Classe energetica to be:	A1	
Classe energetica as is:	C	
Δconsumi:	-27,73	kWh/m²

Table 3-29:new energy class and consumption reduction after the installation of a geothermal heat pump

As it can be seen, this energy efficiency measure has a great positive impact; in fact, the consumption reduction is equal to -27,73 kWh/m^2 which means that the building switched from a C class to an A1 class.

3.2.2 Photovoltaic plants

The installation of a photovoltaic plant is the second energy efficiency intervention that has been considered. In the as-is situation there is already a photovoltaic plant on the roof, but since it has a very low performance, the installation of different panels types would be better.

Moreover, the installation of a new photovoltaic plant has been considered as, in the examined building, there is a platform roof which surrounds the entrance and is exposed towards south-east. The installation of polycrystalline panels on the roof and the installation of thin layer of amorphous silicon on the platform have been chosen.

Thanks to the photovoltaic file, it was possible to evaluate the electricity production of the photovoltaic plant on the platform; the area of this plant is about 260 m^2 (value obtained referring to the dimensions of the platform roof).

In the following table the monthly and total electricity production of this plant is evaluated:

Calcolo dell'energia prodotta mensilmente dall'impianto fotovoltaico $E_{el,PV,out}$ (kWh)													
	GEN	FEB	MAR	APR	MAG	GIU	LUG	AGO	SET	OTT	NOV	DIC	TOT
$E_{el,PV,out}$	612,612	950,04	1528,8	1659,84	2031,12	2129,4	2358,72	2063,88	1616,16	1051,596	642,096	563,472	17207,74

Table 3-30: electricity production of the roof platform photovoltaic plant

As it can be seen from the previous figure, the electricity production is very low with respect to the installed area; this is because the thin layer of amorphous silicon has a low efficiency but, on the other hand, it is the cheapest type. Since the platform has a height of about 2,5 meters, it is affected by several shadings, so that the installation of very efficient panels is not convenient from an economic point of view. Indeed, if the cost and the electricity production are compared, it can be noticed that the high price and the high efficiency do not involve a significant production of electricity; as a consequence, it is more convenient to consider panels with a lower efficiency but with a decidedly lower investment cost.

Instead, the photovoltaic panels on the roof have been replaced with higher efficiency ones and, for this reason, the polycrystalline panels have been chosen. The higher cost of these panels is justified by a significant increase in electricity production; in the following table the as-is situation and the production of the polycrystalline panels are compared with respect to the same installed area:

Technology	Electricity production (kWh)
Thin layer of amorphous silicon	15024
Polycrystalline	32551

Table 3-31:comparison of the electricity production of the different photovoltaic plants

As it can be seen from the values the polycrystalline production is more than twice of that of amorphous silicon, thus justifying the higher cost.

3.2.3 Building Management system for the interior lighting

The third energy efficiency measure that is considered is the installation of building management system for the interior lighting. This choice has been done by considering the value of the primary energy associated to the interior lighting; in fact, this value is very high (E_{ill}= 83,34 kWh/m^2) and it has a great impact on the global primary energy. Moreover, by looking at the building features, one can note that the facades are mainly glazed and, for this reason, the installation of photosensor can have a significant influence on the interior lighting primary energy since, those sensors are able to evaluate the presence and the impact of the natural light.

In order to evaluate the positive impact of the photosensors, the Block B has been used; the consumption reduction and the new energy class are shown in the table below:

Riduzione dei consumi a seguito dell'intervento:	
Consumi to be:	104,12 kWh/m^2
Consumi as is:	137,47 kWh/m^2
Classe energetica to be:	A1
Classe energetica as is:	C
Δconsumi:	-33,35 kWh/m^2

Table 3-32: photosensors impact on consumption and energy class

As expected, photosensors have a great impact on the consumption reduction, in fact the installation of these involves a reduction equal to 33 kWh/m^2.

3.2.4 Energy efficiency scenarios

After the energy efficiency interventions have been chosen, they are combined in order to obtain four different energy efficiency scenarios; in this chapter the scenarios and their impacts are shown.

- **Scenario 1**: the first scenario is composed by the installation of a geothermal heat pump and photosensors. In the sheet "6- Scenari di ottimizzazione" of the block B one can see the positive impact of these two combined measures; in fact, thanks to the multiple-choice cells, the geothermal heat pump and the photosensors have been chosen and then the consumption decrease, sum of the two reductions, has been calculated.

SCENARIO 1		
Tipologia di interventi		Riduzione consumi (kWh/m²)
Pompa di calore geotermica	Per climatizzazione invernale e estiva	-27,73448388
BMS illuminazione	Fotosensori	-33,35061385
		0
		0
TOTALE:		-61,08509773

Table 3-33: consumption reduction of the scenario 1

As it can be seen from the previous figure, the scenario 1 involves a reduction equal to 61 kWh/m2. Considering that the global primary energy of the as-is building is equal to 137 kWh/m^2, it can be said that this scenario has a very good positive impact from an energetic point of view. At this point, the new energy class and the NZEB check are evaluated by clicking on the specific bottom.

Classe energetica a seguito dello scenario 1	
Consumi (kWh/m²)	Classe energetica
76,39	A2
Calcola classe	

L'edificio è nZEB?
NO

Figure 3-7: energy class and NZEB check of the scenario 1

Through the combination of these interventions the building can reach an A2 class that is one of the best classes. Instead, the NZEB check is not positive; this can be seen from the check table below:

Scenario 1:	verifica
L'edificio rispetta i requisiti sul coeff. Medio globale di scambio termico?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione estiva?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione estiva?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'indice di prestazione energetica?	SI
L'edificio rispetta gli obblighi sull'integrazione con fonti rinnovabili?	SI
L'edificio rispetta gli obblighi sulla potenza elettrica da fotovoltaico?	NO

Table 3-34: NZEB check table of the scenario 1

As shown, the only requirement that is not respected is the one concerning the photovoltaic power. In fact, no energy efficiency interventions regarding the installation of photovoltaic plants have been considered in this scenario. For this reason, in the following scenario the installation of photovoltaic plant will be considered.

- **Scenario 2**: The installation of photovoltaic plants and geothermal heat pump have been considered.

  As for the previous case, the consumption decrease is calculated by adding the two reductions. This scenario involves a consumption reduction equal to 31,3 kWh/m^2 and the new energy class becomes A1. The NZEB check is positive because all of the requirements are respected. Then, even if the consumption reduction of the scenario 1 is twice with respect to this scenario and the energy class is worse, the building is NZEB. This fact can be explained by looking at the corresponding requirements.

  Then, even if the consumption reduction is lower than in scenario #1 the building can be certified as NZEB.

SCENARIO 2		
Tipologia di interventi		Riduzione consumi (kWh/m^2)
Pompa di calore geotermica	Per climatizzazione invernale e estiva	-27,73448388
Fotovoltaico		-3,573714299
		0
		0
TOTALE:		-31,30819818

Table 3-35: consumption reduction of the scenario 2

Classe energetica a seguito dello scenario 2	
Consumi (kWh/m^2)	Classe energetica
106,16	A1
Calcola classe	

L'edificio è nZEB?
SI

Figure 3-8: energy class and NZEB check of the scenario 2

- **Scenario 3**: In the third scenario the installation of photovoltaic plants and photosensors are considered. Neglecting the geothermal heat pump, all requirements concerning the efficiency of heating and cooling systems will not be respected since they were already not compliant in the as-is building.

  The energetic results of this scenario are shown in the figures below:

SCENARIO 3		
Tipologia di interventi		Riduzione consumi (kWh/m^2)
BMS illuminazione	Fotosensori	-33,35061385
Fotovoltaico		-3,573714299
		0
		0
TOTALE:		-36,92432815

Table 3-36: consumption reduction of the scenario 3

Classe energetica a seguito dello scenario 3	
Consumi (kWh/m^2)	Classe energetica
100,55	A1
Calcola classe	

L'edificio è nZEB?
NO

Figure 3-9: energy class and NZEB check of the scenario 3

Scenario 3:	verifica
L'edificio rispetta i requisiti sul coeff. Medio globale di scambio termico?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la climatizzazione estiva?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di utilizzazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione invernale?	SI
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la climatizzazione estiva?	NO
L'edificio rispetta i requisiti sull'efficienza dei sottosistemi di generazione per la produzione di ACS?	SI
L'edificio rispetta i requisiti sull'indice di prestazione energetica?	SI
L'edificio rispetta gli obblighi sull'integrazione con fonti rinnovabili?	SI
L'edificio rispetta gli obblighi sulla potenza elettrica da fotovoltaico?	SI

Table 3-37:NZEB check table of the scenario 3

As expected the requirement on the efficiency of the cooling system is not respected, then the building is not NZEB.

- **Scenario 4**: the fourth scenario combines all the energy efficiency measures; in fact, geothermal heat pump, photovoltaic plant and photosensors are considered. In this scenario, there is a difference regarding the photovoltaic plant as no installation on the roof platform is considered. On the other hand, the extension of the area (300 m^2) and the change of panels type (polycrystalline) on the roof are considered. For this reason, the consumption reduction due to photovoltaic installation is different from the previous cases.

SCENARIO 4		
Tipologia di interventi		Riduzione consumi (kWh/m^2)
Pompa di calore geotermica	Per climatizzazione invernale e estiva	-27,73448388
BMS illuminazione	Fotosensori	-33,35061385
Fotovoltaico		-2,88
-		0
TOTALE:		-63,96509773

Table 3-38: consumption reduction of the scenario 4

Classe energetica a seguito dello scenario 4	
Consumi (kWh/m^2)	Classe energetica
73,51	A2
Calcolo classe	

L'edificio è nZEB?
SI

Figure 3-10: energy class and NZEB check of the scenario 4

As in the scenario 2, the building, after these measures, can be considered an NZEB building; this scenario is the best from the point of view of energetic parameters. In order to choose the best scenario, the economic analysis must be done once the investment cost has been assessed. In the following paragraph the investment costs of all these scenarios are calculated.

3.2.5 Investment cost of the scenarios

To evaluate from an economic point of view the different scenarios it is necessary to estimate the initial investment cost. In this case the cost that will be considered is the difference between the cost of the interventions in the as-is situation and the cost of the new technologies considered in the to-be situation. This needs to be done because, as previous mentioned, the energy efficiency measures are evaluated on the project and not on the existing building; then it is proper to consider a differential cost. Only in the case installations are not present in the building project, such as new photovoltaic plants, the investment cost will be not differential but absolute. It is important to state that all the costs are estimated based on price lists and approximated costs; therefore, some tolerable errors could occur.

The cost of the geothermal heat pump intervention is the difference between the cost of the reversible air-water heat pump and the cost of the geothermal heat pump that involves all the costs of geothermal pipes, perforation etc. So, it is appropriate to start by estimating the price of the reversible air-water heat pump. For this purpose, the Daikin price list has been used [34]. Moreover, in this calculation also the costs of pumps, valves and boiler are considered. The investment cost of the geothermal heat pump takes into account the cost of the heat pump and the costs of pumps, valves and boiler, the cost of the geothermal pipes and the cost of drilling and pipes installation. In order to estimate the heat pump investment cost the Alpha Innotec price list has been used [35]. Instead, the cost of drilling, pipes installation and geothermal pipes were derived from the lectures of "Technology for renewable energy sources" course [36].

In the following table the investment cost for the geothermal heat pump intervention is shown:

	PRICE
Reversible air-water heat pump + kit	159600 €
Geothermal heat pump + kit	137640 €
Drilling and pipes installation	42500 €
Geothermal double U pipes	68000 €
DIFFERENTIAL COST:	88540 €

Table 3-39: Geothermal heat pump cost

Instead, the cost of the photosensors is not a differential cost because in the project photosensors were not considered; in order to estimate this cost, the B.E.G price list has been used [37]. Moreover, to evaluate this price the number of photosensors to be installed must be estimated. For this purpose, the planimetry of a typical floor has been used. In fact, by looking at the office design the number of photosensors has been estimated.

In the figure below, the number and the positions of the photosensors (yellow points) are shown:

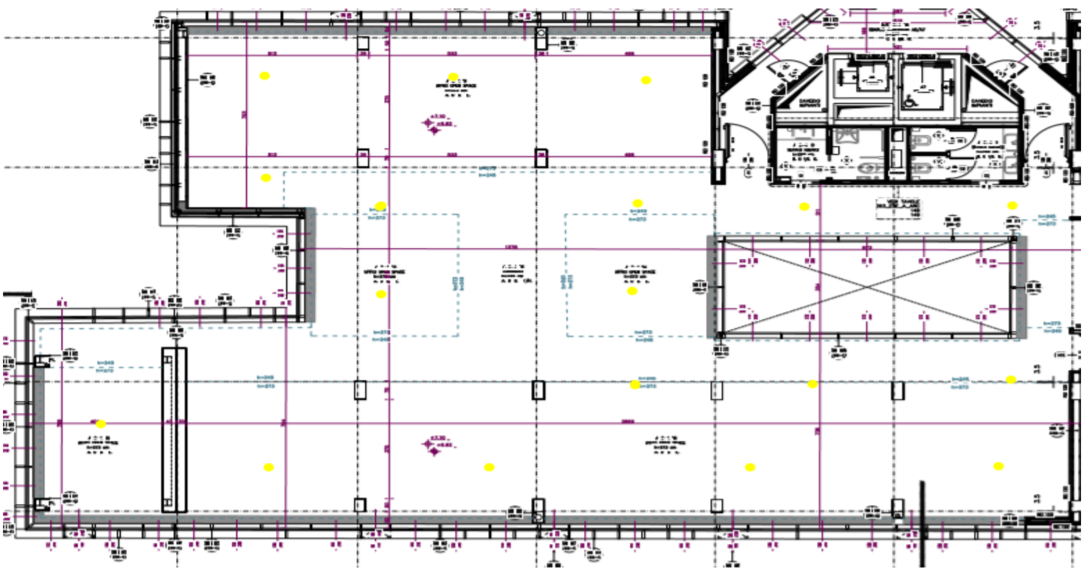


Figure 3-11: Photosensors design

In the previous figure, a fourth fraction of the standard floor is represented; then, to discover the total number of photosensors, those seen in the figure must be multiplied by four times the number of floors (six). The total number of photosensor that have to be installed results 450.

The investment cost for this intervention is shown in the following table:

	PRICE
Photosensors LUXOMAT	60151,50 €

Table 3-40: Photosensors cost

The investment cost for photovoltaic measure is divided into two components: the cost of the photovoltaic installed on the roof platform and the cost of the photovoltaic plant on the roof.

The first component is not a differential cost because in the project there isn't any photovoltaic plant on the roof platform; instead, the cost for the photovoltaic plant on the roof is a difference between the cost of the technology present in the project and the cost of the new panels. In the prices estimation, the inverter and installation cost are also considered.

For the roof platform installation, the Chimei thin layer of amorphous silicon panels have been chosen [38]; the peak power is equal to 100 kW and the total number of installed panels is 162.

The inverter chosen is "Inverter fotovoltaico EXE modello O15K" [39].

The total cost of the roof platform installation is presented below:

	PRICE
Photovoltaic plant on roof platform	11402,50 €

Table 3-41:Photovoltaic plant on roof platform cost

The cost of the photovoltaic plant on the roof is the difference between the cost of the thin layer of amorphous silicon panels and the cost of polycrystalline panels.

The Chimei thin layer of amorphous silicon panels and the IBC PolySol 270 VL4 panels have been chosen. The inverter chosen for the as-is situation is "Inverter fotovoltaico EXE modello O15K" [39] and that for the to-be situation is "Inverter fotovoltaico SAMIL POWER serie Solar Lake 30000TL-PM" [40].

The differential cost is shown below:

	PRICE
Photovoltaic plant AS-IS	10242,5 €
Photovoltaic plant TO-BE	22422,3 €
DIFFERENTIAL COST:	12179,8 €

Table 3-42: Photovoltaic plant on the roof differential cost

This cost is exact if one considers the scenario #2 and #3 but it is not suitable for the scenario #4; for the latter, in which the platform roof is not present, considering the same types of panels of the previous case, the differential cost is shown below:

	PRICE
Photovoltaic plant AS-IS	10242,50 €
Photovoltaic plant TO-BE	30807,8 €
DIFFERENTIAL COST:	20565,3 €

Table 3-43: Photovoltaic plant on the roof scenario #4 differential cost

To clarify the behavior of the different scenarios a graph is reported below:

Scenario:	Riduzione consumi (kWh/m^2):	Classe energetica as-is:	Classe energetica to-be:	Verifica nZEB:	Costo inerventi (€) :
Scenario 1	-61,09	C	A2	NO	€ 148.691,50
Scenario 2	-31,31	C	A1	SI	€ 112.122,30
Scenario 3	-36,92	C	A1	NO	€ 83.733,80
Scenario 4	-63,97	C	A2	SI	€ 169.256,80

Figure 3-12: Behaviour of the different scenarios

3.3 Energy price scenarios

To evaluate the electricity price the block C has been used. As previous said, the electricity price is calculated based on the hourly curve of the building consumption and on the historical values of the PUN and the PUN forward.

Being under construction, the examined building doesn't have any hourly curve of consumption; for this reason, the hourly curve of consumption of a very similar building (similar geometric features and office building) was considered.

The historical values of PUN and the forward PUN were provided by Engie. Thanks to these values it was possible to establish that the worst PUN, or rather the lowest PUN, is in 2016 with a value of 42,8 €/MWh; this is the value used to construct the worst scenario. Instead, the best PUN, hence the highest one with a value of 75,5 €/MWh in 2012 is used for the best scenario.

In the *figure 3-13* the PUN trend from 2018 to 2024 is shown; obviously this trend will be the same in the three scenarios. Even if the PUN values vary the shape of the curve stays the same.

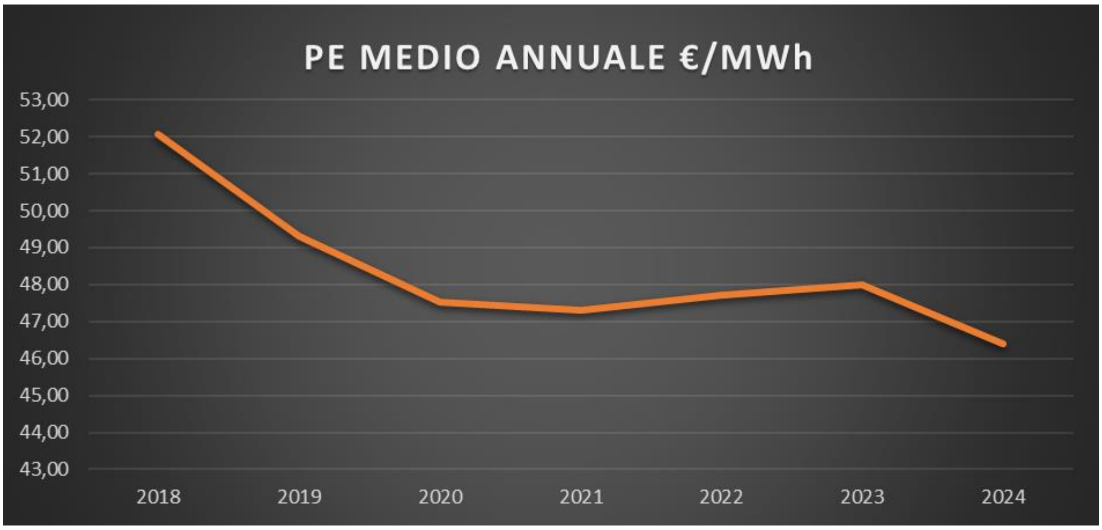


Figure 3-13: Trend of the PUN from 2018 to 2024

Moreover, in order to understand how the hourly curve varies for an office building, two graphs, one considering a typical day of the heating season (Thusday 24th January 2017) and the other considering a typical day of the cooling season (Thursday 13th July 2017), are represented:

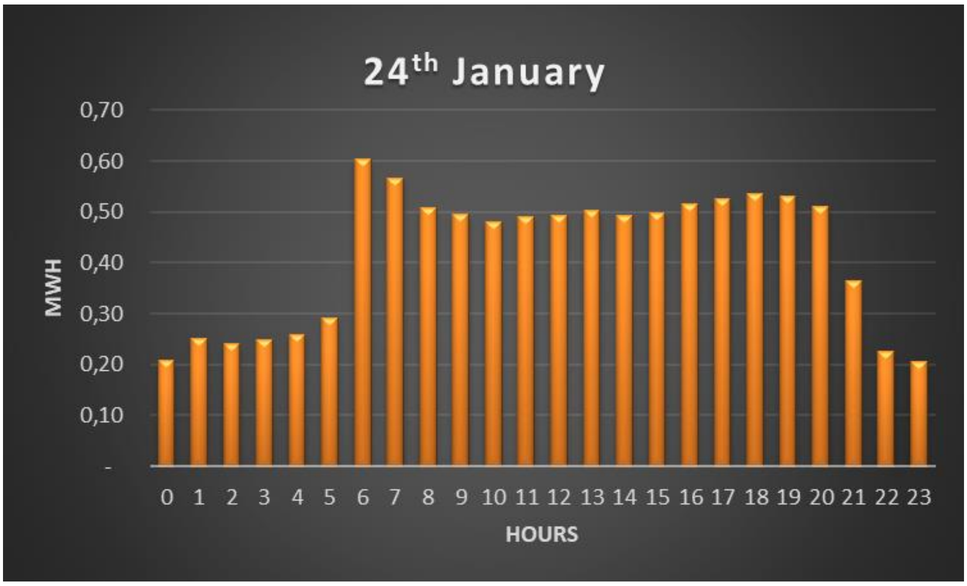


Figure 3-14: Hourly curve of 24th January

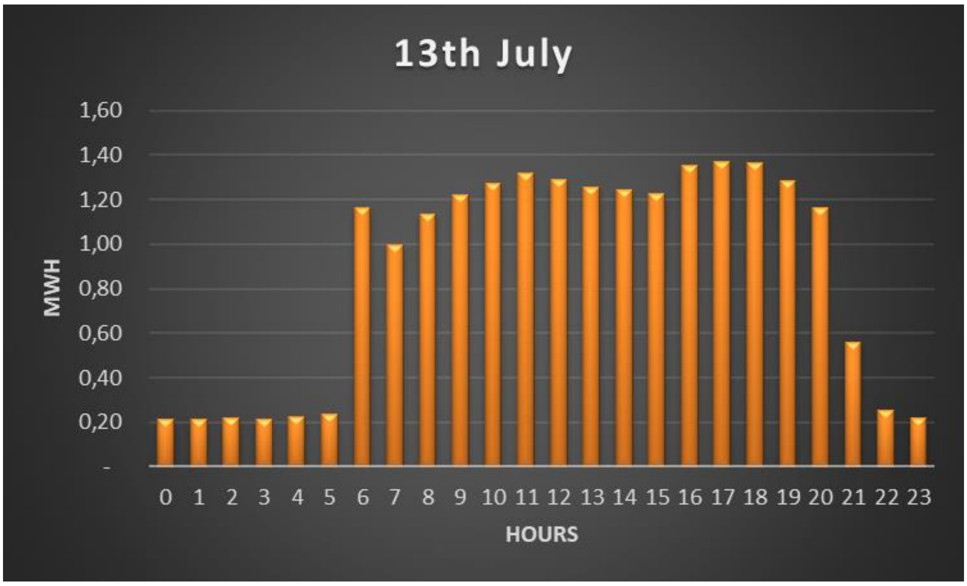


Figure 3-15: Hourly curve of 13th July

As it can be seen from the previous graphs the trend is very similar, even if in the summer period there are three peaks, one that corresponds to the start-up of the cooling machine (6 am) and the others that are at the hottest hours of the day (11 am, 4 pm). Instead, in the winter period the most obvious peak corresponds to the start-up of the heating system (6 am). The main difference, between the two graphs, regards the MWh values; in fact, in the summer period, the building has a decidedly greater consumption. This fact, which is also found in the values of primary energy, is typical when considering an office building whose summer conditioning is very impactful.

In the following tables the electricity price and the PUN of the three scenarios are represented; these values will be used in the block D to perform the economic analysis.

Anno	FORWARD PUN €/MWh	BEST PUN €/MWh	WORST PUN €/MWh
2018	52,08	75,51	42,78
2019	49,31	72,74	40,01
2020	47,53	70,96	38,23
2021	47,31	70,74	38,00
2022	47,71	71,15	38,41
2023	48,00	71,43	38,69
2024	46,41	69,84	37,11
2025	45,56	68,99	36,25
2026	44,86	68,29	35,56
2027	44,17	67,60	34,87
2028	43,47	66,90	34,17
2029	42,78	66,21	33,48
2030	42,08	65,51	32,78

Table 3-44: PUN values

Anno	FORWARD Prezzo energia €/MWh	BEST Prezzo energia €/MWh	WORST Prezzo energia €/MWh
2018	157	181	148
2019	154	178	145
2020	152	176	143
2021	152	175	143
2022	152	176	143
2023	153	176	143
2024	151	174	142
2025	150	174	141
2026	149	173	140
2027	149	172	139
2028	148	171	138
2029	147	170	138
2030	146	170	137

Table 3-45: Electricity prices

3.4 Economic analysis

To perform the economic analysis the results of the block B and then the consumption reduction, the energy class, the NZEB check and the investment costs, and the results of the block C, so the electricity prices are considered. Firstly, the cash flows of the scenarios that consider the consumption reduction are evaluated; they are shown in the following tables:

Anno:	Flussi di cassa (€)- Scenario 1:		
	Caso Forward	Caso Best	Caso Worst
2018	€ 93.382	€ 107.294	€ 87.860
2019	€ 91.566	€ 105.477	€ 86.043
2020	€ 90.440	€ 104.352	€ 84.918
2021	€ 90.254	€ 104.166	€ 84.731
2022	€ 90.522	€ 104.433	€ 84.999
2023	€ 90.706	€ 104.618	€ 85.184
2024	€ 89.666	€ 103.577	€ 84.143
2025	€ 89.107	€ 103.019	€ 83.584
2026	€ 88.650	€ 102.562	€ 83.128
2027	€ 88.194	€ 102.105	€ 82.671
2028	€ 87.737	€ 101.649	€ 82.214
2029	€ 87.280	€ 101.192	€ 81.758
2030	€ 86.824	€ 100.735	€ 81.301

Table 3-46: Cash flows of the scenario #1

Anno:	Flussi di cassa (€)- Scenario 2:		
	Caso Forward	Caso Best	Caso Worst
2018	€ 47.862	€ 54.992	€ 45.031
2019	€ 46.930	€ 54.061	€ 44.100
2020	€ 46.354	€ 53.484	€ 43.523
2021	€ 46.258	€ 53.388	€ 43.428
2022	€ 46.395	€ 53.526	€ 43.565
2023	€ 46.490	€ 53.620	€ 43.660
2024	€ 45.957	€ 53.087	€ 43.126
2025	€ 45.670	€ 52.801	€ 42.840
2026	€ 45.436	€ 52.567	€ 42.606
2027	€ 45.202	€ 52.332	€ 42.372
2028	€ 44.968	€ 52.098	€ 42.138
2029	€ 44.734	€ 51.864	€ 41.904
2030	€ 44.500	€ 51.630	€ 41.670

Table 3-47: Cash flow of the scenario #2

Anno:	Flussi di cassa (€)- Scenario 3:		
	Caso Forward	Caso Best	Caso Worst
2018	€ 56.447	€ 64.856	€ 53.109
2019	€ 55.349	€ 63.758	€ 52.011
2020	€ 54.669	€ 63.078	€ 51.330
2021	€ 54.556	€ 62.965	€ 51.218
2022	€ 54.718	€ 63.127	€ 51.380
2023	€ 54.830	€ 63.239	€ 51.491
2024	€ 54.200	€ 62.610	€ 50.862
2025	€ 53.863	€ 62.272	€ 50.525
2026	€ 53.587	€ 61.996	€ 50.249
2027	€ 53.311	€ 61.720	€ 49.972
2028	€ 53.035	€ 61.444	€ 49.696
2029	€ 52.759	€ 61.168	€ 49.420
2030	€ 52.483	€ 60.892	€ 49.144

Table 3-48: Cash flow of the scenario #3

Anno:	Flussi di cassa (€)- Scenario 4:		
	Caso Forward	Caso Best	Caso Worst
2018	€ 97.785	€ 112.353	€ 92.002
2019	€ 95.883	€ 110.450	€ 90.100
2020	€ 94.704	€ 109.272	€ 88.921
2021	€ 94.509	€ 109.077	€ 88.726
2022	€ 94.789	€ 109.357	€ 89.007
2023	€ 94.983	€ 109.551	€ 89.200
2024	€ 93.893	€ 108.461	€ 88.110
2025	€ 93.308	€ 107.876	€ 87.525
2026	€ 92.830	€ 107.398	€ 87.047
2027	€ 92.352	€ 106.919	€ 86.569
2028	€ 91.873	€ 106.441	€ 86.091
2029	€ 91.395	€ 105.963	€ 85.612
2030	€ 90.917	€ 105.485	€ 85.134

Table 3-49: Cash flow of the scenario #4

The cash flows have been calculated by multiplying the electricity prices by the consumption reduction evaluated in MWh.

In addition to these cash flows, those related to the increase in the rent must also be considered; to quantify these cash flows the values proposed by "Borsino immobiliare" [27] are considered. The table reported below represents the differential coefficients for the real estate values based on the energy class:

Valore patrimoniale immobile		
Classe	MIN (€/mq)	MAX (€/mq)
A3	80	150
A2	53	100
A1	27	50
A	0	0
B	-80	-150
C	-160	-200
D	-210	-250
E	-260	-300
F	-310	-350
G	-360	-400

Table 3-50: Differential coefficient for real estate values

To obtain the corresponding coefficients for the rent value, a proportion has been set based on the value of the property in that specific area and on the value of the rent in the same area:

$$V_{real-estate} : V_{rent} = C_{real-estate} : C_{rent}$$

Where $V_{real\text{-}estate}$ is the real estate value of the building expressed in €/m², V_{rent} is the rent value expressed in €/m², $C_{real\text{-}estate}$ is the differential coefficient for real estate and C_{rent} is the unknown and then the differential coefficient for rent value.

Thanks to this proportion it is possible to build the same table but considering the rent values.

Valore locazione immobile		
Classe	MIN (€/mq)	MAX (€/mq)
A3	0,42	0,83
A2	0,28	0,55
A1	0,14	0,28
A	0,00	0,00
B	-0,42	-0,83
C	-0,84	-1,11
D	-1,10	-1,38
E	-1,37	-1,66
F	-1,63	-1,93
G	-1,89	-2,21

Table 3-51: Differential coefficient for rent values

The cash flows that refer to the increase in the rent values were built making some considerations:

- The value assigned to the as-is situation is -0,84 €/m2 because the building is a C class, but the consumptions were very close to class B and then the minimum, that, in this case, is the best value (because they are demerit coefficients) has been chosen
- The value assigned to the scenario #1 is +0,28 €/m2 because the building is A2 class but the NZEB check is negative and the minimum, that, in this case, is the worst value (because they are merit coefficients) has been chosen.
- The value assigned to the scenario #2 is +0,28 €/m2 because the building is A1 class but the NZEB check is positive then the maximum has been chosen.
- The value assigned to the scenario #3 is +0,14 €/m2 because the building is A1 class and the NZEB check is negative then the minimum has been chosen.
- The value assigned to the scenario #4 is +0,55 €/m2 because the building is A2 class and the NZEB check is positive.

After the coefficients have been assigned the cash flows have been calculated:

FLUSSI DI CASSA SCENARIO 1:				
Aumento locazione	1,12	€/mq	10896	€/anno
Aumento valore patrimoniale	213	€/mq	2073532	€

Figure 3-16: Cash flows that take into account the rent values and the real estate values for the scenario #1

FLUSSI DI CASSA SCENARIO 2:				
Aumento locazione	1,12	€/mq	10857	€/anno
Aumento valore patrimoniale	210	€/mq	2041133	€

Figure 3-17: Cash flows that take into account the rent values and the real estate values for the scenario #2

FLUSSI DI CASSA SCENARIO 3:				
Aumento locazione	0,98	€/mq	9534	€/anno
Aumento valore patrimoniale	187	€/mq	1814340	€

Figure 3-18: Cash flows that take into account the rent values and the real estate values for the scenario #3

FLUSSI DI CASSA SCENARIO 4:				
Aumento locazione	1,39	€/mq	13543	€/anno
Aumento valore patrimoniale	260	€/mq	2527117	€

Figure 3-19: Cash flows that take into account the rent values and the real estate values for the scenario #4

The economic analysis is performed through the calculation of three different parameters, internal rate of return, pay-back time and net present value, considering the three energy prices scenarios in two different situation: firstly considering the sum of the two cash flows, one related to the consumption reduction and the other related to the increase in rent values and after considering only the consumption reduction cash flows. In the following lines, the economic parameters, in these different cases, and the assumptions made for every scenario are presented:

1. **SCENARIO 1**:

   The scenario #1 includes the installation of a geothermal heat pump and the installation of photosensors. To calculate the amortization of the geothermal heat pump the Italian legislation gives some rules with the "Legge di stabilità 2018"; in fact, it is possible to apply the super-amortization measure that establishes an amortization equal to 130% [41]. Instead, for the photosensors, the amortization percentage was taken from the "Tabella dei coefficienti di ammortamento- DM 31/12/1988" [42] and is equal to 25%.

   In addition to the super-amortization the geothermal heat pump also benefits of some tax deductions called "Ecobonus"; the tax deduction of 65% for heat pumps is still extended in the "Legge di stabilità 2018" until 31 December 2018 [43]. However, there is a maximum threshold of 30000€. Then, since in this case the tax deductions for the heat pumps exceed the threshold, a tax deduction of 30000€ splitted in ten years is considered.

   The assumption that was made is on the target of the internal rate of return (IRR); if the IRR evaluated on the tenth year is lower with respect to the target, the investment is to be discarded, instead, if the IRR is higher the investment is profitable. Then the choice of the target is of significant importance; the Engie target is taken into account and it is equal to 10%, this is a specific value that was chosen precisely for this business case. This value has been used also for the calculation of the net present value such as internal rate of return.

In the table below the economic parameters in the different situations are shown:

SCENARIO #1				
Energy prices scenarios:		**Best**	**Forward**	**Worst**
Consumptions reduction + increase in the rent value	IRR (10 yrs)	86%	65%	59%
	PBT	2,61 yrs	3,13 yrs	3,42 yrs
	NPV (10 yrs)	267.209 €	211.413 €	210.565 €
Only consumptions reduction	IRR (10 yrs)	69%	52%	46%
	PBT	2,99 yrs	3,74 yrs	4,11 yrs
	NPV (10 yrs)	223.507 €	167.711 €	145.561 €

Table 3-52: Economic parameters of the scenario #1

2. **SCENARIO 2**:

The scenario #2 involves the installation of a geothermal heat pump and the installation of a photovoltaic plant; the same considerations made previously for the heat pump are valid. For the photovoltaic plant the amortization is 9% [44]. Tax deductions for photovoltaics amount to 50% to be divided into ten years as established by "Legge di stabilità 2018"; also this deduction belongs to the "Ecobonus" [43].

In the following table the economic parameters of the scenario #2 are represented:

SCENARIO #2				
Energy prices scenarios:		**Best**	**Forward**	**Worst**
Consumptions reduction + increase in the rent value	IRR (10 yrs)	57%	45%	43%
	PBT	3,35 yrs	3,93 yrs	4,23 yrs
	NPV (10 yrs)	125.295 €	96.698 €	85.346 €
Only consumptions reduction	IRR (10 yrs)	40%	30%	26%
	PBT	4,34 yrs	5,38 yrs	5,94 yrs
	NPV (10 yrs)	81.594 €	52.996 €	41.644 €

Table 3-53: Economic parameters of the scenario #2

3. **SCENARIO 3**:

The scenario #3 includes the installation of photosensors and photovoltaic plants.

All considerations previously done are valid.

The economic parameters for the third scenario are shown below:

SCENARIO #3				
Energy prices scenarios:		**Best**	**Forward**	**Worst**
Consumptions reduction + increase in the rent value	IRR (10 yrs)	102%	77%	69%
	PBT	2,36 yrs	2,82 yrs	3,05 yrs
	NPV (10 yrs)	182.474 €	148.746 €	135.358 €
Only consumptions reduction	IRR (10 yrs)	75%	56%	49%
	PBT	2,89 yrs	3,64 yrs	4,03 yrs
	NPV (10 yrs)	144.235 €	110.507 €	97.118 €

Table 3-54: Economic parameters of the scenario #3

4. **SCENARIO 4**:

Also for the scenario #4 the same considerations made above are valid; the economic parameters are presented in the following table:

SCENARIO #4				
Energy prices scenarios:		**Best**	**Forward**	**Worst**
Consumptions reduction + increase in the rent value	IRR (10 yrs)	77%	60%	54%
	PBT	2,36 yrs	2,82 yrs	3,05 yrs
	NPV (10 yrs)	277.212 €	218.785 €	195.591 €
Only consumptions reduction	IRR (10 yrs)	61%	46%	41%
	PBT	2,89 yrs	3,64 yrs	4,03 yrs
	NPV (10 yrs)	222.896 €	164.469 €	141.275 €

Table 3-55: Economic parameters of the scenario #4

As it can be seen from the previous tables, all the scenarios involve excellent values of the economic parameters. This fact can be explained referring to the investment cost that, in this case, is a differential cost and not an absolute one. In fact, if, for example, the total cost of the geothermal heat pump is considered in the scenario #1, the tool returns a value of IRR equal to 11%, a PBT equal to seven years in the case of forward energy prices and considering both the consumption reduction and the increase in rent values. This highlights how important it is to consider differential and not absolute prices.

It is right and proper, at this point, to compare the behavior of the different scenarios from an economic point of view; for this purpose, some graphs are reported below.

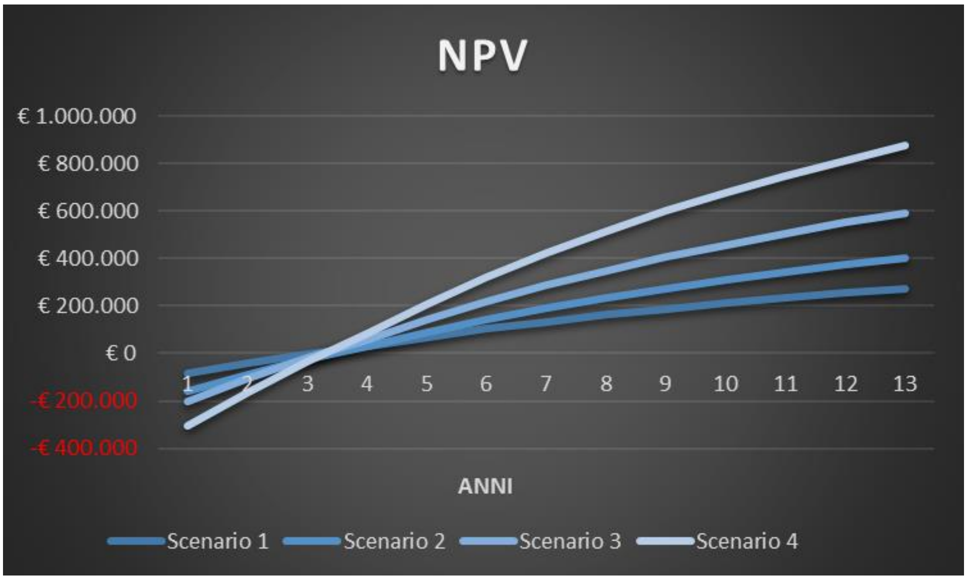


Figure 3-20: Comparison of the net present value considering the forward energy prices and both the consumption reduction and the increase in rent values.

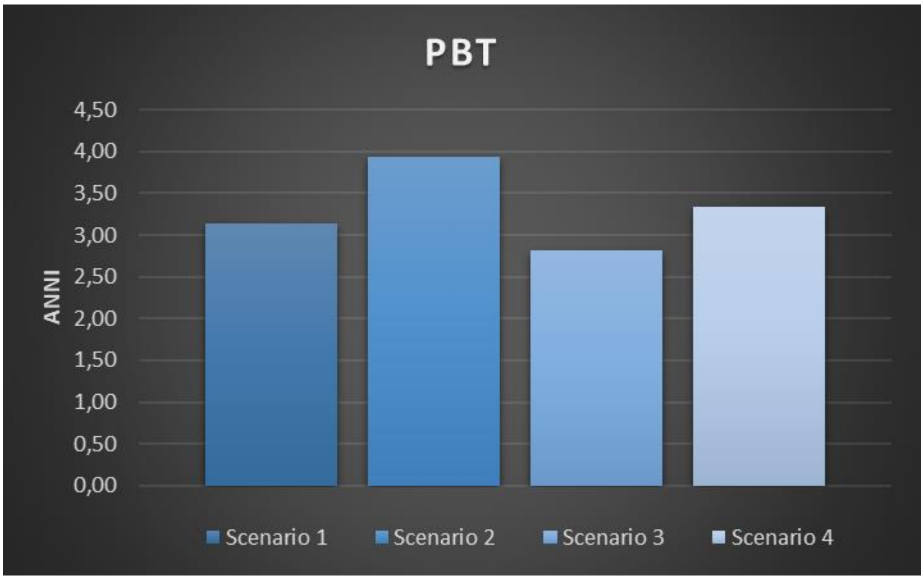


Figure 3-21:Comparison of the pay-back time considering the forward energy prices and both the consumption reduction and the increase in rent values.

Scenario:	IRR (10 anni)
1	65%
2	45%
3	77%
4	60%

Table 3-56: Comparison of the internal rate of return considering the forward energy prices and both the consumption reduction and the increase in rent values.

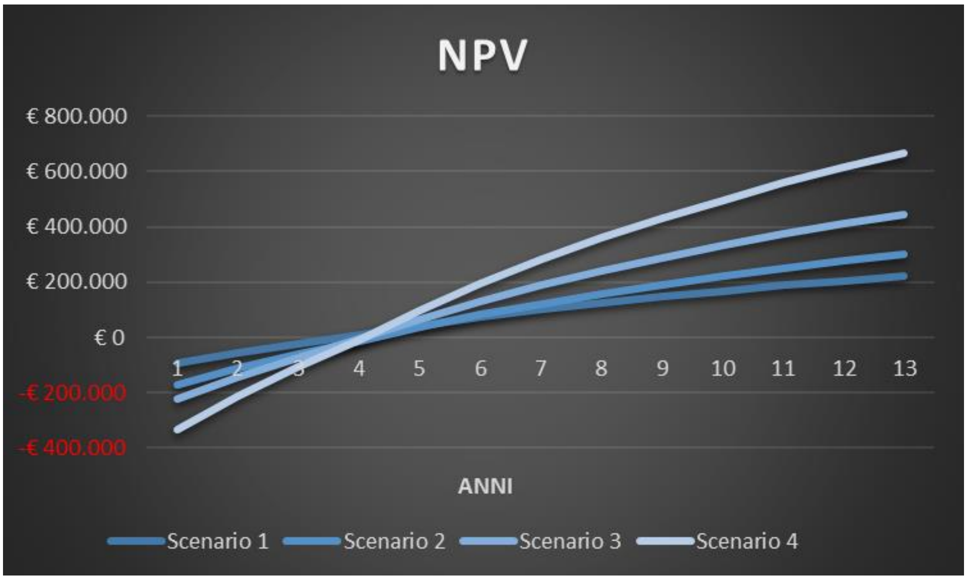


Figure 3-22:Comparison of the net present value considering the forward energy prices and only the consumption reduction

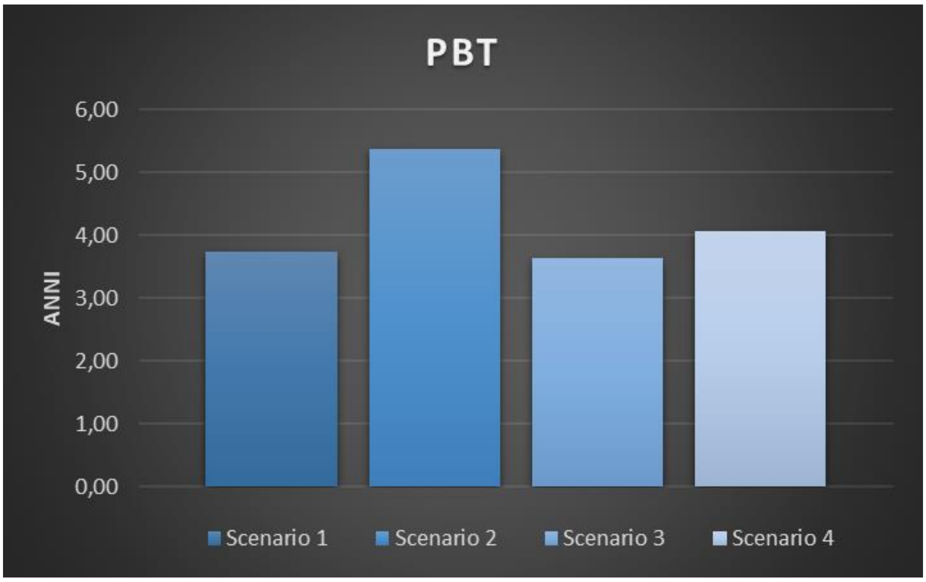


Figure 3-23: Comparison of the pay-back time considering the forward energy prices and only the consumption reduction

Scenario:	IRR (10 anni)
1	52%
2	30%
3	56%
4	46%

Table 3-57: Comparison of the internal rate of return considering the forward energy prices and only the consumption reduction

As it can be seen from the graphs, the NPV of the scenario #4 is always the best; however, this does not happen if the IRR is considered. In fact, the IRR of the scenario #3 is always better. Concerning the scenario #2 the IRR values, in both cases, are higher than in the scenario #4 and lower than in the scenario #3; instead the NPV is lower.

The scenario #1 is the worst both for IRR and NPV. Concerning the pay-back time, the scenario #2 has the worst value followed by scenario #4.

To choose the best scenario, a trade-off between the three parameters is necessary; for this purpose, the IRR was the parameter chosen for evaluations, giving it greater weight with respect to the others. Therefore, the scenario #3 turns out to be the best, from an economic point of view, because it always has the best IRR, an intermediate NPV and always the lowest PBT.

At this point, the dashboard reports of all the scenarios are shown in order to evaluate both the energetic and economic behavior of each individual scenario and choose the best one.

3.5 Dashboard reports

In this chapter the dashboard reports for each energy efficiency scenario are shown and discussed. Only for the first scenario the entire dashboard will be reported in order to have a complete overview; for the other scenarios the single sections are only shown.

- **SCENARIO 1: Geothermal heat pump + Photosensors**

Figure 3-24: Dashboard report of the scenario #1

To understand the several sections of this dashboard, it is right and proper to discuss them separately.

1. Energy performance:

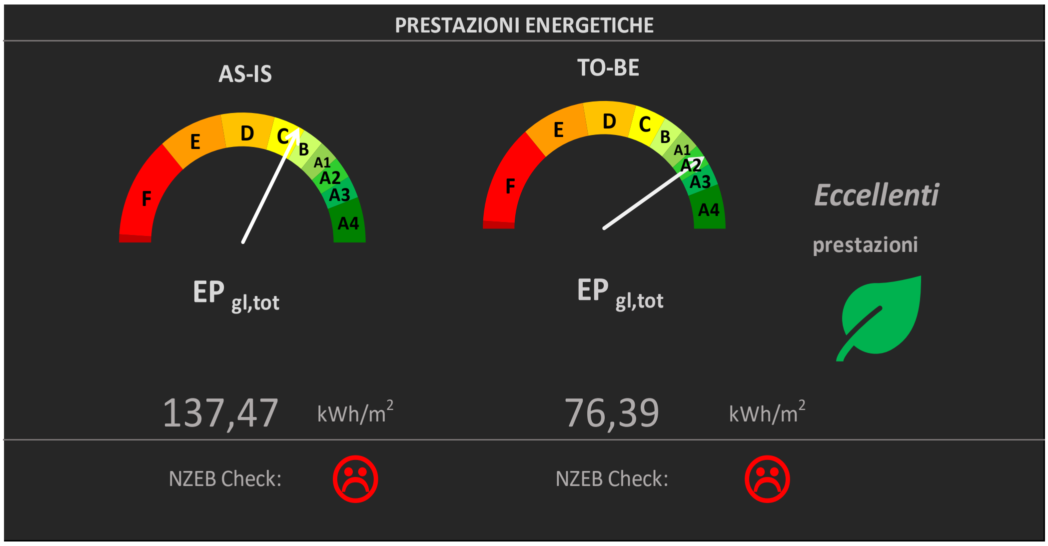
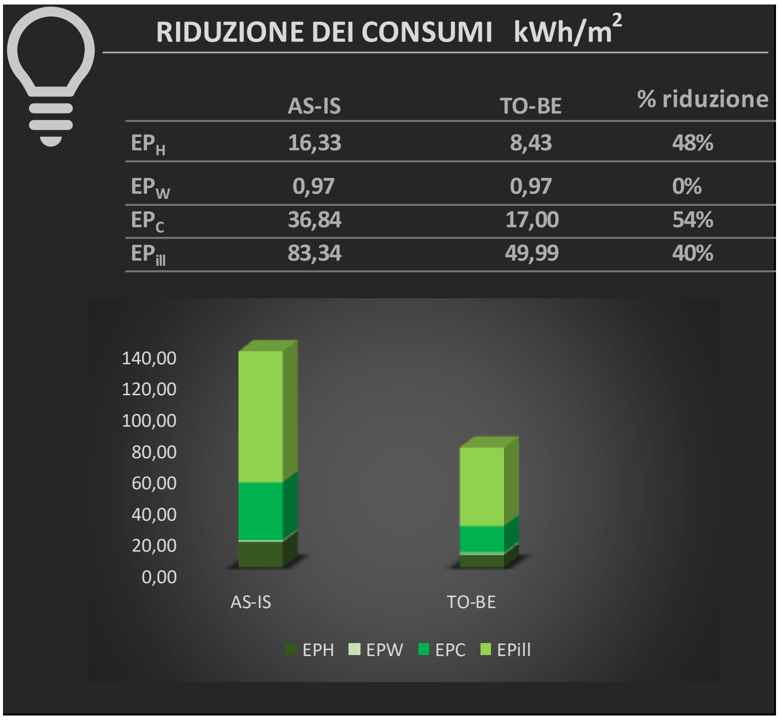


Figure 3-25: Energy performance of the scenario #1

As it can be seen from the graph, thanks to scenario #1 the building becomes of class A2 with a global primary energy equal to 76,39 kWh/m^2. Instead, as in the as-is situation, the NZEB check is negative. The to-be building can be considered with excellent performances.

2. Consumption reductions:


RIDUZIONE DEI CONSUMI kWh/m^2

	AS-IS	TO-BE	% riduzione
EP_H	16,33	8,43	48%
EP_W	0,97	0,97	0%
EP_C	36,84	17,00	54%
EP_{ill}	83,34	49,99	40%

Figure 3-26: Consumptions reduction of the scenario #1

As it can be seen, the consumptions reduction regards almost all services; the consumption for heating decreases by 48%, those regarding the air-conditioning in summer period decreases of 54%; these two positive impacts are attributable to the geothermal heat pump installation. Instead, the photosensors installation allows to reduce the lighting consumption of 54%. Thanks to these values, it is easy to understand that both the energy efficiency measures perform very well in terms of consumption reduction.

3. Investment cost vs consumptions reduction:

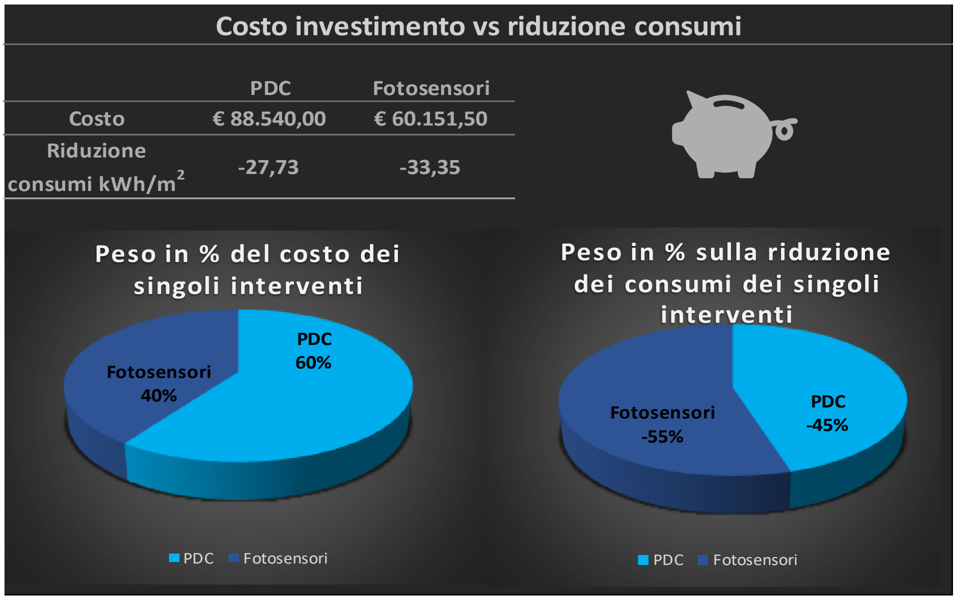


Figure 3-27: Investment cost vs consumptions reduction for the scenario #1

Thanks to these graphs the two measures can be compared from the investment cost and consumptions reduction point of views. As it can be seen, the two interventions are very similar even if the photosensors turn out to be the best option, because their percentage weight on the investment cost is lower (40%) even if they involve a greater consumption reduction (-55%).

4. Increase in the real estate and rent values of the building:

Figure 3-28: Increase in the real estate and rent value of the building

Thanks to this scenario the rent value of the building increase of 1,12 €/m^2 and the real estate value of 213 €/m^2; these two earnings have a low percentage weight but considering the high area of the building they have a good absolute value: +10896 € per year if the rent value is considered and +2.332.723 € if the real estate value is considered. Moreover, the NZEB check is negative and this has a negative impact on the increase in these values.

5. Economic analysis:

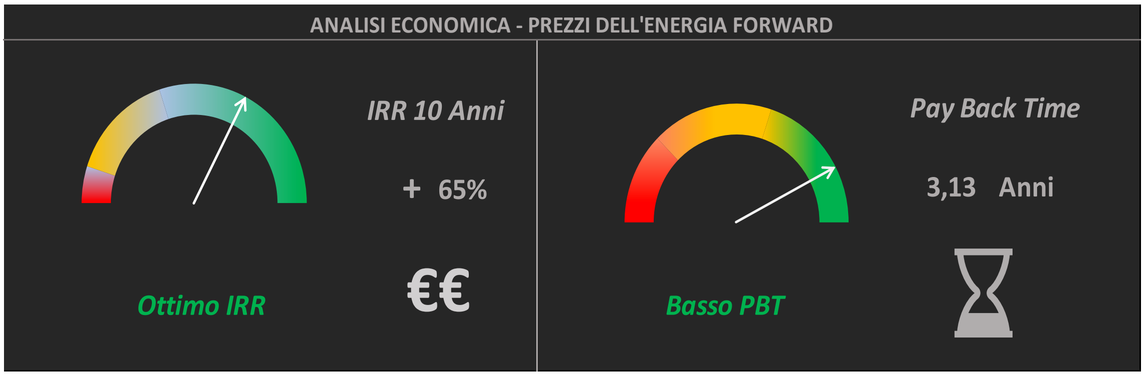


Figure 3-29: Economic analysis of the scenario #1

The internal rate of return and the pay-back time are evaluated in this section. Both these parameters have excellent values.

6. Economic analysis vs energy prices:

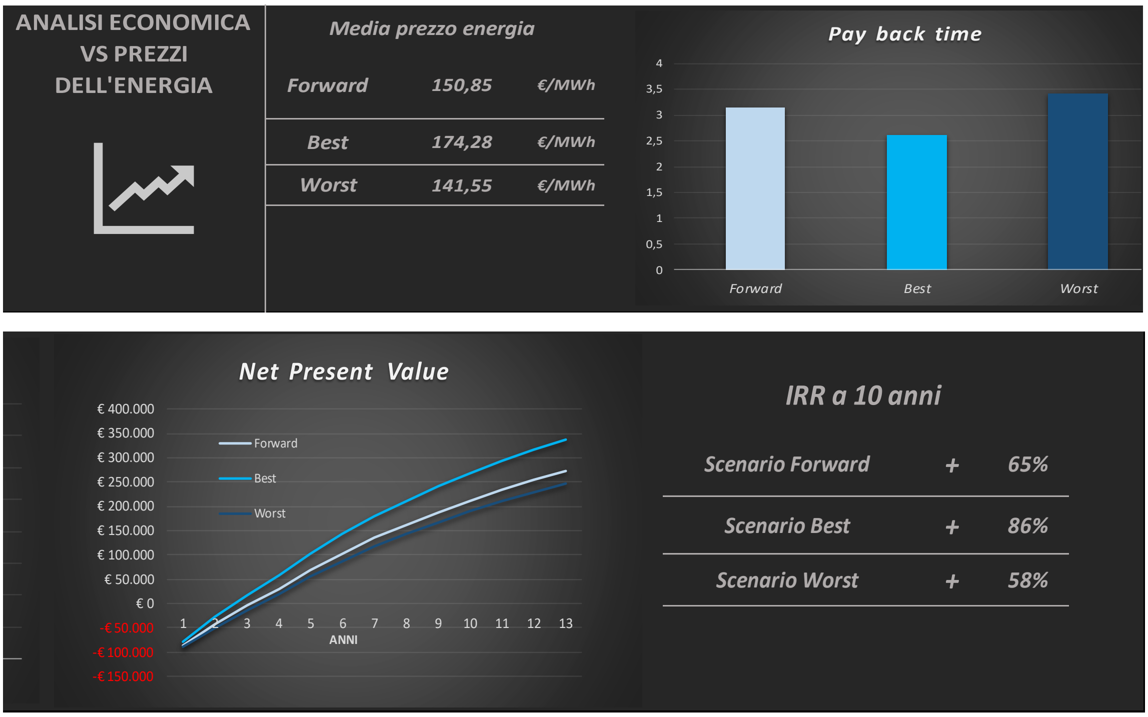


Figure 3-30: Economic analysis vs energy prices

As it can be seen from the first table, the gap between the best and worst energy prices scenario is about 33 €/MWh. Thanks to the bar graph one can see how this gap affects the pay-back time; in the best case this has a value of about 2,5 years, instead in the worst one it is equal to 3,4 years. Both these values are excellent and the real pay-back time will almost certainly fall within this gap. Thus, it is possible to state that, from the point of view of pay-back time, the investment is profitable. The net present value is, in any case, very good; in fact, the three curves have a steep slope which is a positive factor. In the end, the internal rate of return is evaluated; it has a lowest value equal to 58% and a highest value equal to 86%, both in the range of the excellent values.

- **SCENARIO 2: Geothermal heat pump + Photovoltaic**

1. Energy performance:

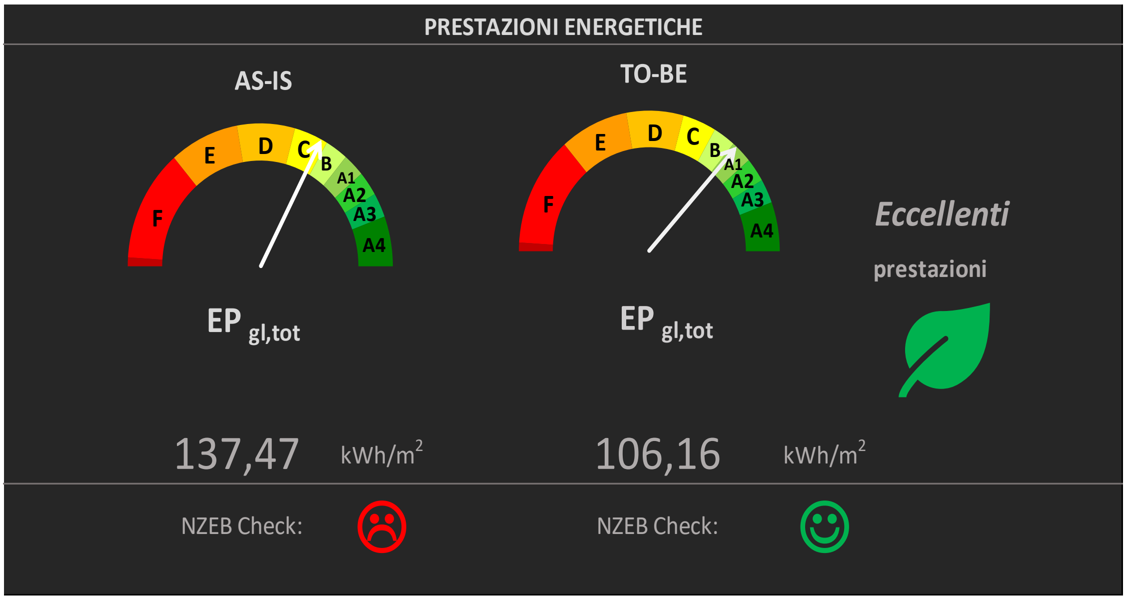


Figure 3-31: Energy performance of the scenario #1

As it can be seen from the graph, thanks to scenario #2 the building becomes of class A1 with a global primary energy equal to 106,16 kWh/m². Although the energy class is worse than in scenario #1 and the global primary energy is higher, the NZEB check is positive. This fact will surely have a positive impact on the real estate value of the building.

2. Consumption reductions:

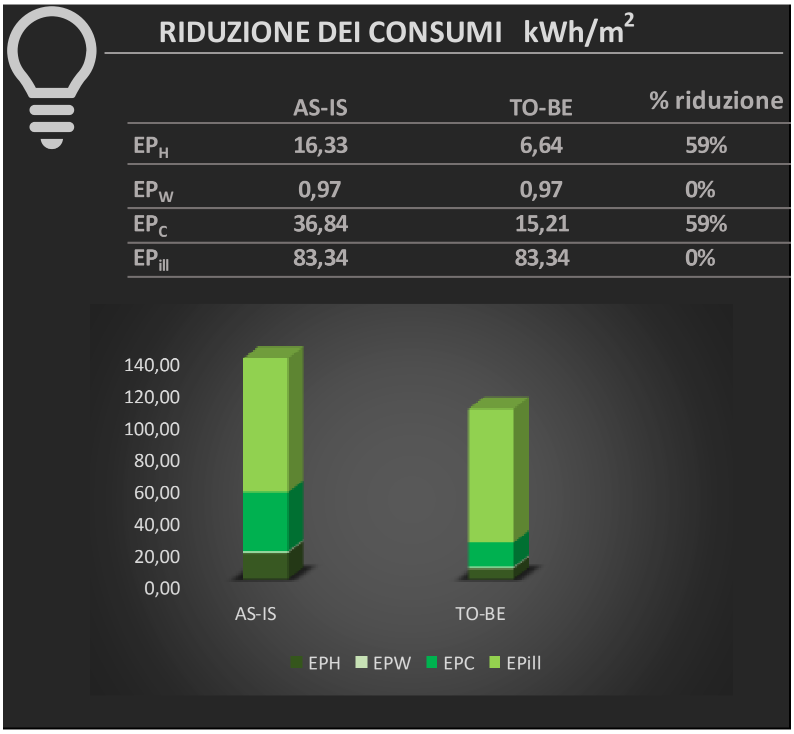


Figure 3-32: Consumptions reduction of the scenario #1

As it can be seen, the consumption reduction regards half of the services; the consumption for heating decreases by 59% such as those regarding the air-conditioning in summer period. These two positive impacts are attributable both to the geothermal heat pump installation and to the photovoltaic installation. To understand if both the energy efficiency measures have high performances it is necessary to move to the following analysis.

3. Investment cost vs consumptions reduction:

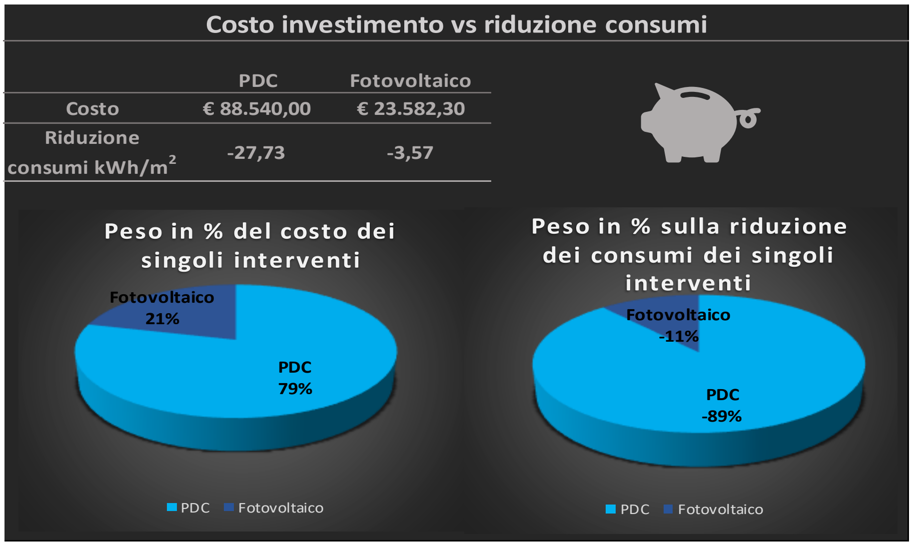


Figure 3-33: Investment cost vs consumptions reduction for the scenario #1

Thanks to these graphs the two measures can be compared from the point of view of investment cost and consumptions reduction; as it can be seen, the photovoltaic plant installation has a low investment cost with respect to the geothermal heat pump, but it also has a low influence on the consumption reduction. The geothermal heat pump turns out to be the best intervention; this because its percentage weight on the investment cost is 79% but it involves a great consumption reduction (-89%). If these values are compared with the same values of the photovoltaic, it is easy to note that the latter performs in a worse way.

4. Increase in the real estate and rent values of the building:

Figure 3-34: Increase in the real estate and rent value of the building

Thanks to this scenario the rent value of the building increase of 1,12 €/m^2 and the real estate value of 210 €/m^2; these two earnings have a low percentage weight but they have a good absolute value: +10857 € per year if the rent value is considered and +2.041.133 € if the real estate value is considered. The NZEB positive influence is found in these values; in fact, although the building is of a worse class, the rent value of the property remains the same with respect to the previous scenario.

5. Economic analysis:

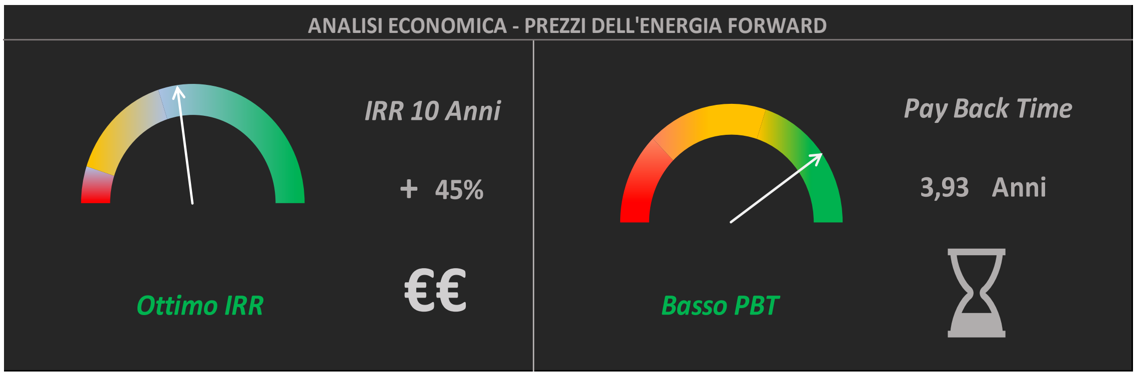


Figure 3-35: Economic analysis of the scenario #1

The internal rate of return and the pay-back time are evaluated in this section. Both these parameters have excellent values even if they are both worse with respect to those in scenario #1.

6. Economic analysis vs energy prices:

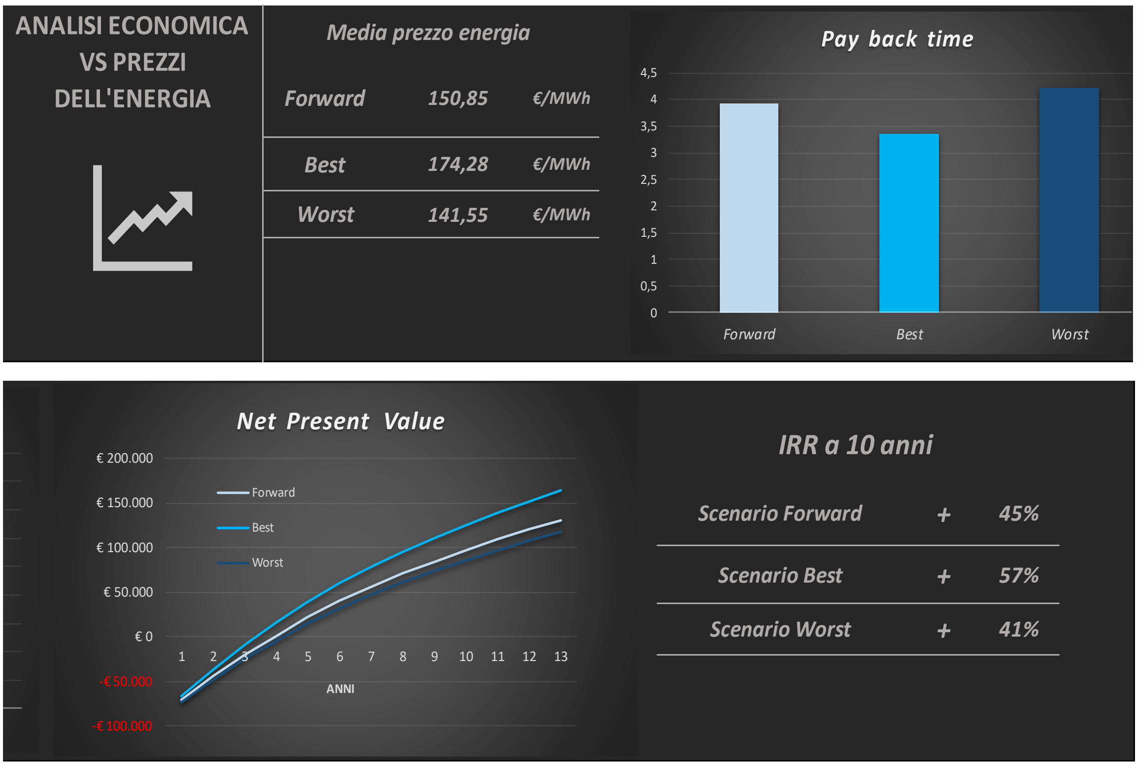


Figure 3-36: Economic analysis vs energy prices

Thanks to the bar graph, one can see the pay-back time behavior; in the best case this has a value of about 3,4 years, instead in the worst case it is equal to 4,2 years. Both these values are excellent, and the real pay-back time will almost certainly be in this gap; thus, it is possible to state that, from the point of view of pay-back time, the investment is profitable. The net present value is, in any case, very good; it is possible to notice that the NPV curve of the forward scenario is very close with respect to those of the worst case; this behavior is found in all the scenarios because it depends on the gap between the energy forward price and the energy worst price that is lower with respect to the gap considering the forward and the best energy price. In the end, the internal rate of return is evaluated, and this has a lowest value equal to 41% and a highest value equal to 57%, both in the range of the excellent values even if they are decidedly lower than the previous scenario.

- **SCENARIO 3: Photosensors + Photovoltaic**

1. Energy performance:

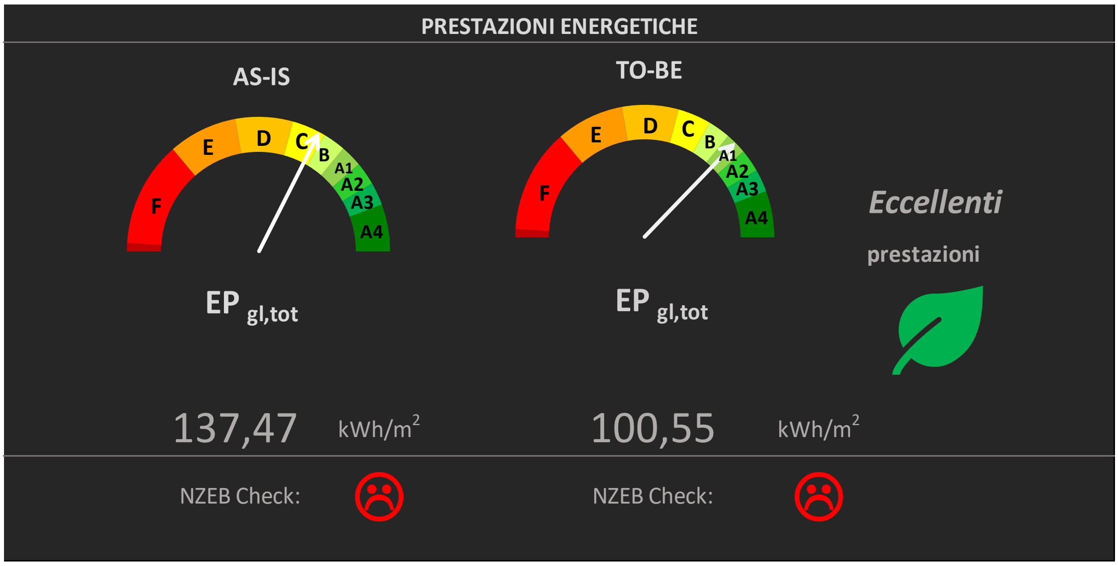


Figure 3-37: Energy performance of the scenario #1

As it can be seen from the graph, thanks to scenario #3 the building becomes of class A1 with a global primary energy equal to 100,55 kWh/m². The energy class is worse than scenario #1 and equal to the scenario #2; the NZEB check is negative. For now, this scenario turns out to be the worst from the energy performance point of view.

2. Consumption reductions:

RIDUZIONE DEI CONSUMI kWh/m²

	AS-IS	TO-BE	% riduzione
EP_H	16,33	14,54	11%
EP_W	0,97	0,97	0%
EP_C	36,84	35,05	5%
EP_{ill}	83,34	49,99	40%

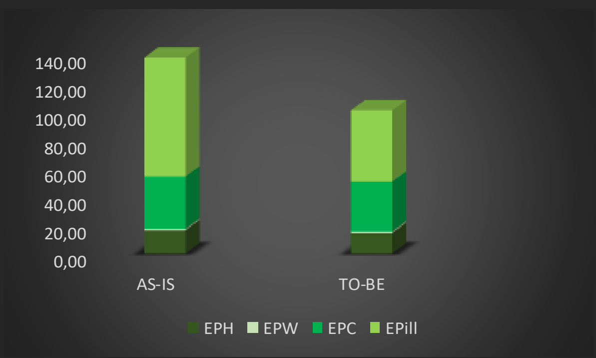


Figure 3-38: Consumptions reduction of the scenario #1

Looking at the percentages of consumption reduction it is possible to notice that they are lower than the other cases except for the lighting consumption. The consumption for heating only decreases by 11% and that regarding the summer air-conditioning is even lower (5%). These two reduction percentages are attributable to the photovoltaic installation. Instead, the photosensors involve a greater reduction, as in the scenario #1.

3. Investment cost vs consumptions reduction:

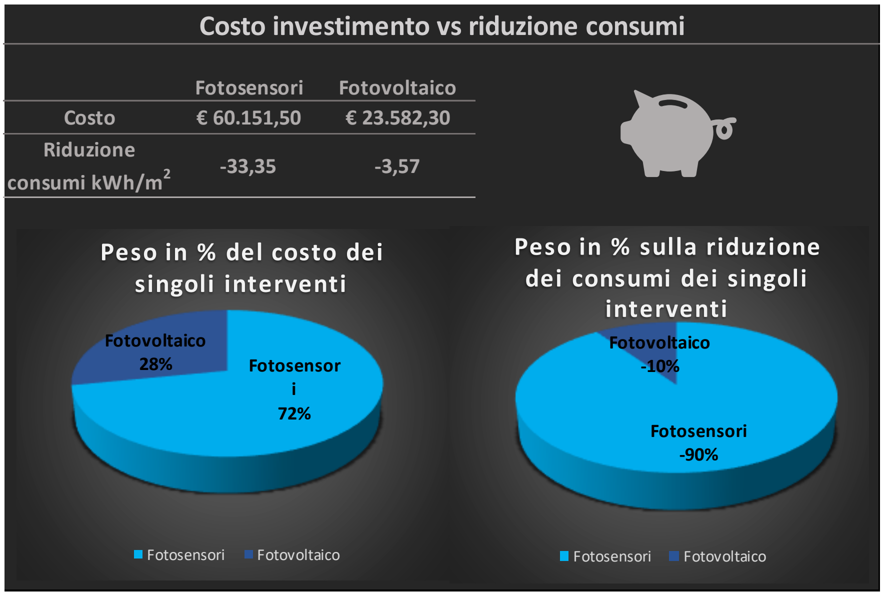


Figure 3-39: Investment cost vs consumptions reduction for the scenario #1

Thanks to these graphs the two measures can be compared from the point of view of investment cost and consumptions reduction; as it can be seen, the photovoltaic plant installation has a low investment cost with respect to the photosensors, but it also has a low influence on the consumption reduction. It is easy to note, however, that the lower cost does not justify such a low impact on consumption; for this reason, the photosensors turn out to be the best intervention.

4. Increase in the real estate and rent values of the building:

Figure 3-40: Increase in the real estate and rent value of the building

As it can be seen from the previous graph, the rent value of the building increase of 0,98 €/m² and the real estate value of 187 €/m², values much lower than other scenarios. This is due to the concomitance of two situations: worse energy class and negative NZEB check.

5. Economic analysis:

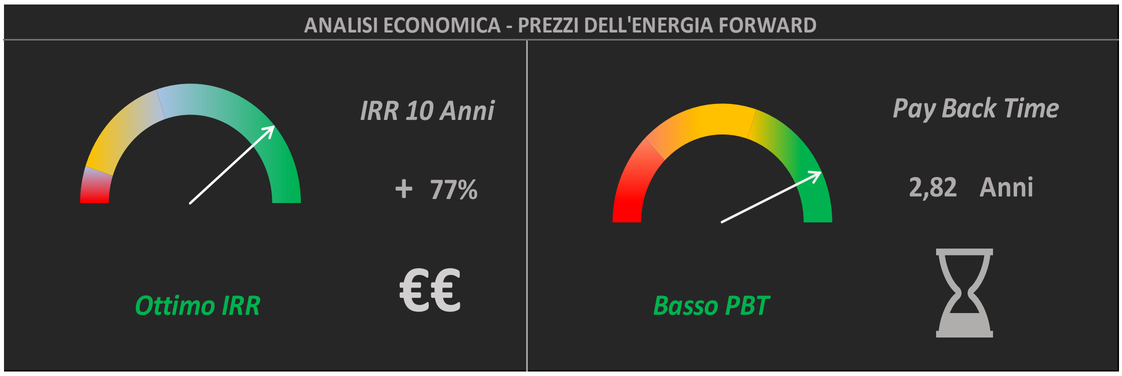


Figure 3-41: Economic analysis of the scenario #1

If compared to the other parameters analyzed above, the scenario seems to be the worst. This is reversed if the economic parameters are considered since they are the best. Both these parameters have excellent values and thus, from an economic point of view, this is the best scenario.

6. Economic analysis vs energy prices:

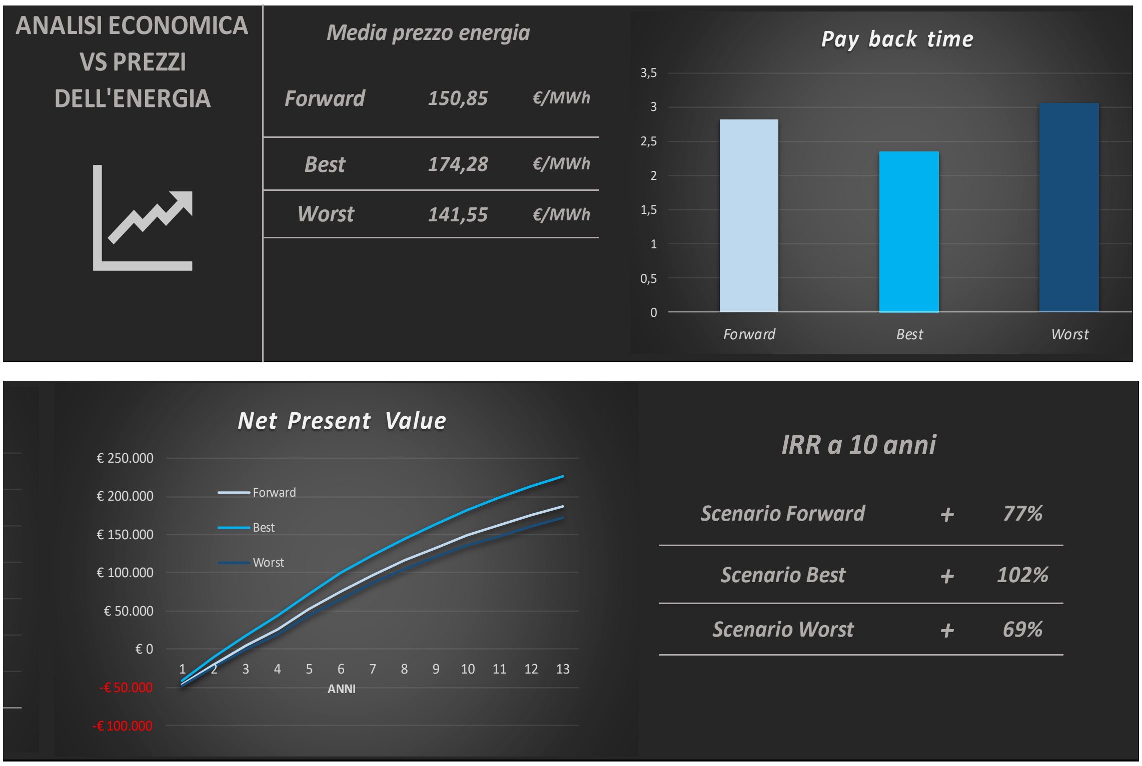


Figure 3-42: Economic analysis vs energy prices

By looking at this graph, it can be possible to clearly understand how this scenario is the best from an economic point of view. In fact, if the worst PBT of this scenario is compared to the forward PBT of the other scenarios, this turns out to be still the best. The IRR values are all very high; in the best case the IRR even exceeds 100%. Thus, it is possible to state that this is the most profitable investment.

- **SCENARIO 4: Geothermal heat pump + Photosensors + Photovoltaic**

1. Energy performance:

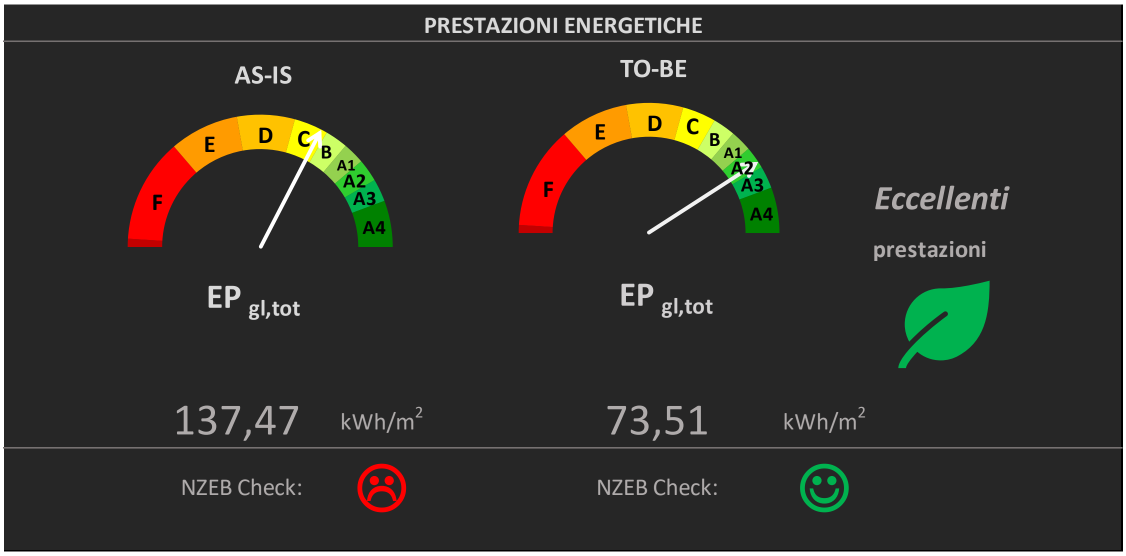


Figure 3-43: Energy performance of the scenario #1

Thanks to scenario #4 the building becomes of class A2 with a global primary energy equal to 73,51 kWh/m^2, that is the lowest value. The NZEB check is positive. It is possible to state that this scenario is the best from an energy performance point of view

2. Consumption reductions:

Looking at the percentages of consumption reduction (Figure 3-44) it can be possible to notice that they are very high for each service except for the hot water. The consumption for heating decreases by 59% like that regarding the summer air-conditioning. These two reduction percentages are attributable to both the photovoltaic installation and the geothermal heat pump. Instead, the photosensors involve a great lighting reduction.

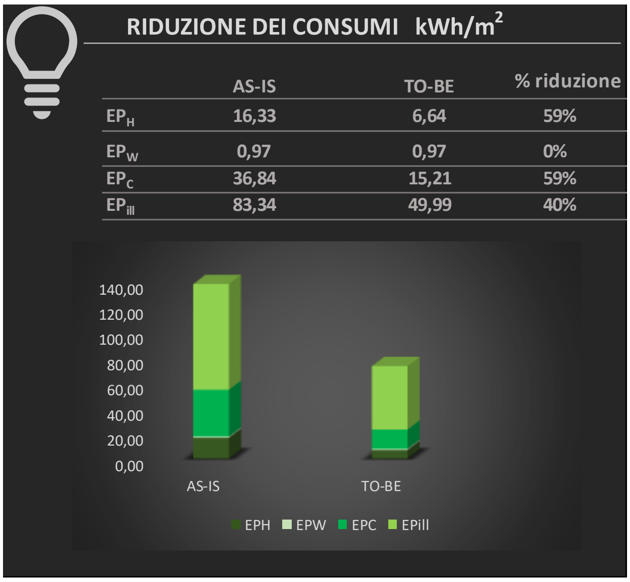


Figure 3-44: Consumptions reduction of the scenario #1

3. Investment cost vs consumptions reduction:

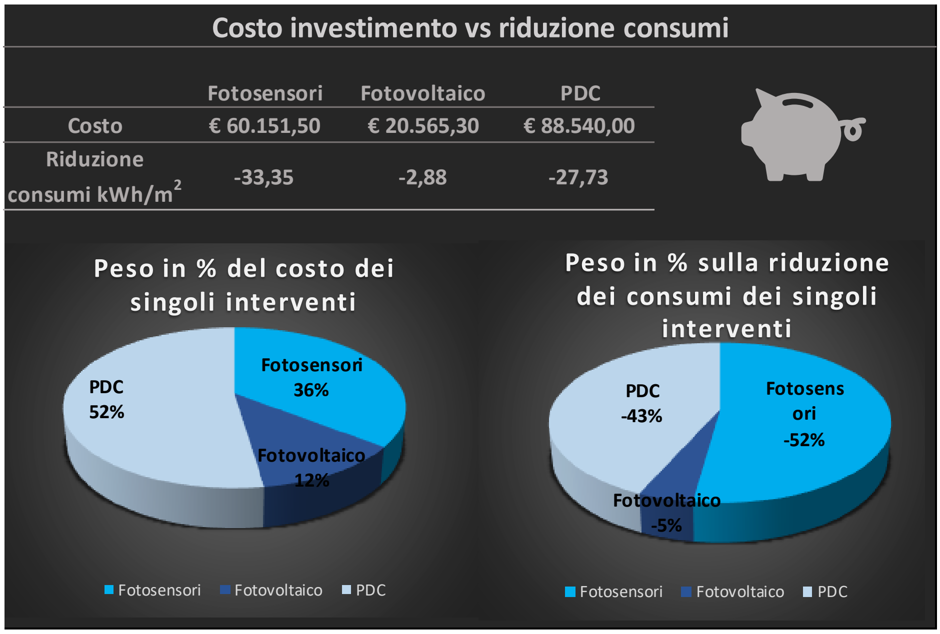


Figure 3-45: Investment cost vs consumptions reduction for the scenario #1

Thanks to these graphs the three measures can be compared from the point of view of investment cost and consumptions reduction; as it can be seen, all the interventions have a good behavior; in fact, if the investment cost is high also the consumption reduction is high. As in the previous scenario the photosensors turn out to be the best intervention.

The photovoltaic plant installation has a low investment cost with respect to the others, but it also has a low weight on the consumption reduction. It is easy to note, however, that the lower cost does not justify such a low impact on consumption (-5%). The geothermal heat pump has a slightly higher weight (52%) on the investment cost with respect to the consumption reduction (-43%).

4. Increase in the real estate and rent values of the building:

Figure 3-46: Increase in the real estate and rent value of the building

The rent value of the building increase of 1,39 €/m^2 and the real estate value of 260 €/m^2. These values are the best and this is due to the fact that in addition to the A1 class the NZEB check is also positive. The concomitance of these two positive effects brings to the highest values.

5. Economic analysis:

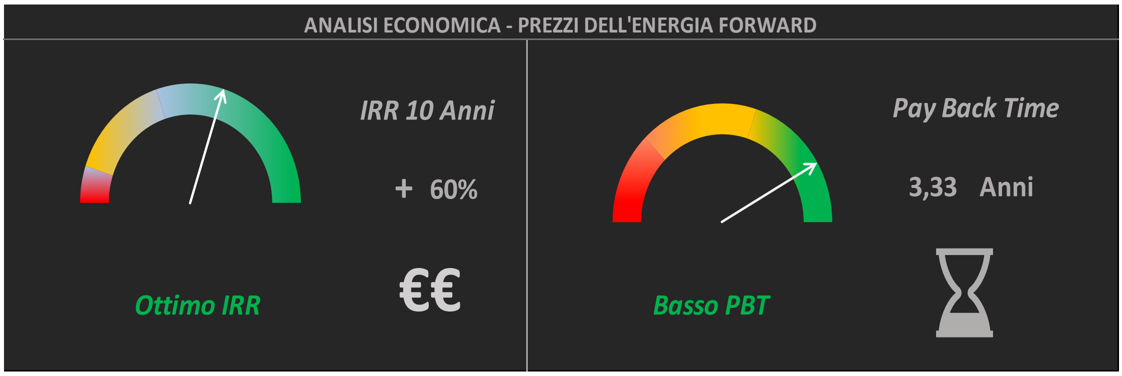


Figure 3-47: Economic analysis of the scenario #1

As it can be seen from the figure above, the values, that the economic parameters assume, are intermediate values if compared to the other scenarios but, despite this, they result excellent values.

6. Economic analysis vs energy prices:

Figure 3-48: Economic analysis vs energy prices

Although the energy prices scenario, the pay-back time is always very low (worst case: 3,6 years); the net present value grows with a steep slope and the internal rate of return values are often very good. As mentioned before, the values turn out to be intermediate between the different scenarios. Thus, unlike the previous scenario, this is the best if the energy performance and the rent/real estate values are considered but, from an economic point of view, this is not the best.

After the various scenarios were presented and discussed individually, a comparison was made considering the forward energy prices:

	Energy class	NZEB check	Rent value	IRR (10 yrs)	PBT	NPV (10 yrs)
Scenario 1	A2	NO	+1,12 €/m^2	+65%	3,13 yrs	211.413 €
Scenario 2	A1	YES	+1,12 €/m^2	+45%	3,93 yrs	96.698 €
Scenario 3	A1	NO	+0,98 €/m^2	+77%	2,82 yrs	148.746 €
Scenario 4	A2	YES	+1,39 €/m^2	+60%	3,33 yrs	218.785 €

Table 3-58: Comparison of the scenarios

To choose the best scenario, a trade-off between the energy performance and the economic parameters must be done.

By looking at this table, it is easily to understand that the scenario 1 and scenario 2 must be discarded; the scenario 1 has an excellent energy class but the NZEB check is negative, furthermore, the economic parameters have intermediate values. The scenario 2, has an energy class worse than the scenario 1 but the NZEB is positive; however, the economic parameters are the worst. Instead, the scenario 3 has the worst energy performance (A1 class and NO NZEB) but it has the best economic parameters and for this reason it is considered in the choice. The scenario 4, on the contrary, has the best energy performance with an A2 class and the NZEB check positive; moreover, it also has the maximum increase in the rent value; instead, the economic parameters are worse both with respect to scenario 1 and to scenario 4 except for the net present value that turns out to be the best.

At this point, to choose the best scenario, it is necessary to decide whether to give more importance to the economic or energetic parameters.

In the following chapter the choice of the best scenario is shown and explained.

CHAPTER 4: Conclusions and future perspectives

The idea of this thesis work is to implement a tool able to evaluate the buildings' energy efficiency and to develop some energy efficiency measures. For this purpose, **Building Renovation Tool** has been conceived with the aim to be user-friendly, effective and innovative; the main innovation of this tool is the implementation of a section dedicated to the increase in real estate value of the buildings thanks to the energy efficiency. Furthermore, the economic analysis can be performed and then the tool is able to give a report in which all the results are presented, both from an energetic an economic point of view.

Thanks to the creation of the **Building Renovation Tool**, it has been possible to study the energy performances of an office building located in Milan. The case study is a project of building renovation, all the energy efficiency measures considered are evaluated in comparison with the technological choices proposed in the project.

After the building has been implemented, the energy efficiency measures that better fit the building are chosen. Thanks to the tool, it is possible to compare the various energy efficiency scenarios. As it can be seen from the previous chapter the two best scenarios turn out to be the scenario #3, hence the photosensors and photovoltaic installations, and the scenario #4, photosensors, geothermal heat pump and photovoltaic installations. The scenario #3 has the best economic parameters, then, from an economic point of view, it is the most profitable investment; instead, the scenario #4 has the best energy performance and the best increase in rent value. Some assumptions have been done to choose the best one:

- the photosensors are the best energy efficiency measure because of their relatively low investment cost and their high consumption reduction;
- the geothermal heat pump is a good intervention because, although its high investment cost, it decreases the heating and cooling consumptions of many percentage points;
- the photovoltaic, instead, has a low impact on the consumptions and this fact is not justify by such a low price;
- the photovoltaic is useful in order to verify the NZEB check.

By looking at the economic parameters it is possible to state that the scenario #4 involves excellent values, even if they are lower than scenario #3. The best values of IRR and PBT of scenario #3 do not justify such a lower energy performance and, for this reason, the scenario #4 has been chosen.

In the end, the application of the **Building Renovation Tool** to the case study allowed to test it, demonstrating its effectiveness and its usefulness to support the decision of energy retrofit interventions. Then, the goal of the thesis is reached.

Moreover, some improvements on the tool can be considered in the future. In fact, the tool is not able to evaluate the humidity or the air quality of the indoor environment. At this purpose, it would be good to implement a section able to evaluate the air humidity and the air pollution because, in this way, other multiple benefits, such as the increase in productivity or the healthy improvements, could be considered.
Furthermore, the tool is able to manage only a limited number of efficiency measures; it would be appropriate to add new energy efficiency interventions, so more choices will be possible.
Finally, only the Nearly Zero Energy Building check is performed; for this reason, the LEED certification could be implemented to give an additional value to the tool.

In conclusion, the thesis reaches its objective, identifying the best energy efficiency scenarios for the case study and thanks to this result, it is possible to state that the **Building Renovation Tool** could be an effective and smart tool for the buildings' energy efficiency evaluations.

References:

[1] European Commission, *"Energy Roadmpap 2050"*, Pubblication office of the European Union, Luxembourg, 2012.

[2] F. Allard, D. Braham, G. Goeders, P. Heiselberg, L. Jaremar, R. Kosonen, J. Lebrun, L. Mazzarella, J. Railio, O. Seppanen, M. Schmidt, M. Virta, J. Kurnitski, *«How to define nearly net zero energy buildings nZEB»*, *REHVA J.,* May 2011.

[3] EuropeanCommision, «*DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)*», Official Journal of the European Union, Luxembourg, 18.6.2010.

[4] C. Herring, «*20th International Passivhaus Conference 2016*», 25 April 2016. [Online]. Available: https://www.greenbuildingstore.co.uk.

[5] «*Disposizioni in merito alla disciplina per l'efficienza energetica degli edifici e per il relativo attestato di prestazione energetica, a seguito della DGR 3868 del 17.7.2015*», Regione Lombardia, 30.7.2015.

[6] N. Campbell, «*Capturing the Multiple Benefits of Energy Efficiency*», International Energy Agency, Paris, 2014.

[7] « *UNI/TS 11300-1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale*», Ente italiano di normazione, Ottobre 2014.

[8] T. Cornaviera, «*appunti di edilizia*», 2005. [Online]. Available: http://www.cornaviera.it.

[9] Cestec S.p.A., Associazione regionale dei costruttori edili lombardi, Politecnico di Milano, «*Abaco dei ponti termici*», 4 Novembre 2011.

[10] Ministero dello Sviluppo Economico, «*Decreto Ministeriale 26/6/2009 : Linee guida nazionali per la certificazione energetica degli edifici*», 2009.

[11] « *UNI/TS 11300-2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale, per la produzione di acqua calda sanitaria, per la ventilazione e per l'illuminazione in edifici non residenziali*», Ente italiano di normazione, Ottobre 2014.

[12] « *UNI-EN 15193: Requisiti energetici per illuminazione*», Ente italiano di normazione, 2008.

[13] « *UNI/TS 11300-3: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione estiva*», Ente italiano di normazione, Marzo 2010.

[14] « *DECRETO N.176 Allegato H: Metoo di calcolo*», Regione Lombardia, 12.01.2017.

[15] « *UNI/TS 11300-5: Calcolo dell'energia primaria e della quota di energia da fonti rinnovabili*», Ente italiano di normazione, Marzo 2016.

[16] JRC-Joint Reseach Center, «*Photovoltaic Geographical Information System - Interactive Maps*», [Online]. Available: http://photovoltaic-software.com.

[17] « *DECRETO N.176 Allegato B: Descrizione dell'edificio di riferimento e parametri di verifica*», Regione Lombardia, 12.02.2017.

[18] « *UNI/TS 11300-4: Utilizzo di energie rinnovabili e di altri metodi di generazione per la climatizzazione invernale e per la produzione di acqua calda sanitaria*», Ente italiano di normazione, Marzo 2016.

[19] « *UNI 11466: Sistemi geotermici a pompa di calore - Requisiti per il dimensionamento e la progettazione*», Ente italiano di normazione, 2012.

[20] Portoraro, «*Dispense del Corso: Impiego industriale dell'energia*» Dipartimento Energia Politecnico di Torino, 2015-2016.

[21] GME-Gestore Mercati Energetici, «*Vademecum della borsa elettrica italiana*», Settembre 2012.

[22] GME-Gestore Mercati Energetici, «*GESTORE MERCATI ENERGETICI*», 02 03 2018. [Online]. Available: www.mercatoelettrico.org.

[23] P. Autiero, «*#Energia – Prezzo a Pun. Cosa significa, come funziona e cosa devi sapere in merito.*», 22 03 2013. [Online]. Available: https://pasqualeautiero.wordpress.com.

[24] F. Luiso, «*La bolletta elettrica nel mercato libero*», Autorità per l'energia elettrica il gas e il sistema idrico, Milano, 2015.

[25] ARERA- Autorità di Regolazione per Energia Reti e Ambiente, Gennaio 2018. [Online]. Available: https://www.arera.it.

[26] Agenzia delle entrate,«*Osservatorio del mercato immobiliare- Banca dati delle quotazioni immobiliari*», 01 2017. [Online]. Available: https://wwwt.agenziaentrate.gov.it.

[27] Borsino Immobiliare, «*Coefficienti Energetici*», 2015. [Online]. Available: https://www.borsino-immobiliare.com.

[28] P. Leone, A. Lanzini, V. Verda, «*Dispense del Corso: Thermal design and optimization*» Dipartimento Energia-Politecnico di Torino, 2016.

[29] « *UNI-10349: Dati climatici*», Ente italiano di normazione, 2015.

[30] Clivet, «*DATI PER IL CALCOLO SECONDO UNI/TS 11300 parte 4* », Clivet s.p.a, 23 Gennaio 2017.

[31] P. Monzò, M. Bernier, J. Acuna, P. Mogensen, «*A Monthly Based Bore Field Sizing Methodology with Applications to Optimum Borehole Spacing*», ASHRAE Transactions, 2016.

[32] Caleffi, «*Impianti a pompe di calore geotermiche*», *Idraulica,* Giugno 2010.

[33] Casa e clima, «*Dimensionamento di sonde verticali e pozzi d'acqua abbinati a pompe di calore*», 13 Settembre 2011. [Online]. Available: http://www.casaeclima.com.

[34] DAIKIN, «*Listino prezzi*», Gennaio 2017.

[35] Alpha-innotec, «*Listino prezzi e modelli*», Marzo 2016.

[36] G. Fracastoro, «*Dispense del Corso: Technology for renewable energy sources*», Dipartimento Energia- Politecnico di Torino, 2016.

[37] B.E.G, «*LUXOMAT*».

[38] IoRisparmioEnergia, «*Fotovoltaico*», 2018. [Online]. Available: https://www.iorisparmioenergia.com.

[39] EXE-inverter, «*EXE inverter fotovoltaico*», 2018. [Online]. Available: http://www.exeinverter.com.

[40] Samil Power, 2018. [Online]. Available: http://www.samilpower.com.

[41] CheckUp-Energetico, «*Super ammortamento 2018, agevolazioni fiscali per aziende*», 22 Gennaio 2018. [Online]. Available: http://www.checkupenergetico.com.

[42] « *DM-31/12/1988: Tabella dei coefficienti di ammortamento*», Ministero delle Finanze, 1988.

[43] AllEnergy&Architecture, «*Ecobonus*», 2018. [Online]. Available: http://www.allenergya.com.

[44] FutureEnergy, «*AE: nuove aliquote ammortamento*», 1 Aprile 2017. [Online]. Available: http://www.futureenergy.it.

List of Figures:

List of Tables:

Acknowledgements:

Ringrazio il Professor Andrea Lanzini, la Professoressa Cristina Becchio e Giulia Vergerio per il tempo dedicatomi e per i preziosi consigli; ringrazio inoltre l'Ingegner Simone Cannelli e l'Ingegner Carlo Perrone per avermi guidato ed aiutato nello sviluppo del tool e per avermi dato la possibilità e l'opportunità di lavorare in una realtà aziendale come Engie Italia.

Ringrazio anche il mio papà, la mia mamma e Matteo che mi hanno supportato e sopportato, non solo per lo svolgimento di questa tesi, ma durante tutti gli anni dell'università e hanno sempre creduto in me. Un grazie va anche a mia nonna, a Mali, a mia madrina e a Franco e Cri che mi sono sempre stati vicini.
Grazie a Luca, Albi e Chicco che mi hanno fatto sorridere e coccolato in tutti questi anni.

Ringrazio Marco, Francesca e Francesca, i compagni di corso che hanno saputo rendere speciale questo percorso universitario; ringrazio tutti gli altri miei amici, i coinquilini abusivi, le mie compagne di squadra, le amiche di una vita e Lula per essermi sempre stati vicino e di supporto.