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Energy Retrofit Intervention on a Condominium Building

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Alla mia famiglia.

ABSTRACT

The human activity unequivocally influences the current warming trend of atmosphere, ocean, and land. Since 1750, the Green House Gasses concentration has been increasing constantly, mainly due to the usage of fossil fuels, reaching annual average values of 410 ppm for carbon dioxide (CO_2) in the last years [1].

For this reason, since the Kyoto protocol in 1997, the governments around the world have embarked on a path with the aim of reducing polluting emissions caused by the usage of fossil sources. Some years later, with the Paris agreement, they set a goal on limiting the temperature rise well below to 2°C compared to the preindustrial levels, improve the energy efficiency of the processes and technologies, and increase the penetration of renewable energies. Furthermore, with the European Climate Law entered into force on 29 July 2021, the intermediate goal of reduce the emissions of GHG at least of 55% by 2030 compared to the levels of 1990 and the Net Zero Emission by 2050 has set.

With the increase of population, of the living standards and urbanization, the global energy demand continues to grow, making the adoption of more efficient technologies and the use of renewable energy resources necessary in sectors like industry, transport, buildings to achieve all the sustainable goals set.

The building sector is responsible for the 40% of the energy consumption and 36% of the CO_2 emissions in the EU. A third of the buildings are over 50 years old and the 75% of them are energy inefficient [7]. Therefore, the retrofit of buildings is taking on a very important role to reduce the energy demand using insulating materials or more efficient technologies to produce heat, such as heat pumps and condensing boiler.

In Italy, to help the energy requalification of buildings and to help businesses and citizens to deal with the economic crisis, some tax incentives have been activated. One of these is the "*Superbonus 110%*". This dissertation focuses on the energy redevelopment of a 1960s condominium located in the province of Savona thanks to the adoption of this tax incentive.

After a first introductory chapter on the climate crisis, a description of the various bonuses currently in force in Italy will be provided. The following chapter will approach the building as it stands, followed by a chapter describing the interventions and the improvements that will be made. The last chapter will be an economic analysis of both the total cost of energy requalification and the convenience of changing the heat generator.

This work was carried out in collaboration with *O.C.Clim S.r.l.*, a company that deals with the installation and maintenance of air conditioning systems in Liguria and now it works also on *Superbonus 110%*.

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1. INTRODUCTION

1.1. Climate change

The human activities unequivocally influence the current warming trend of atmosphere, ocean, and land. As a matter of fact, since 1750, the Green House Gasses (GHG) concentration continually increases due to anthropogenic activities, reaching annual average values of 410 ppm for carbon dioxide (CO_2) in the last ten years [1] (Figure 1).

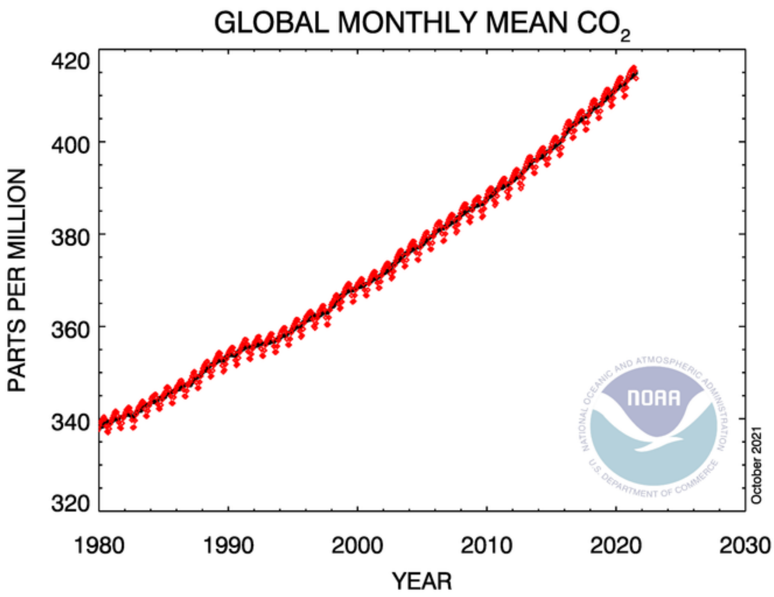


Figure 1 - Global monthly means CO2 since 1980 [2]. The red line represents the monthly mean values, centred in the middle of each month. The black one represents the same values after a correction for the average seasonal cycle.

In addition to CO_2, other GHG emitted by human activities are Methane (CH_4), Nitrous oxide (N_2O) and Fluorinated gases (F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) (Figure 2).

Regarding CO_2, the primary source of emission is the fossil fuels' use. Furthermore, it can result from deforestation, land clearing for agriculture and degradation of soil. Obviously, CO_2 is emitted and absorbed naturally in its carbon cycle. The CH_4 emission is mainly due to agricultural activities, energy use, and waste management. The main activity producing N_2O is the use of fertilizer in agriculture and partially the burning of fossil fuels. The F-gases emission is due to industrial processes and pesticides.

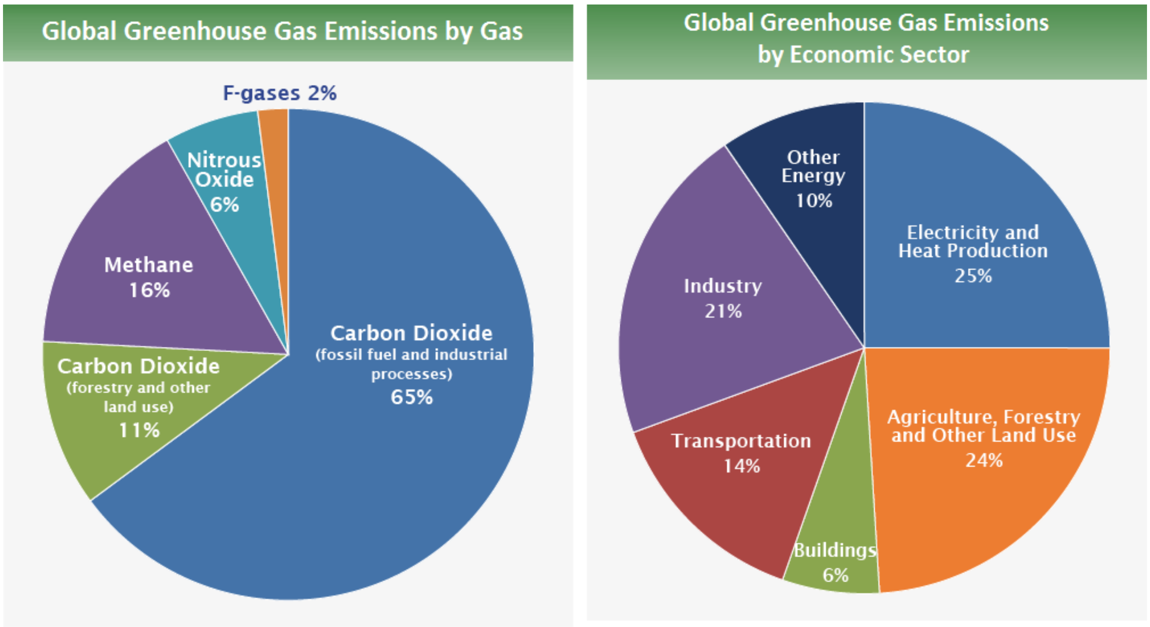


Figure 2 - Global GHG emissions by gas and by sector [9].

Each GHG has different effects on the Earth's warming, they can differ in the ability to absorb the energy (radiative efficiency) and how long they stay in the atmosphere (lifetime). To evaluate the impacts of the different gas and to compare them, the Global Warming Potential (GWP) was developed. It is the measure of how much energy the emission of 1 ton of a gas will absorb over a given period, relative to the emission of 1 ton of CO_2 [10]. The higher the GWP, the greater the impact on the greenhouse effect. For the gases mentioned above and over a given period (100 years), there are GWP values of [10]:

- CO_2: GWP = 1, is the reference;
- CH_4: GWP = 28 – 36, it remains in atmosphere about a decade (much less then CO_2), but it absorbs much more energy than CO_2;
- N_2O: GWP = 265 – 298, on average it remains in atmosphere for more than 100 years;
- F-gases: GWP = thousand or ten of thousand depending on the gas.

The earth temperature depends on the balance between the energy entering and exiting the atmosphere. This equilibrium is maintained thanks to the GHG that absorb the infrared radiation released from the earth, making life on earth possible. Unfortunately, the increase in concentration of these gases, plus other gases like water vapour, leads to a greater absorption of this infrared radiation causing a global temperature increase. It is observed that each of the past four decades has been successively warmer than any previous decade since the 1850s [1] (Figure 3).

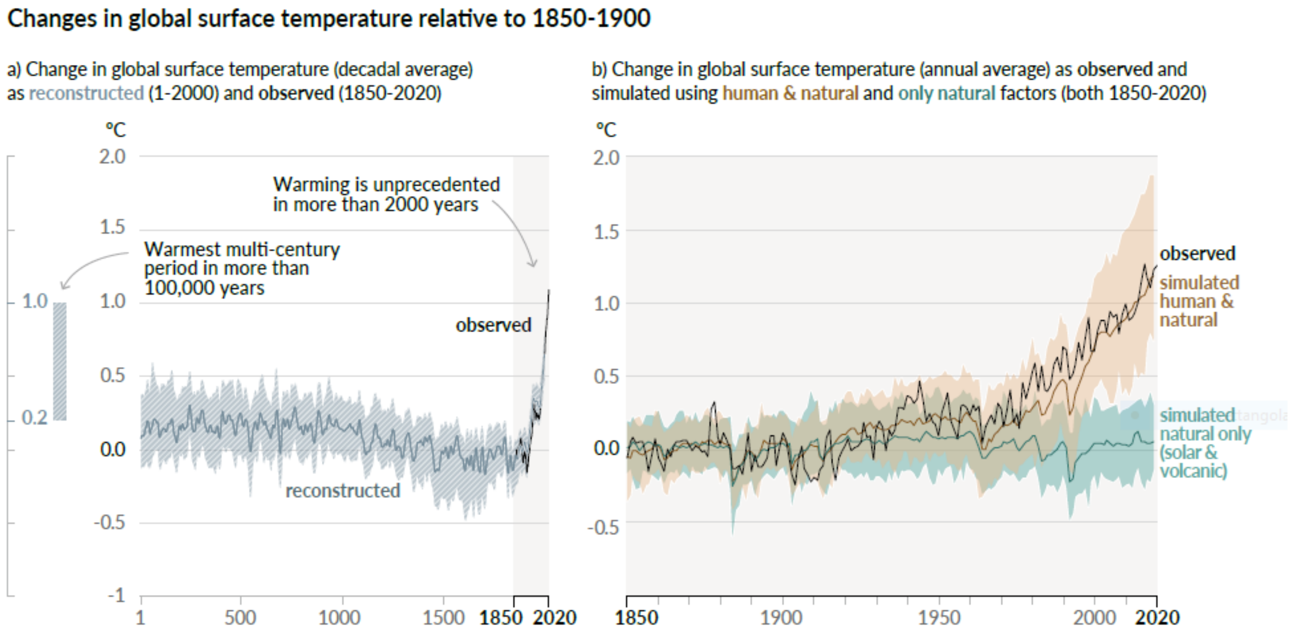


Figure 3 - History of global surface temperature change [1]

This increase in temperature causes many other environmental problems. For example, in the recent years has been observed that [1]:

- the number of extreme events (heat waves, heavy precipitation, droughts and tropical cyclones) is increased, and they are more intense;
- the melting of the glaciers and the decrease in Arctic Sea ice area;
- the global upper ocean temperature has been increasing since 70s and due to CO2 emissions, they are undergoing an acidification. Furthermore, the global mean sea levels increase by 0.20 m between 1901 and 2018.

The increase of GHG and the consequent increase in temperature is the greatest challenge facing countries around the world nowadays.

The first step taken by member of the United Nation Framework Convention on Climate Change (UNFCCC) was the Kyoto Protocol. This treaty was adopted on the 11th of December 1997, but only on the 16th of February 2005 became effective. It establishes that the industrialized countries must reduce by 5% their GHG emission compared to 1990 levels over the five-year period 2008-2012.

In EU in 2009 was adopted the Climate and Energy Package that is a set of legislative measure to reach three main goals (known as 20-20-20 by 2020):

- 20% reduction of GHG emission compared to 1990;

- 20% increase of penetration of renewable resources;
- 20% improvement in energy efficiency.

On the 12th of December 2015, the Paris Agreement was adopted at COP21 to legally bind an international treaty on climate change. The goal is to limit global warming to well below 2°C, making effort to limit it to 1.5°C compared to pre-industrial levels and to reach the peak on GHG emissions as soon as possible.

The last step was taken on the 29th of July 2021, when, with the European Climate Law, the goal set in the Green Deal was written into law. The law set the long-term objective of net zero emissions of GHG by 2050 in EU by investing on green technologies and protecting the natural environment. There is also the intermediate goal of reducing the GHG emission of 55% by 2030 compared to 1990 levels.

1.2. Building sector

The building sector is responsible for the 40% of the energy consumption and 36% of the CO_2 emissions in the EU, considering construction, usage, renovation, and demolition [7]. A third of the buildings are over 50 years old and the 75% of them are energy inefficient [7]. The energy inefficiency is a problem because a large part of the energy used is wasted. It is important to minimize these wastes by improving existing buildings and use better insulation material when constructing new houses.

With the retrofit of existing buildings, the EU could reduce the total energy consumption by 5-6% and reduce the CO_2 emissions by about 5% [11]. Unfortunately, less than 1% of the buildings are renovated each year and this rate of renovations should be at least double to meet the climate and energy goals [11].

Often the difficulty to renovate the buildings is due to the high cost of the interventions, for this purpose, the Energy Performance of Buildings Directive (EPBD) 2010/31/EU and the Energy Efficiency Directive (EED) 2012/27/EU were revised in 2018 making easier the access to financing. These directives establish long-term renovation strategies with the goal to decarbonise the buildings by 2050, that the new buildings must be nearly zero-energy buildings (NZEB), and the introduction of smart technologies to control the energy consumption.

As shown in Figure 4, most of the final energy consumption in the residential sector in the EU is covered by natural gas (32.1%) and electricity (24.7%). After these, there are renewable sources

(20.1%), petroleum products (11.6%), derived heat (8.7%) and solid fuels (coal, 3.4%) [4]. Furthermore, if the consumption is divided according to the use of energy, the greater part of it is due to space heating (63.3%), followed by water heating (14.8%) and lighting (14.1%). To a lesser extent from cooking (6.1%) and space cooling (0.4%) [4].

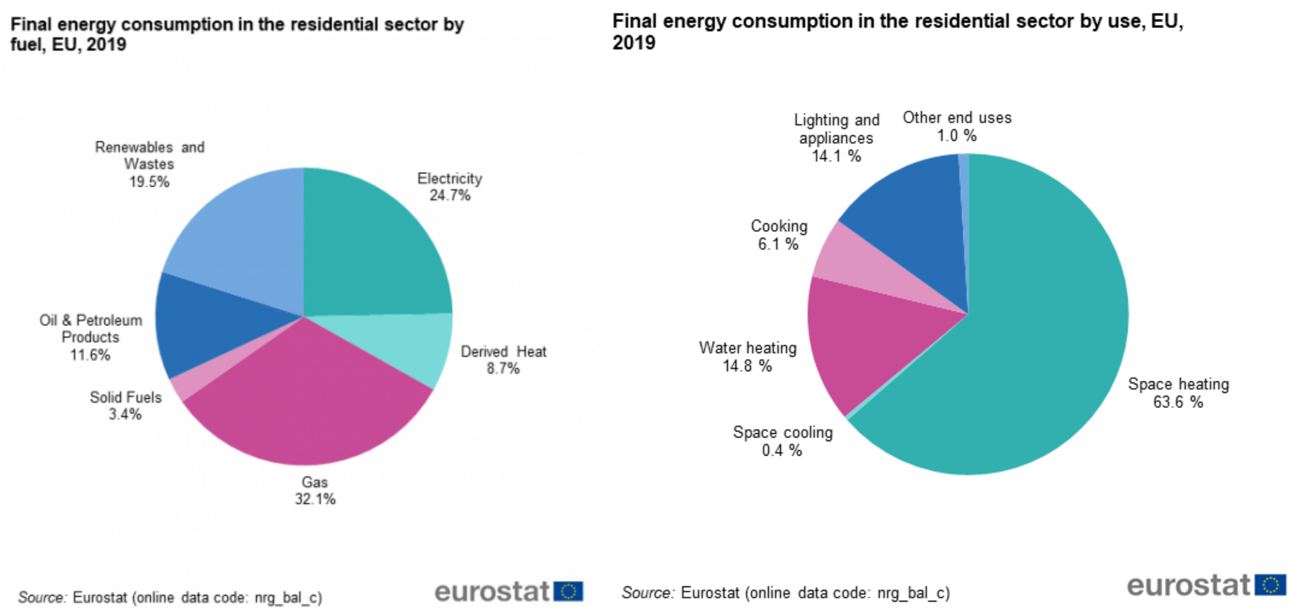


Figure 4 - a) Final energy consumption in the residential sector by fuel, EU, 2019 [4]. b) Final energy consumption in the residential sector by use, EU, 2019 [4]

In Europe some countries rely too much on fossil fuels. For example: Poland is still very dependent on coal, Cyprus and Estonia consume many oil and petroleum products, and other countries rely on natural gas [4].

In Italy, as highlighted by a study made by *Elemens* for *Legambiente* and *Kyoto Club* [16], the 67% of the residential consumption regards the space heating, and the sources used to produce heat are shown in Figure 5. The most used source is Natural Gas (58%), followed by Biomass (28%) and Petroleum products (8%). The cogeneration accounts for 5% and the last 1% comes from Heat Pump, Solar Thermal System and Electricity.

To reduce the consumes, to help the energy requalification of buildings and businesses and citizens to deal with the economic crisis, some tax incentives have been activated. One of these is the "*Superbonus 110%*". This is a tax incentive with the goal of increase the energy efficiency of buildings (thus reducing the wastes of energy), of encourage the anti-seismic interventions, and installation of photovoltaic systems.

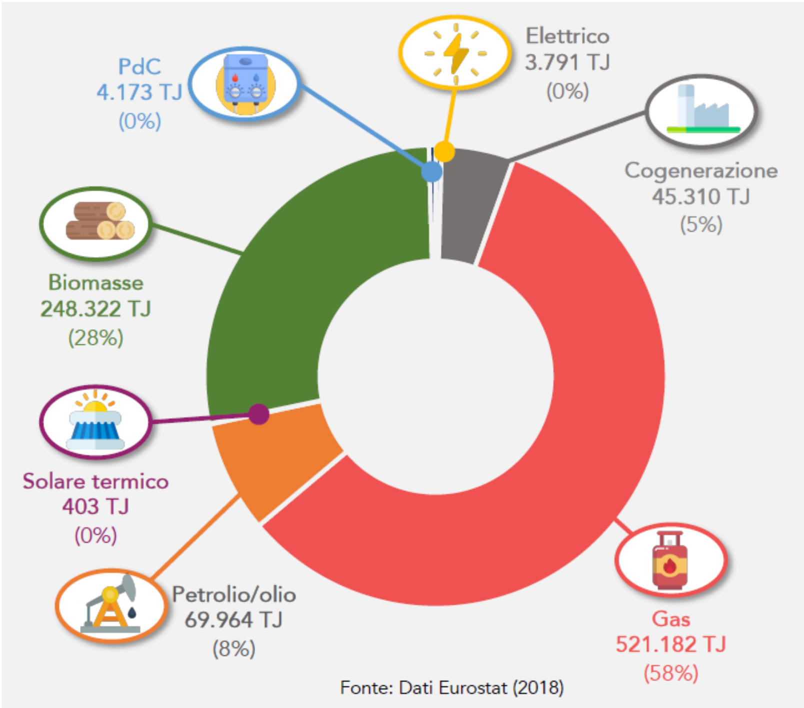


Figure 5 – Heating consumption by source in Italy

2. CURRENT LEGISLATION – SUPERBONUS 110%

In Italy, in order to achieve the goals for the limitation of GHG emissions, for the penetration of the renewable energy resources and to redevelop the real estate field, some tax incentives have been implemented in the building sector. Furthermore, these tax incentives help citizens and businesses to deal with the economic crisis that has long plagued this country.

This chapter wants to introduce all the bonuses in force in this country, focusing mainly on the *Superbonus 110%*. The whole chapter refers to the book "Superbonus 110%" written by De Paolis Dino and published by "Legislazione Tecnica S.r.L." [5].

2.1. Bonus Ristrutturazioni

The main features of this bonus are listed in the table below (Table 1).

Regulatory sources	Art. 16-bis del D.P.R. 917/1986 Comma 1, art. 16 del D.L. 63/2013
Period of application	Expenses incurred up to 31/12/2021 (term thus extended by comma 58, art. 1 della L.178/2020) In the case of interventions falling under the "*Bonus ristrutturazioni*" that can be "*trainati*" into the *Superbonus 110%,* the final deadline is extended based on the deadline set for the *Superbonus 110%*
Expenditure ceiling	€ 96,000 per real estate unit
Deduction percentage	50% of the expenses incurred
Deduction period	10 annual instalments of the same amount

Table 1- "Bonus Ristrutturazioni" features [5]

The types of interventions that fall under this bonus are:

1. ordinary maintenance, extraordinary maintenance, restoration and conservative rehabilitation, building renovation (as defined by art.3 del D.P.R. 380/2001), carried out on the common parts of residential buildings (as defined by art. 1117 del Codice Civile);
2. ordinary maintenance, extraordinary maintenance, restoration and conservative rehabilitation, building renovation (as defined by art.3 del D.P.R. 380/2001), carried out on individual residential real estate units of any cadastral category, including rural ones, and on their appurtenances;
3. interventions for the reconstruction and restoration of property damaged following calamitous events (also different from those in the previous numbers 1 and 2), provided that a state of emergency has been declared;

4. interventions relating to the construction of appurtenant garages or parking spaces, including shared property;
5. interventions with the purpose of eliminating architectural barriers (this intervention can be "*trainati*" into the *Superbonus 110%* regime);
6. adoption of measures with the purpose of prevent the risk of third parties carrying out illegal acts;
7. works with the purpose of wiring of buildings, the containment of noise pollution;
8. works with the purpose of achieving energy savings with particular regard to the installation of systems based on the use of renewable energy sources (regarding photovoltaics, these interventions can be "*trainati*" into the *Superbonus 110%* regime);
9. adoption of anti-seismic measures with particular regard to the execution of works for the static safety of the structural parts of buildings (so-called "*Sismabonus*", which under certain conditions can take advantage of greater benefits or fall within the 110% super bonus regime);
10. remediation of asbestos and execution of works aimed to avoid domestic accidents;
11. interventions to replace the existing emergency generator with the latest ones fuelled by gas (case in point introduced by comma 60, art.1 della L. 178/2020).

2.2. Ecobonus and Eco-Sismabonus

This type of bonus was born to improve the energy efficiency of the buildings and therefore to reduce their consumption. The table below (Table 2) shows its main features.

Regulatory sources	Commi 344-347, art. 1 della L. 296/2006 Art. 14 del D.L. 63/2013 D.M. 06/08/2020
Period of application	Expenses incurred up to 31/12/2021 (term thus extended by comma 58, art. 1 della L.178/2020) In the case of interventions falling under the "*Ecobonus*" that can be "*trainati*" into the *Superbonus 110%*, the final deadline is extended based on the deadline set for the *Superbonus 110%*
Expenditure ceiling	Variable ceiling depending on the types of interventions
Deduction percentage	Between 50% and 85% of the expenses incurred depending on the types of interventions
Deduction period	10 annual instalments of the same amount

Table 2 - "Ecobonus" features [5]

The interventions that are included in this bonus are:

1. interventions of global energy requalification of existing buildings;
2. interventions of energy requalification of the building envelope including windows, fixtures and solar shields (they can be considered as "*trainati*" in the *Superbonus 110%* regime);
3. installation of photovoltaic panels (they can be considered as "*trainati*" in the *Superbonus 110%* regime);
4. substitution of winter air conditioning systems (they can be considered as "*trainati*" in the *Superbonus 110%* regime);
5. purchase and installation of biomass plants or micro-generators (they can be considered as "*trainati*" in the *Superbonus 110%* regime);
6. purchase and installation of multimedia devices for remote control of the heating or air conditioning system (they can be considered as "*trainati*" in the *Superbonus 110%* regime);
7. interventions of energy requalification on common parts of condominium buildings;
8. interventions of energy requalification with the simultaneous adoption of anti-seismic measures on common parts of condominium buildings.

2.3. Sismabonus

Almost the entire Italian peninsula is at risk from seismic activity. A bonus for the reinforcement of existing structures was therefore introduced. It has the following features (Table 3).

Regulatory sources	Lettera i), art. 16-bis del D.P.R. 917/1986 Commi da 1-bis a 1-septies, art. 16 del D.L. 63/2013
Period of application	Expenses incurred up to 31/12/2021 (deadline set by comma 2, art. 1 della L. 11/12/2016, n. 232) In the case of interventions falling under the "*Sismabonus*" that can be "*trainati*" into the *Superbonus 110%*, the final deadline is extended based on the deadline set for the *Superbonus 110%*
Expenditure ceiling	€ 96,000 per real estate unit
Deduction percentage	Between 70% and 85% of the expenses incurred in the presence of particular conditions concerning the classification of seismic risk
Deduction period	5 annual instalments of the same amount

Table 3 - "Sismabonus" features [5]

The following intervention are included in the bonus:

1. adoption of anti-seismic measures with particular regard to the execution of works for the static safety of the structural parts of buildings or complexes of buildings structurally connected;
2. expenses incurred for the classification and seismic verification of the buildings.

Both are included in the *Superbonus 110%* regime.

2.4. Bonus Facciate

The following table (Table 4) shows the main features.

Regulatory sources	Commi da 219 a 224, art. 1 della L. 160/2019 D.M. 06/08/2020
Period of application	Expenses incurred up to 31/12/2021 (term thus extended by comma 58, art. 1 della L.178/2020)
Expenditure ceiling	There is no ceiling
Deduction percentage	90% of the expenses incurred
Deduction period	10 annual instalments of the same amount

Table 4 - "Bonus Facciate" features [5]

This bonus includes:

1. intervention on the opaque structures of the facades, only for cleaning and/or external painting;
2. intervention on the opaque structures of the facades, also influential from a thermal point of view;
3. interventions on balconies, friezes, and ornamental elements.

2.5. Bonus Colonnine Ricarica Veicoli

This bonus presents the following features (Table 5):

Regulatory sources	Art. 16-ter del D.L. 63/2013
Period of application	Expenses incurred up to 31/12/2021 In the case of interventions falling under the "*Bonus colonnine ricarica veicoli*" that can be "*trainati*" into the *Superbonus 110%*, the final deadline is extended based on the deadline set for the *Superbonus 110%*
Expenditure ceiling	€ 3,000
Deduction percentage	50% of the expenses incurred
Deduction period	10 annual instalments of the same amount

Table 5 - "Bonus colonnine ricarica veicoli" features [5]

The interventions that fall in this bonus are:

1. purchase and installation of charging infrastructures for vehicles powered by electricity;
2. initial costs for requesting additional power up to a maximum of 7 kW (they can be considered as "*trainati*" in the *Superbonus 110%* regime).

2.6. Superbonus 110%

The *Superbonus 110%* is a tax relief introduced by the "*Decreto Rilancio*" which raises the deduction rate of expenses incurred for specific interventions in the field of energy efficiency, anti-seismic interventions, installation of photovoltaic systems or infrastructures for charging electric vehicles to 110% in buildings.

Originally, the deduction, was for expenses incurred from 01/07/2020 to 31/12/2021, but with subsequent regulatory changes (legge 30/12/2020, n. 178 – legge di bilancio 2021 and decreto legge 06/05/2021, n. 59) the *Superbonus* 110% has been extended.

For this bonus the interventions are divided in:

- *Trainanti*:
    A. interventions to insulate the opaque envelope of condominium buildings, single-family buildings and functionally independent real estate units;
    B. interventions to replace the centralized winter air conditioning system of condominium buildings, or autonomous of single-family buildings and functionally independent real estate units;
    C. anti-seismic upgrading of buildings, including expenses incurred for the classification and seismic verification of buildings and for the installation of continuous structural monitoring systems for anti-seismic purposes.
- *Trainati*:
    D. energy efficiency interventions that fall within the "*Ecobonus*" (interventions from 2 to 6), if carried out together with one of the "*trainanti*" interventions A or B;
    E. photovoltaic system installation interventions that fall within the "*Bonus ristrutturazioni*" (intervention 8), if carried out together with one of the "*trainanti*" interventions A, B or C;
    F. interventions regarding the elimination of architectural barriers that fall within the "*Bonus ristrutturazioni*" (intervention 5), if carried out together with one of the "*trainanti*" interventions A or B;

G. interventions regarding the installation of charging stations for electric vehicles referred to art. 16-ter del D.L. 63/2013, if carried out together with one of the "*trainanti*" interventions A, B or C.

2.6.1. Ecobonus 110%

The art. 119 del D.L. 19/05/2020, n. 34 ("Decreto Rilancio", converted in law by L. 17/09/2020, n. 77) disposes to the commi 1, 2 and 3, that the deductions for energy efficiency interventions - referred to the art. 1 del D.L. 63/2013 ("*Ecobonus*") – apply to the 110% regime. This bonus is valid for the following subjects and with the relative deadlines for the expenses (Table 6):

SUBJECT	PERIOD OF APPLICATION
Physical persons on single real estate units	Between 01/07/2020 and 30/06/2022
Condominiums and individuals on buildings with 2-4 real estate units, fully owned	Between 01/07/2020 and 30/06/2022, extendable to 31/12/2022 if at 30/06/2022 the work progress status of at least 60% has been reached
IACP and health institutes	Between 01/07/2020 and 30/12/2022, extendable to 30/06/2023 if at 30/12/2022 the work progress status of at least 60% has been reached
Building cooperatives and third sector subjects	Between 01/07/2020 and 30/06/2022

Table 6 - Superbonus 110% beneficiaries and related deadlines [5]

As regards the deductions, they are usable in annual instalments:

- 5 annual instalments if incurred between 01/07/2020 and 31/12/2021;
- 4 annual instalments from 01/01/2022.

The interventions called "*trainati*" can be reduced into two categories:

- interventions of thermal insulation of the opaque building envelope (executable on common parts of condominium buildings, on single-family buildings or on real estate units in possession of certain autonomy requirements located inside multi-family buildings, lettera a, comma 1, art. 119 del D.L. 34/2020);
- interventions to replace the existing winter air conditioning system (executable on common parts of condominium buildings for the centralized system – lettera b, comma 1, art. 119 del D.L. 34/2020 – or on single-family buildings or on real estate units in possession of certain autonomy requirements located inside multi-family buildings, lettera c, comma 1, art. 119 del D.L. 34/2020);

The concessions are also allowed in the context of demolition and reconstruction interventions, as defined by art. 3 del D.P.R: 380/2001, comma 1, lettera d (comma 3, ultimo period, art. 119 del D.L. 34/2020; Circolare 08/08/2020, n.24/E, punto 2), in compliance with the requirements.

In all cases, the intervention must concern existing buildings or real estate units equipped with a functioning heating system or reactivable through an ordinary or extraordinary maintenance intervention. The property in question must have a residential use and the "*trainante*" intervention can be also performed on a pertinence.

2.6.1.1. Trainanti intervention

The details of the types of "*trainanti*" interventions, with the related expenditure and deduction ceilings, are provided below.

- Lettera a, art. 119 del D.L. 34/2020. Building envelope of entire buildings or autonomous real estate units:

Description of the intervention	Thermal insulation of opaque vertical, horizontal and inclined surfaces (vertical walls, floor and ceilings, roofs) affecting the building envelope with an incidence greater than 25% of the gross dispersing surface. The intervention must be carried out with the use of insulating materials compliant with the provisions of the decree on minimum environmental criteria (CAM) for construction, D.M.11/10/2017 for the insulation material.
Interested properties	The interventions in question can be performed on: - entire building (single-family, condominium or multi-family); or - single real estate unit located inside a multi-family building, which is functionally independent and has one or more independent accesses from the outside.
Expenditure ceilings	The expenditure ceilings are differentiated according to the type of property on which action is taken: a) € 50,000 for single-family buildings or single autonomous real estate units; b) in multi-family buildings: - € 40,000 for each real estate unit up to the eighth; - € 30,000 for each real estate unit from the ninth onwards. Increases to the subsidized ceilings are conceived for areas affected by seismic events. Also included in the eligible expenses: - expenses relating to the certificates and sworn statements to be issued by the technicians in charge; - - the costs for the insulation of the roof, even if it is not an element of separation between the heated volume and the outside and obviously

	contributes to the achievement of the incidence for at least 25% of the dispersing surface
Deduction ceilings	The deduction ceilings are obtained by applying the percentage of 110% to the above eligible expenditure ceilings: a) € 55,000 for single-family buildings or single autonomous residential units; b) in multi-family buildings: - € 44,000 for each real estate unit up to the eighth; - € 33,000 for each real estate unit from the ninth onwards.

Table 7 - Features of interventions on building envelope of entire buildings or autonomous real estate units [5].

- Lettera b, art. 119 del D.L 34/2020. Air conditioning systems on common parts of buildings.

Description of the intervention	Replacement of existing winter air conditioning systems on the common parts of the buildings with centralized system for heating, cooling or supply of domestic hot water. The system being installed can be: - condensing, with efficiency at least equal to the product class A provided by EU Regulation UE 811/2013, Annex II, Table 1 (efficiency ≥ 90); - heat pumps; - hybrids (integrated heat pump with condensing boiler); - geothermal; - micro-cogeneration plants; - solar collectors. The interventions in question can also be combined with photovoltaic systems and related storage systems referred to in paragraphs 5 and 6 of art. 119 of the D.L. 34/2020. Furthermore, exclusively for mountain municipalities not affected by European infringement procedures n. 2014/2147 or 2015/2043 connection to efficient district heating systems, as defined by art. 2 of Legislative Decree 102/2014, paragraph 2, letter tt).
Interested properties	The interventions in question can be carried out on an entire condominium or multi-family building.
Expenditure ceilings	The expenditure ceilings are differentiated according to the type of property on which action is taken: - € 20,000 for each real estate unit up to the eighth; - € 15,000 for each real estate unit from the ninth onwards. Increases to the subsidized ceilings are conceived for areas affected by seismic events. Also included in the eligible expenses: - costs relating to the disposal and reclamation of the replaced plant: - the expenses for the replacement of the existing collective flue, by

	means of multiple or new collective flue systems, compatible with condensing appliances, with the CE marking referred to in EU Regulation 305/2011, in compliance with the minimum performance requirements provided for by the UNI 7129- 3 (point 2.1.2 of Circular 08/08/2020, n.24/E). - expenses relating to the certificates and sworn statements to be issued by the technicians in charge.
Deduction ceilings	The deduction ceilings are obtained by applying the percentage of 110% to the above eligible expenditure ceilings: - € 22,000 for each real estate unit up to the eighth; - € 16,500 for each real estate unit from the ninth onwards.

Table 8 - Air conditioning systems on common parts of buildings [5].

- Lettera c, art. 119 del D.L 34/2020. Air conditioning systems on single-family buildings or autonomous real estate units.

Description of the intervention	Replacement of existing winter air conditioning systems with systems for heating, cooling or the supply of domestic hot water. The plants to be installed can be: - condensing, with efficiency at least equal to the product class A conceived by EU Regulation 811/2013, Annex II, Table 1 (seasonal energy efficiency for space heating ns ≥ 90); - with heat pump: - hybrids (heat pump integrated with condensing boiler); - geothermal; - micro-cogeneration plants; - solar collectors. The interventions in question can also be combined with photovoltaic systems and related storage systems referred to in paragraphs 5 and 6 of art. 119 of the D.L. 34/2020. In addition, the following are also facilitated: - exclusively for non-methanized areas in municipalities not affected by European infringement procedures nos. 2014/2147 or 2015/2043 the installation of biomass boilers with emissions in line with the 5-star class pursuant to Ministerial Decree 07/11/2017, n. 186, Annex 1; - - exclusively for mountain municipalities not affected by European infringement procedures nos. 2014/2147 or 2015/2043 connection to efficient district heating systems, as defined by art. 2 of Legislative Decree 102/2014, paragraph 2, letter tt).
Interested properties	The interventions in question can be performed on: - single-family building; or - single real estate unit located inside a multi-family building that is

	functionally independent and has one or more independent accesses from the outside.
Expenditure ceilings	The expenditure ceiling is equal to € 30,000. Increases to the subsidized ceilings are conceived for areas affected by seismic events, see dedicated paragraph. The following items also fall within the eligible expenses: - disassembly, disposal and reclamation of the replaced plant; - supply and installation of all thermal, mechanical, electrical and electronic equipment, hydraulic and masonry works necessary for the professional replacement of the existing heating system with the new condensing generator; - adaptation of the distribution network, accumulation systems, water treatment systems, control and regulation devices as well as emission systems; - certifications and sworn statements to be issued by the technicians in charge.
Deduction ceilings	The maximum deduction is obtained by applying the percentage of 110% to the maximum eligible expenditure indicated above: € 33,000.

Table 9 - Air conditioning systems on single-family buildings or autonomous real estate units [5].

2.6.1.2. Trainati interventions

The increased measure of 110% applies - pursuant comma 2 of art. 119 del D.L. 34/2020 - also to the other energy efficiency measures referred to art. 14 del D.L. 63/2013, within the spending limits for each of these provided, and on condition that the latter are carried out jointly with one of the interventions subject to the increased rate ("*trainanti*"). This essentially means that the new interventions subject to the 110% subsidy can "attract" interventions already subject to the ordinary *Ecobonus* subsidy within the application of the increased rate, which therefore, if carried out together to new ones, they can also take advantage of the increased rate of 110%. Furthermore, there is also the possibility of deducting expenses in 5 years, instead of 10 as usually happens for interventions that use the *Ecobonus*.

In the following table are summed the interventions defined as "*trainati*" with the ceilings without and with *Superbonus 110%*:

INTERVENTIONS	ORDINARY CEILINGS	CEILINGS WITH SUPERBONUS 110%
Interventions on the envelope of existing buildings, parts of existing buildings or real estate units, concerning opaque vertical	65% Deduction € 60,000 Expenses € 92,307.69	110% Deduction € 60,000 Expenses € 54,545.45

structures and opaque horizontal structures (roofs and floors)		
Purchase and installation of windows including fixtures.	50% Deduction € 60,000 Expenses € 120,000	110% Deduction € 60,000 Expenses € 54,545.45
Purchase and installation of the solar shading referred to Allegato M al D. Leg.vo 311/2006.	50% Deduction € 60,000 Expenses € 120,000	110% Deduction € 60,000 Expenses € 54,545.45
Installation of solar panels to produce hot water for domestic or industrial use and for covering the needs of hot water in swimming pools, sports facilities, shelter and care homes, schools and universities.	65% Deduction € 60,000 Expenses € 92,307.69	110% Deduction € 60,000 Expenses € 54,545.45
Interventions to replace winter air conditioning systems with systems equipped with condensing boilers with an efficiency at least equal to the product class A provided for by Regolamento UE 811/2013, Allegato II, Tabella 1 (efficiency ≥ 90) , and contextual fine-tuning of the distribution system.	50% Deduction € 30,000 Expenses € 60,000	110% Deduction € 30,000 Expenses € 27,272.72
Interventions referred to in the previous point: - if accompanied by the simultaneous installation of advanced thermoregulation systems, belonging to classes V, VI or VIII of the Comunicazione UE 2014/C 207/02; - if you plan to install systems equipped with hybrid appliances, consisting of a heat pump integrated with condensing boiler, assembled in the factory and expressly designed by the manufacturer to work in conjunction; - if expenses are incurred for the purchase and installation of condensing hot air generators.	65% Deduction € 30,000 Expenses € 46,153.85	110% Deduction € 30,000 Expenses € 27,272.72
Replacement, even partial, of winter air conditioning systems with	65% Deduction € 30,000	110% Deduction € 30,000

high efficiency heat pumps, low enthalpy geothermal systems, heat pump water heaters, hybrid systems.	Expenses € 46,153.85	Expenses € 27,272.72
Purchase and installation of winter air conditioning systems with systems equipped with heat generators powered by biomass fuels.	50% Deduction € 30,000 Expenses € 60,000	110% Deduction € 30,000 Expenses € 27,272.72
Purchase and installation of micro-cogenerators to replace existing plants, if the corresponding intervention leads to primary energy savings, as defined in Allegato III del D.M. 04/08/2011, equal to at least 20%.	65% Deduction € 100,000 Expenses € 153,846.15	110% Deduction € 100,000 Expenses € 90,909.09
Installation of multimedia devices for remote control of the heating or air conditioning system (Building Automation)	65% Deduction € 15,000 Expenses € 23,076.92	110% Deduction € 15,000 Expenses € 13,636.36

Table 10 - "Trainati" intervention features and ceilings [5].

In addition to the interventions of the previous table, there are two "*trainati*" ones that require particular attention: photovoltaic systems and storage system and charging station for electric vehicles.

- **Photovoltaic system and Storage system:**

  The art. 119 del D.L. 34/2020 provides in commi 5 and 6 that are deductible to the extent of 110% also the expenses, incurred in the period of validity established in general for the *Superbonus*, for the types of interventions with the expenditure ceilings indicated in the table below (Table 11). To benefit of this deduction, the interventions must be carried out jointly to one of the *Ecobonus 110%* or *Sismabonus 110%* interventions. These interventions are included in the topology referred to comma 1, lettera h), dell'art. 16-bis del D.P.R. 917/1986: "relativi alla realizzazione di opera finalizzate al conseguimento di risparmi energetici con particolare riguardo all'installazione di impianti basati sull'impiego delle fonti rinnovabili di energia". It follows that they share the same expenditure ceiling with other interventions attributable to the same reference regulatory, for example the *Sismabonus* and *elimination of architectural barriers*. In the other cases, the ceilings are cumulative with the ones for interventions both "*trainanti*" and "*trainati*".

The deduction is usable in five annual instalments of the same amount for expenses incurred up to 31/12/2021 and four for expenses from 01/01/2022.

INTERVENTION	MAXIMUM ESPENSE	MAXIMUM DEDUCTION
Installation of photovoltaic solar systems on buildings or even just on appliances (Circolare 22/12/2020, n. 30/E, punto 4.3.2). The systems must be installed on buildingswithin the definitions provided from art. 1 del D.P.R. 412/1993, comma 1, lettere a), b), c) e d)	€ 48,000, in any case within the limit of € 2,400 for each kW of nominal power of the system, reduced to € 1,600 for each kW if the installation is carried out in the context of building renovation, new construction or urban renovation (art. 3 del D.P.R. 380/2011, comma 1, lettere d), e) ed f)	€ 52,800
Contextual or subsequent installation of storage systems integrated in photovoltaic systems	€ 1,000 for each kWh of storage capacity	€ 1.100 for each kWh of storage capacity

Table 11 - Features of intervention of photovoltaic systems and storage systems [5].

The spending limit is established separately for the installation of photovoltaic solar system and storage system. Furthermore, the limit refers to the single real estate unit. However, the maximum power limit that can be facilitated, according to what is read in the Circolare 22/12/2020, n. 30/E, punto 4.3.3:

- if the system is at the service of the condominium, it refers to the condominium building;
- if the system is at the service of the single housing unit, it must refer to the single unit.

It follows that the maximum power limit that can be facilitated is 20 kW (48,000/2,400) or 30 kW (48,000/1,600) if the installation is carried out as part of the building interventions indicated.

The comma 7 dell’art. 119 del D.L. 34/2020 establishes that the deduction for the photovoltaic systems cannot be combined with other public incentives and other forms of concessions. For example, it is possible to upgrade an existing photovoltaic system that benefits from incentives as “*Conto Energia*”, but the new installation cannot access to this benefit.

- **Charging station for the electric vehicles:**

  The art. 119 del D.L. 34/2020 states at comma 8 that the expenses for the installation of electric vehicle charging station are deductible to the extent of 110%, pursuant to art. 16-ter del D.L. 63/2013. The deduction is recognized for expenses as shown in chapter 2.5. However, following the innovation introduced by L. 30/12/2020, n. 178 (Legge di bilancio 2021 art. 1, comma 66), il comma 8, art 119 del D.L. 34/2020, provides that – without prejudice to the interventions in progress for which the limit of expenditure is € 3,000 – the expenditure ceilings for this type of intervention decreased to:

  - € 2,000 for single-family buildings or for functionally independent real estate units;
  - € 1,500 for multi-family buildings and condominiums that install up to a maximum of 8 columns;
  - € 1,200 for multi-family buildings and condominiums that install more than 8 columns.

  As for the spending limit, it is specified that (Circolare 08/08/2020, n. 24/E, punto 2.2.3):

  - This limit is annual and refers to each intervention for the purchase and installation of the recharging infrastructures (therefore an intervention that lasts over two years is always facilitated for the amounts indicated);
  - The aforementioned limit also refers to each taxpayer, and therefore constitutes the maximum amount of expenses admitted to the deduction even in the event that, in the same year, the taxpayer has incurred expenses for the purchase and installation of more charging infrastructure;
  - If the expenditure is incurred by several taxpayers within the maximum limit envisaged, it must be divided among those entitled to it on the basis of the cot incurred by each.

  To take advantages of the subsidy, these interventions must be carried out in conjunction with one of the *Ecobonus 110%* interventions. The deductions in question can be used in five annual instalments of the same amount.

2.6.1.3. Energy Performance Certificate (EPC)

In order to access the incentive, the interventions must ensure improvement of at least two energy classes or the achievement of the highest energy class. Therefore, the EPC must be evaluated both before and after the interventions. The improvement of the energy class does not necessarily have to be only from the main "*trainanti*" interventions, but it can be achieved by considering as a whole also any "*trainati*" interventions.

In the case of condominium or buildings with multiple real estate units, the EPC is called conventional EPC and it has value only for the *Superbonus 110%* concession. The conventional EPC is calculated considering the building in its entirety, it is the sum of the products of the corresponding indices of the individual real estate units by their usable area and dividing the result by the total usable area of the entire building (punto 12.3 dell'Allegato A al Decreto Requisiti).

2.6.2. Sismabonus 110%

The art. 119 del D.L. 34/2020 disposes to the comma 4 that the deduction for the interventions of structural and anti-seismic adaptation – referred to the commi da 1-bis a 1-septis, art. 16 del D.L. 63/2013 ("*Sismabonus*"), apply the extent of 110% for the expenses incurred from 0/07/2020 until30/06/2022 (term extended by L. 30/12/2021, n. 178, art. 1, comma 66, lettera f).

This extension is not valid for IACP and similar subject. As regards condominiums and people who intervene on buildings with 2-4 real estate units entirely owned, if the work progress at 30/06/2022 is at least 60%, the term will be extended for a further 6 months (31/12/2022).

The ordinary "*Sismabonus*" provides:

- a basic deduction rate of 50%, for interventions relating to the adoption of anti-seismic measures with regard to the execution of static safety works (intervention referred to lettera i), comma 1, dell'art. 16-bis del D.P.R. 917/1986);
- aliquots increased to a variable extent between 70% and 85% of the expense incurred, depending on the improvement achievable in the seismic risk classification (certified by D.M. 28/02/2017, n. 58) with the intervention that is carried out and the type of property concerned.

The new aliquots take over the previous rates in the period of validity of the "*Superbonus 110%*". They also apply to cases of purchase of anti-seismic houses directly from the company that has provided for the demolition and reconstruction and then to the sale within 18 months from the end of the intervention (comma 1-septis, art. 16 del D.L. 63/2013, "*Sismabonus acquisiti*").

The expenditure ceilings of € 96,000 remains fixed per property unit, which therefore leads in this case to a maximum deduction of € 105,600. Lastly, the intervention of ordinary or extraordinary maintenance, for example the renovation of external and internal walls, ceilings, floors, the hydraulic and electrical system necessary to complete the anti-seismic intervention, are also included in the maximum spending limit of € 96,000.

3. STATE OF AFFAIRS

In this chapter, a description of the building is shown. Starting from its characteristics, up to the heating system, the water heater for the domestic hot water (DHW) and the stratigraphy of the opaque and transparent components.

In order to carry out all the evaluations, the *TerMus* software of *ACCA* was used. *ACCA* is the Italian leader in Building Information Modelling (BIM) and technical software for construction, engineering, and architecture. *TerMus* is the BIM software for energy certification, verification of the energy performance of buildings and the design of energy efficiency interventions for the *Superbonus 110%*.

3.1. General data

The building is a condominium located in Varazze, a town overlooking the Ligurian Sea in the province of Savona (Figure 6). It is located in Via Monsignor F. Callandrone 16 (Figure 7) and was built in 1969.

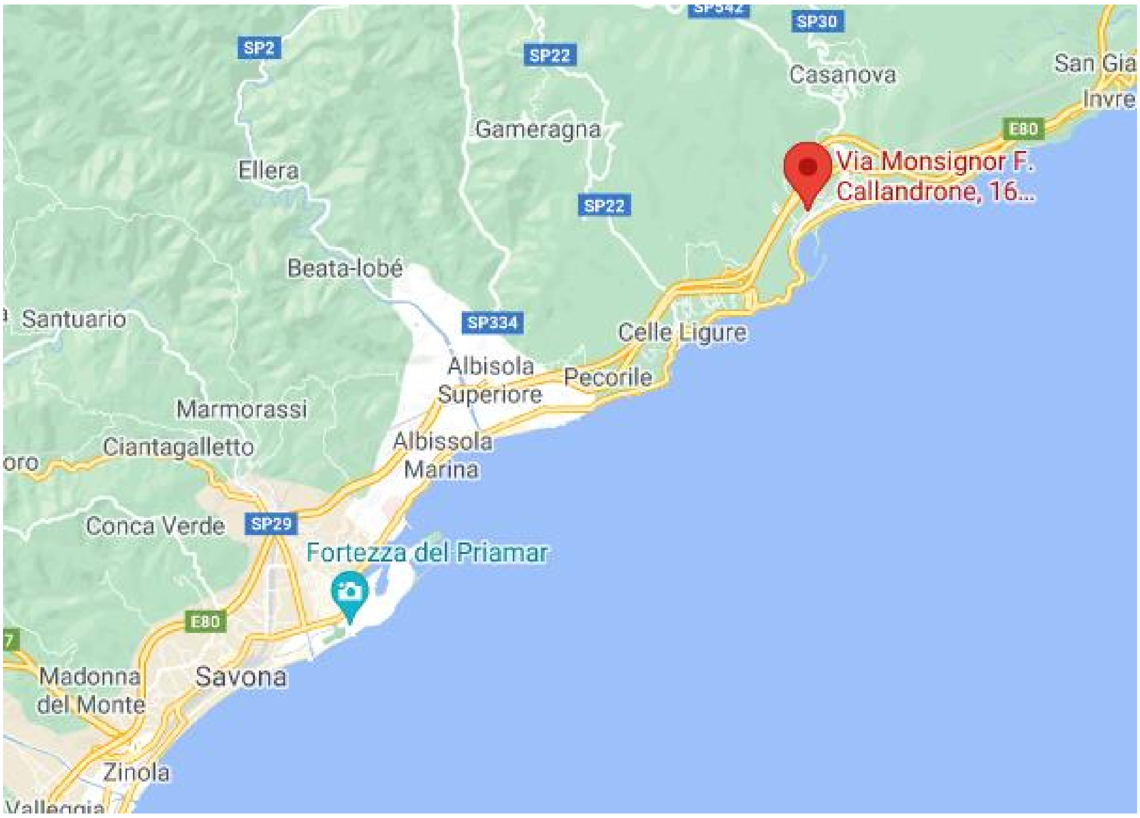


Figure 6 - Building location 1 [3]

Figure 7 - Building location 2 [3]

In Figure 8, the data based on the municipality are represented. The software automatically searches on the database the various data necessary for the project for the climate zone of interest (in this case D, that means that the heating season is from the 1st of November until the 15th of April), both for summer and winter case. This way, values of external temperature, external relative humidity, wind velocity and the degrees-day are calculated. In addition, monthly average values of temperature and the humidity are also measured.

The intervention that will be carried out will be an intervention of extraordinary maintenance. Furthermore, the software needs the type of legislation that must be used (the *Superbonus 110%* follows a national legislation, but for example, the calculation of the building's energy class only, follows the regional legislation), the number of the residential unit (in this case twenty-two), the limit values considered (those after the 01/01/2019).

The lasts necessary general data are the type of the building (multi-family), the number of facades exposed to the wind (higher than 1) and the building's position in order to evaluate a wind coefficient that take into account if the building is located in a city, outskirts or rural area (in this case it is located in a city).

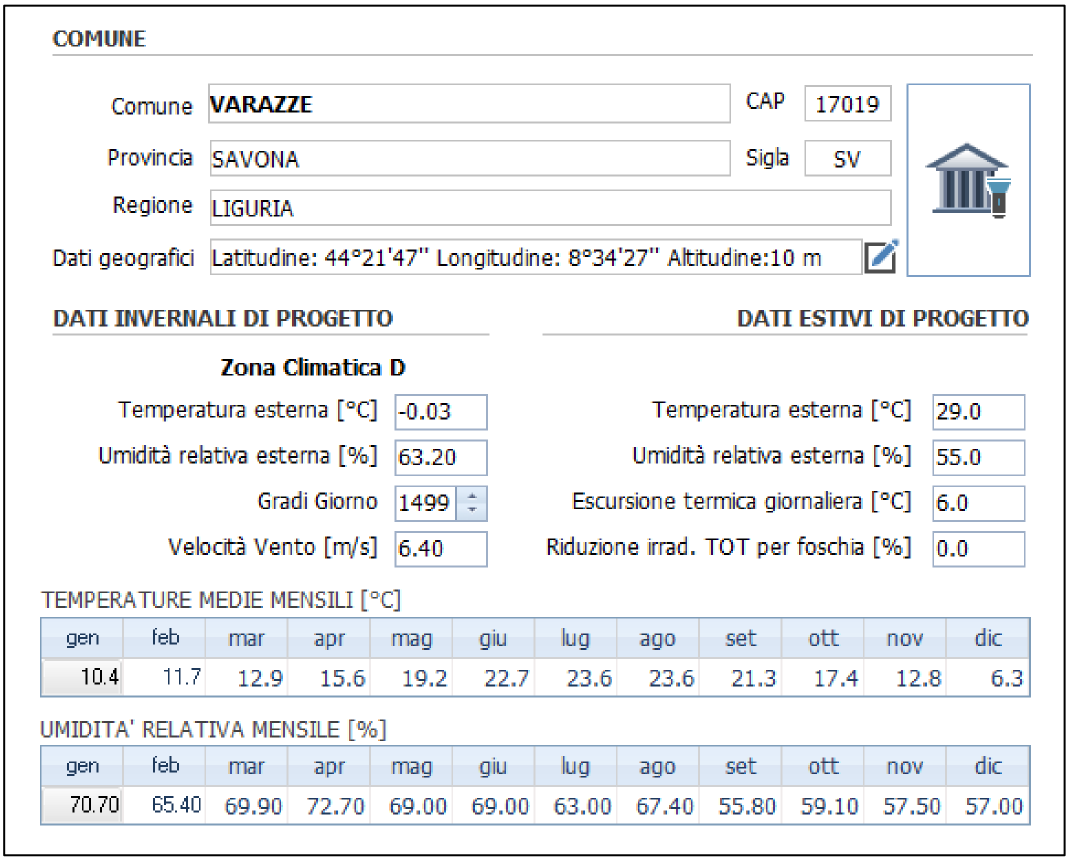


Figure 8 - General data 1

3.2. Building and flats' descriptions

For each residential unit, designated use, internal condition, and features must be defined.

In this building, some apartments are second houses, and they are used only for a limited time of the year. If the purpose of this work were to define an energy analysis with precision, this factor would have to be taken into account. However, in the case of *Superbonus 110%*, the worst possible scenario must be considered, i.e. the scenario in which all the apartments are inhabited. Therefore, the designated use is dwellings used as residences permanently (E1).

In Figure 9, the hygrometric characteristics are evaluated by means of the UNI EN ISO 13788, which defines the internal condition as regards the temperature (20°C in winter and 26°C in summer) and the humidity (always 50%).

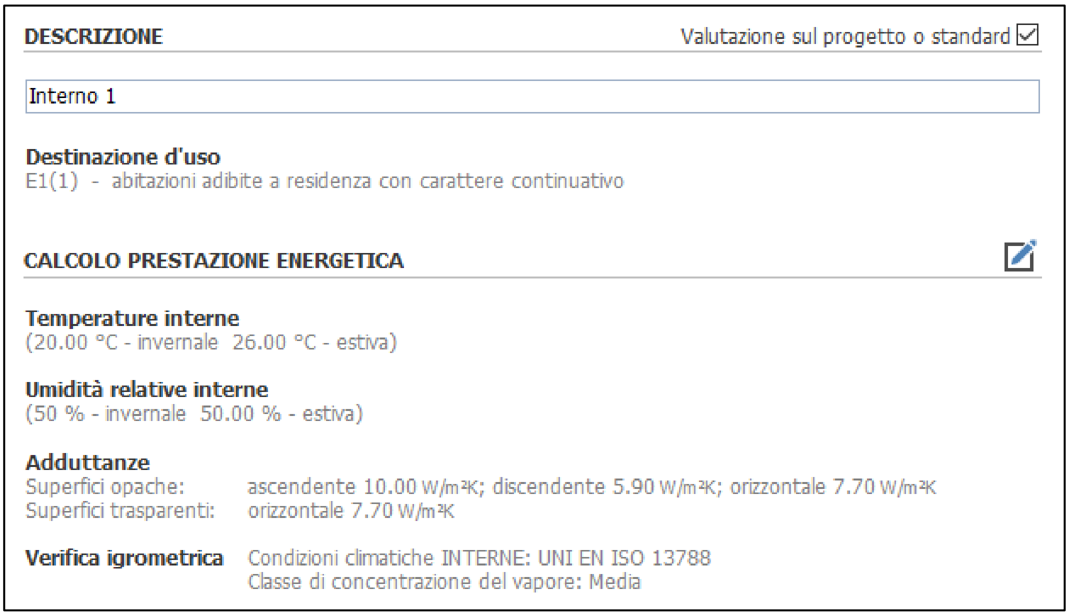


Figure 9 - Hygrometric features

The next step is the definition of the zones. This means that it is necessary specify which services are present in the apartments. In this case heating, production of DHW and ventilation are present for all the units. The apartment n. 1 is used as example for all of them. There is cooling only in the apartments n. 4 and n. 19.

Regarding the heating it is necessary to define the typology of the heating terminals (radiators), their power, their position and if there is the isolation on the external walls or not. In this case there is no isolation on the walls and so a correction factor equals to -0.04 (decrease of 4% on the efficiency calculated) is considered (Figure 10). Furthermore, the type of regulation must be selected: manual, centralized, for single ambient, with valve or not. In this building there are no thermoregulation valves and therefore the regulation is centralized with only the possibility to switch on or off.

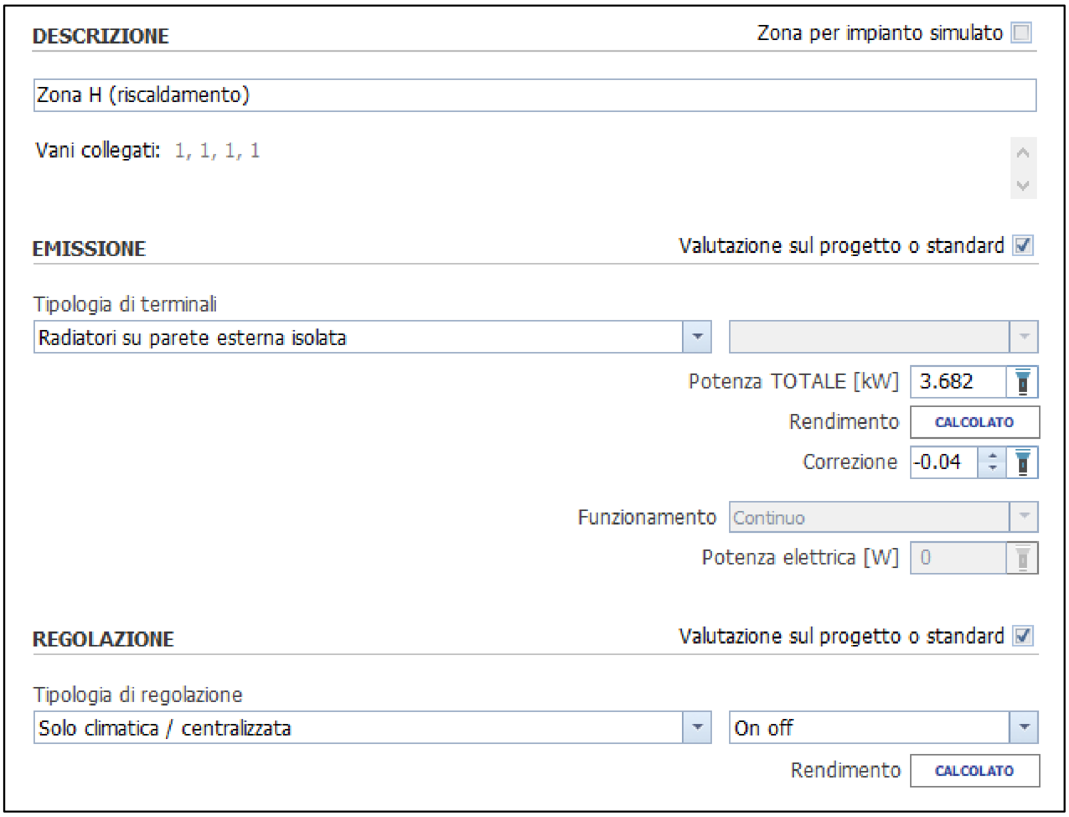


Figure 10 – Heating type of terminals and regulation

Furthermore, the heating system power is needed for each flat. In Table 12 are shown the thermal needs for each apartment calculated from the "Relazione energetica, ex legge 10" of this building (courtesy of the engineer Quinternetto).

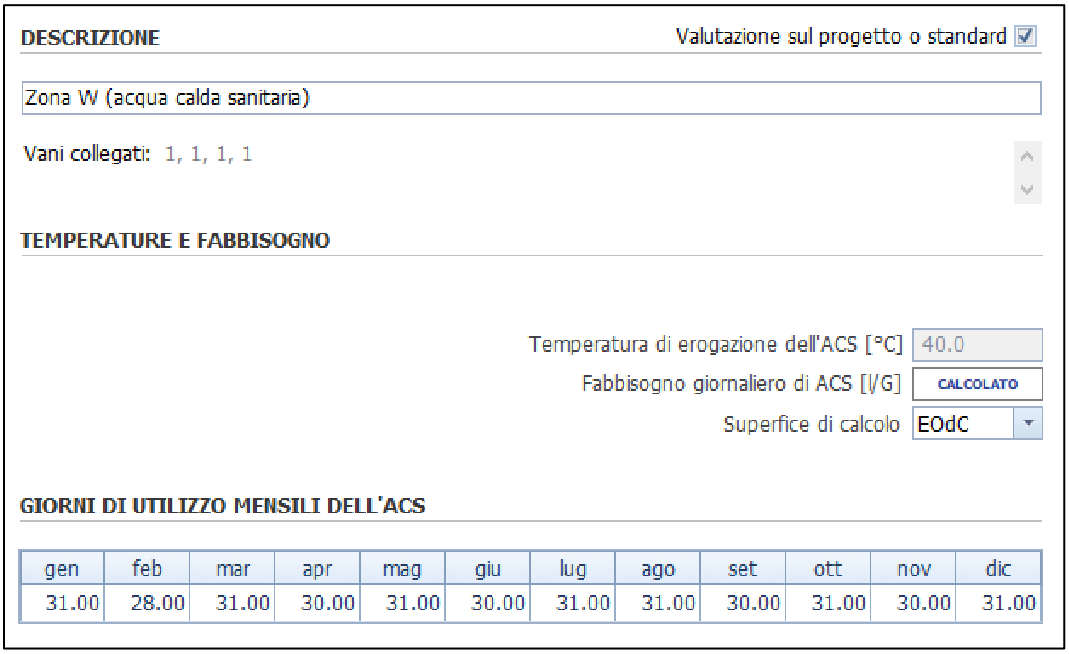


Figure 11 - DHW definition

Apartment	Thermal needs
n°	W
1	3,682
2	4,258
3	3,077
4	2,765
5	8,113
6	2,919
7	4,292
8	2,569
9	3,681
10	3,122
11	3,431
12	2,346
13	5,204
14	2,569
15	3,847
16	2,559
17	2,719
18	2,720
19	6,258
20	3,258
21	4,524
22	7,825

Table 12 - Dispersions in each flat

Then the definition of the DHW (Figure 11), with temperature and days of utilizations is necessary. The software automatically calculates the daily needs of water, setting the supply temperature of 40°C. Obviously, the DHW is required every day.

The last service that needs to be defined for all the apartments is the ventilation. In this case is only natural, with an air exchange of 0.5 vol/h.

Only for the apartments n. 4 and n. 19, it is needed to define the cooling system. In the apartment n. 4 two unit of 2.5 kW are present for a total of 5 kW. Three 2.5 kW split units are installed in the apartment n. 19, for a total of 7.5 kW. The type of regulation is for both apartment single room with step of 1°C. In Figure 12 the example of n. 19.

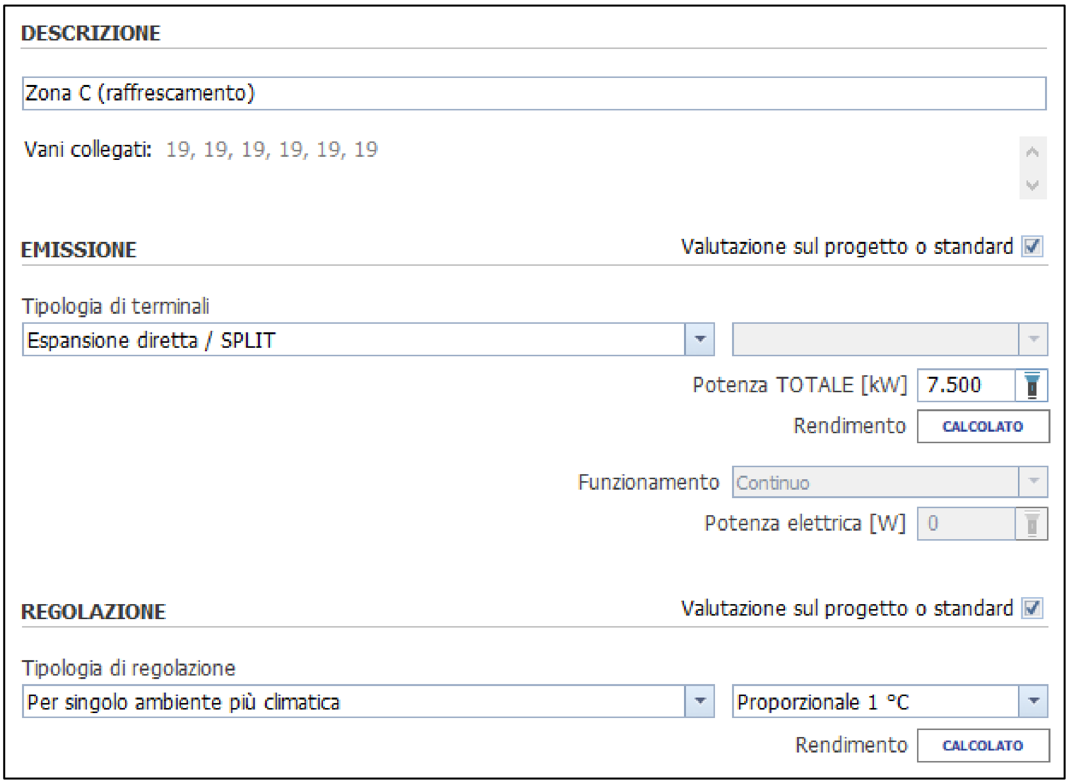


Figure 12 - Cooling system for apartment n. 19

In addition to the flats, environments without heating must be defined. The heat exchange correction factor between the heated environments and the unheated ones (b_{tr}) is evaluated through the Prospetto 7 UNI/TS 1300-1:2014, which provides data and methods for determining the building's thermal energy, needs for summer and winter air conditioning. In particular, this factor, that is different from 1 if the temperature of the unheated environment is different from that of the external environment, multiply the global heat transfer coefficient (H_{ui} [W/K]) between the heated environment and the unheated environment to find the overall heat transfer coefficient for transmission (H_U [W/K]).

For this building, five environments without heating are evaluated:

- Elevator: defined as "internal circulation areas without external walls and with an air exchange rate of less than 0.5 vol/h". Correction factor equal to 0.
- Cellars: defined as "environment with external doors and windows with at least two external walls". Correction factor equal to 0.6.
- Stairs: defined as "environment with one external wall". Correction factor equal to 0.4.
- Attic: defined as "attic with high ventilation rate without felt or planking (example roofs covered with tiles)". Correction factor equal to 1.

- Embankment: defined as “floor or wall against the ground”. Correction factor equal to 0.45.

3.3. Heat generators

The building is heated through a centralized system and radiators. The generator, which is located in the boiler room, it is a water heater installed in 1982 and fuelled with diesel oil. Its nominal power is equal to 205 kW and its efficiency is around 85%.

The efficiency of the distribution network for the heating system is evaluate by means the UNI/TS 11300-2 Prospetti 21-23. The software requires specification of the type of system (centralized system with non-insulated uprights with horizontal distribution in the basement), the distribution type (non-insulated uprights running in the cavity of the external walls), the horizontal distribution insulation (insufficient, severely deteriorated, or non-existent insulation), height (4 floors and more), design flow temperature (80 °C) and the design return temperature (60 °C). With this definition, the efficiency calculated for the distribution system is equal to 0.89.

Regarding the production of DHW, each flat has its own heater, which are listed in Table 13. In the case of electric heaters, the volume is equal to 80 litres.

Also, the efficiency of the distribution system of the DHW needs to be defined. To do so, the UNI/TS 11300-2: Prospetto 34 is used. It calculates an efficiency for all systems equal to 0.9259 for all the system installed after the entry into force of law 373/76.

Apartment	Type	Power	Efficiency
n°	-	kW	-
1	Gas	20	0,866
2	Gas	24	0,868
3	Gas	11	0,861
4	Electric	1.2	0,750
5	Electric	1.2	0,750
6	Gas	11	1,070
7	Gas	17	0,865
8	Gas	17	0,865
9	Gas	19	0,866
10	Gas	20	0,866
11	Gas	11	0,861
12	Gas	11	0,861
13	Gas	20	0,866
14	Electric	1.2	0,750
15	Gas	11	0,861
16	Gas	18	0,865
17	Gas	18	0,865
18	Gas	11	0,861
19	Gas	19	0,866
20	Electric	1.2	0,750
21	Gas	18	0,865
22	Gas	17	0,865

Table 13 – Heat generators for domestic hot water

3.4. Building planimetry

The building is composed by four floors, the ground floor, an attic, and the roof. The height of the floors is 3 m, while that of the ground floor is 2.5 m.

On the ground floor, there are garages and cellars for each apartment (Figure 13). Furthermore, there is an embankment, elevator, and stairs. In the first and the fourth floor, there are five apartment each as shown in Figure 14-17. The second and the third floor have six apartment each (Figure 15-16). There is also an unheated attic under the roof (Figure 18-19).

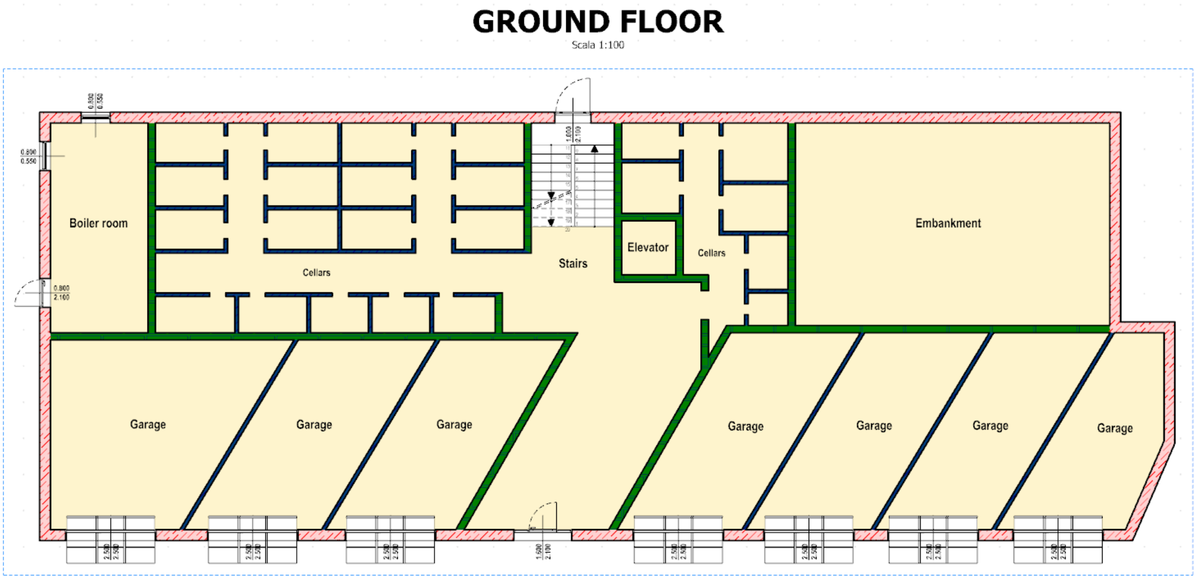


Figure 13 - Planimetry of the ground floor

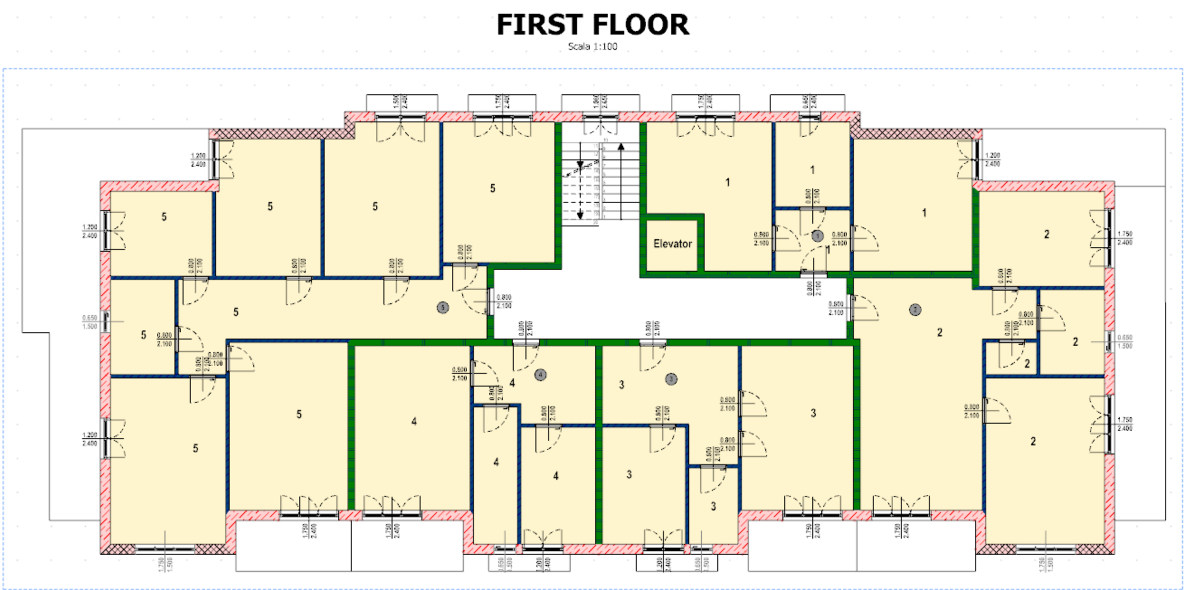


Figure 14 - Planimetry of the first floor

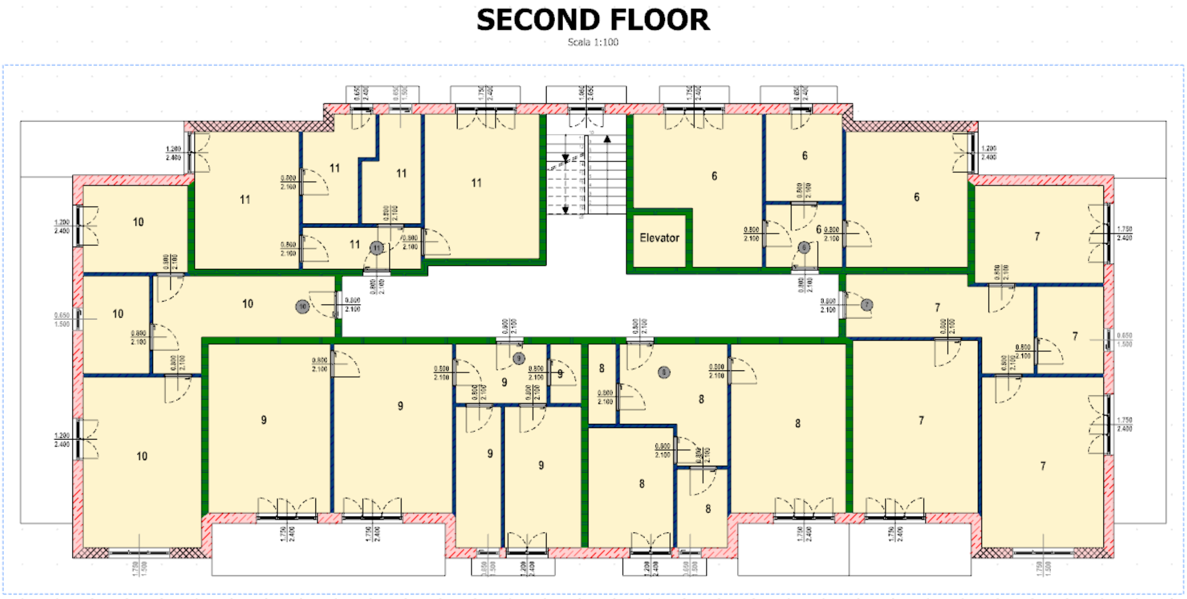


Figure 15 - Planimetry of the second floor

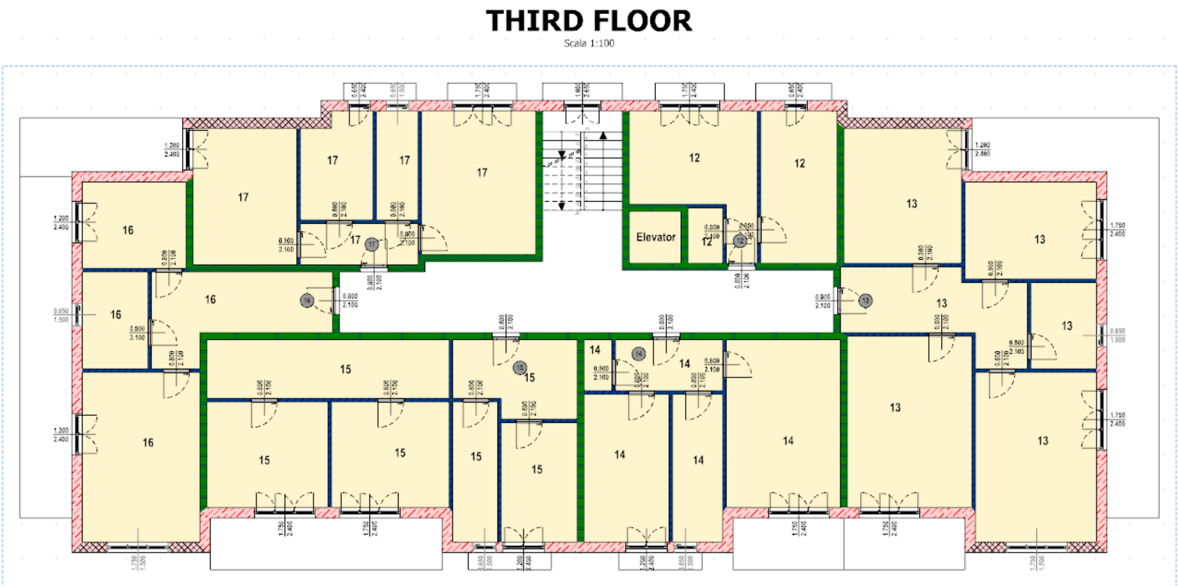


Figure 16 - Planimetry of the third floor

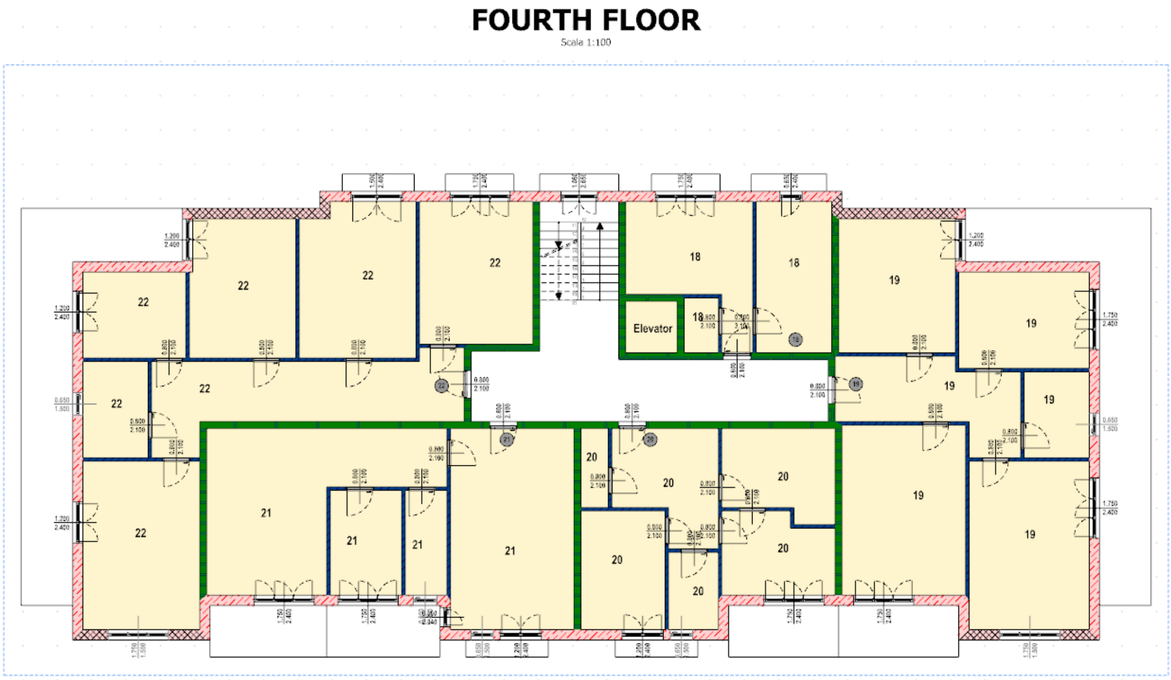


Figure 17 - Planimetry of the fourth floor

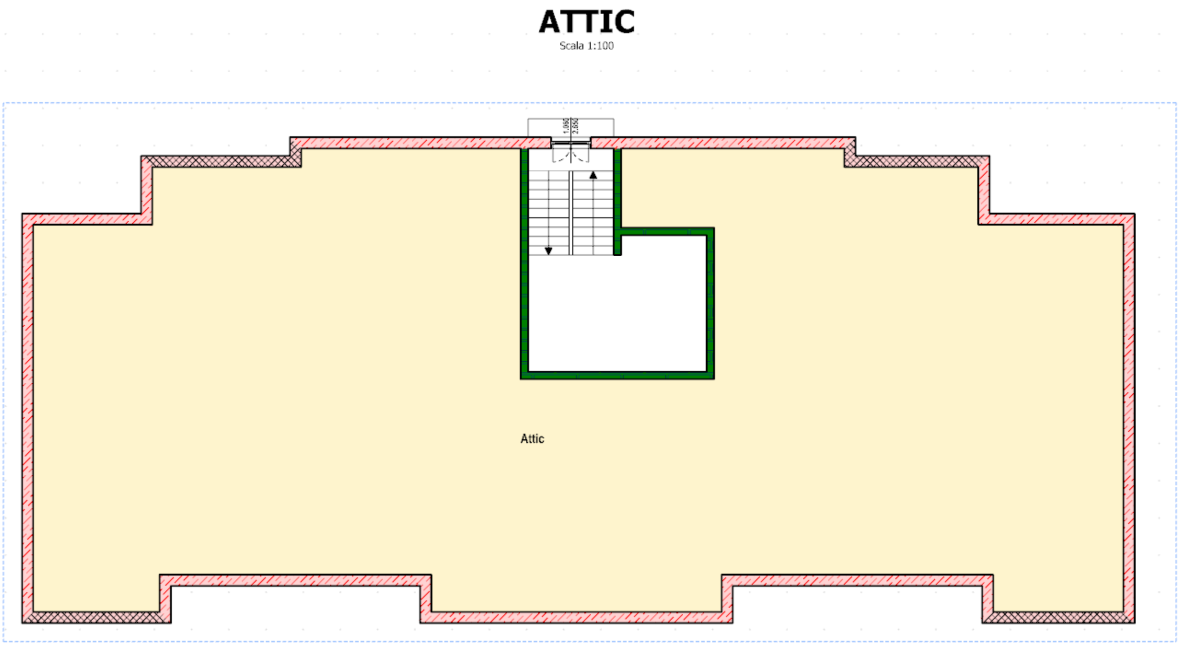


Figure 18 - Planimetry of the attic

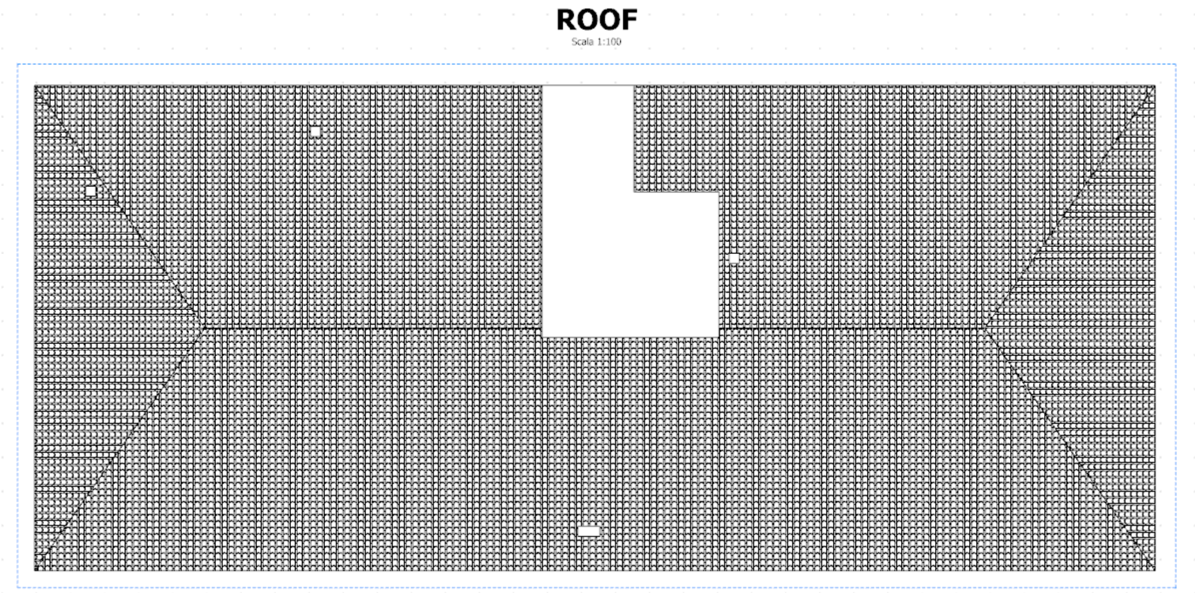


Figure 19 - Planimetry of the roof

The following figures provide the stratigraphy of the vertical and horizontal elements of the buildings. In Figure 20, the legenda of the stratigraphy of vertical opaque components is represented. The structure of the external walls is a solid brick wall with cavity, and it has a thickness of 300 mm (they are divided in two only to facilitate the positioning of the insulation in the software for the purpose of the case with future improvements). The walls that divide the flats is composed by solid brick of thickness of 200 mm and the internal walls of the flats are again solid brick walls, but with a thickness of 100 mm. All the previous walls are finished with a layer of plaster both on internal and external surfaces.

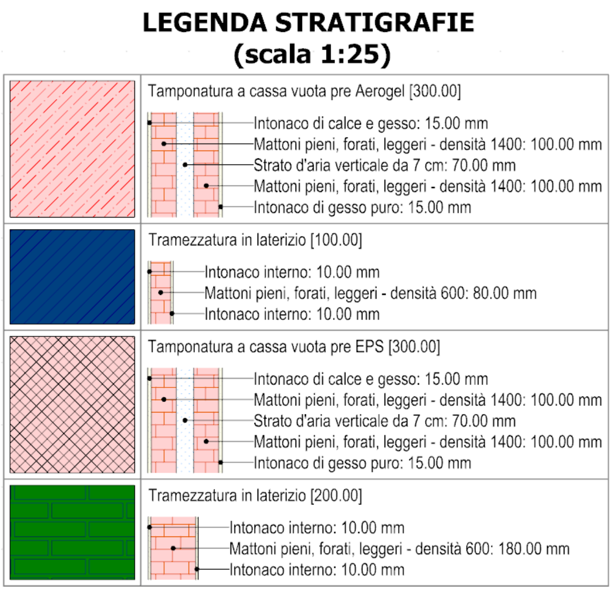


Figure 20 - Stratigraphy vertical elements

The characteristics of all the walls are summed in the tables below.

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza interna	0		7.7000				0.1299
1	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
2	Mattoni pieni, forati, leggeri - densità 600	80	0.2470	3.0875	48.00	5.3611	840	0.3239
3	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
	Adduttanza esterna	0		7.7000				0.1299

Table 14 – Characteristics of the internal wall. Thickness 100 mm

In the case of the internal wall, with thickness of 100 mm (Table 14), the total thermal resistance is equal to 0.6122 m^2K /W, which correspond to a thermal transmittance U of 1.6335 W/ m^2K.

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza interna	0		7.7000				0.1299
1	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
2	Mattoni pieni, forati, leggeri - densità 600	180	0.2470	1.3722	108.00	5.3611	840	0.7287
3	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
	Adduttanza esterna	0		7.7000				0.1299

Table 15 – Characteristics of the internal wall. Thickness 200 mm

In the case of the internal wall, with thickness of 200 mm (Table 15), the total thermal resistance is equal to 1.0171 m^2K /W, which correspond to a thermal transmittance U of 0.9832 W/ m^2K.

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza interna	0		7.7000				0.1299
1	Intonaco di calce e gesso	15	0.7000	46.6667	21.00	10.7222	1´000	0.0214
2	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
3	Strato d'aria verticale da 7 cm	70		5.5556	0.09	1.0000	1´008	0.1800
4	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
5	Intonaco di gesso puro	15	0.3500	23.3333	18.00	10.7222	1´000	0.0429
	Adduttanza esterna	0		25.0000				0.0400

Table 16 - Characteristics of the external wall. Thickness 300 mm

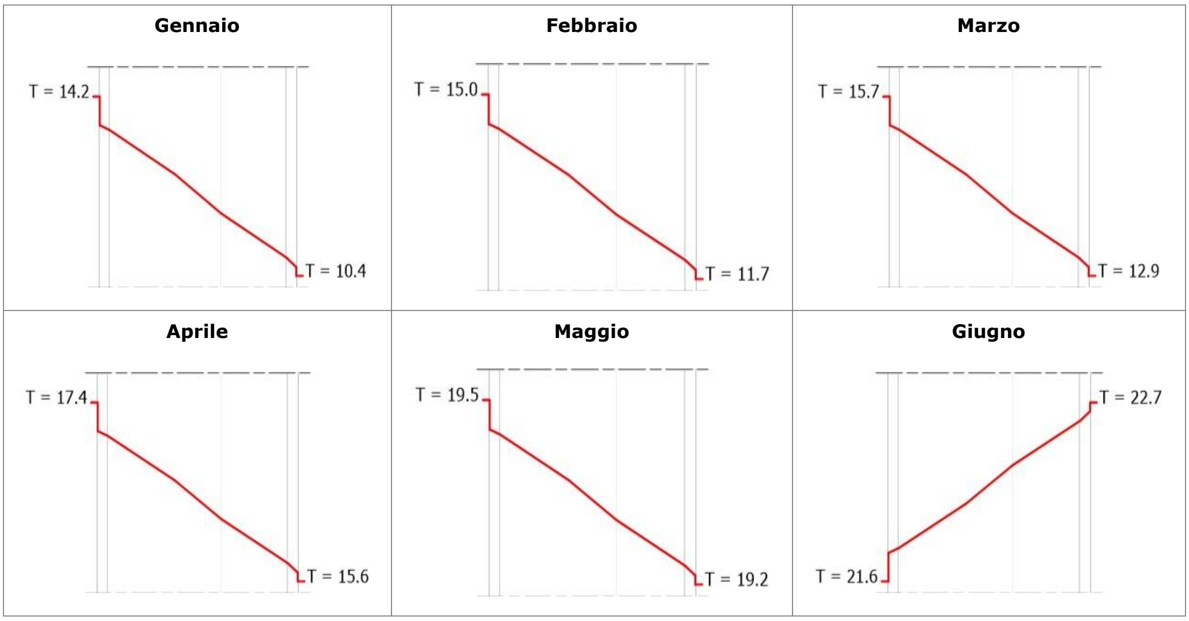
In the case of the external wall, with thickness of 300 mm (Table 16), the total thermal resistance is equal to 0.8142 m^2K/W, which correspond to a thermal transmittance U of 1.2283 W/m^2K.

It is possible to notice that the value of the surface thermal resistance, corresponding to the inverse of the heat transfer coefficient for radiation and convection, is equal to 0.1299 W/m^2K for the internal surface thermal resistance towards neighbouring environments with horizontal air heat-flux, and equal to 0.0400 W/m^2K for the external surface thermal resistance with horizontal air heat-flux outwards as described by UNI EN ISO 6946 (Figure 21).

Resistenza superficiale m^2K/W	**Direzione del flusso termico**		
	ascendente	orizzontale	discendente
R_{si}	0,10	0,13	0,17
R_{se}	0,04	0,04	0,04

Figure 21 - Surface thermal resistance by UNI EN ISO 6946

Regarding the external wall it is also interesting to see the effect of the wall with respect to the temperature (Figure 22). The difference in temperature between the internal and external surfaces is low, this means that the thermal energy can easily pass through the wall, in fact the value of thermal transmittance is high.



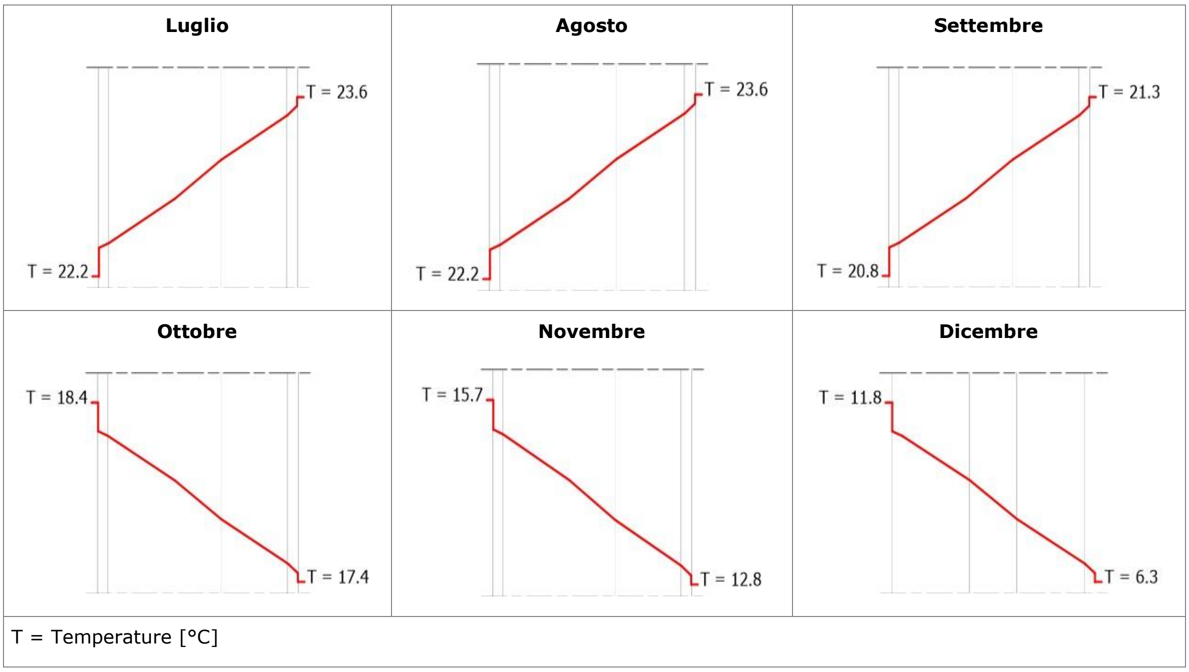


Figure 22 - Diagram of the monthly temperature

Figure 23 shows the stratigraphy of the floors in the whole building. The structure is composed by a main layer of brick and concrete, finished with tiles, forming a 290 mm thick floor. The table below shows its characteristic.

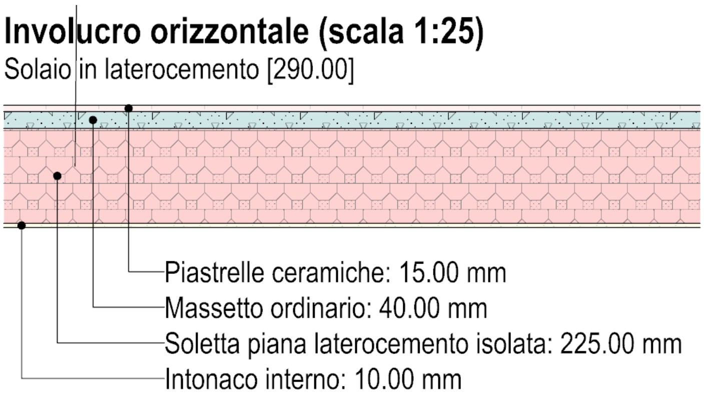


Figure 23 - Stratigraphy of the floors

Strato	Descrizione	Spessore [mm]	Conduttività [W/mK]	Conduttanza [W/m²K]	Massa superficiale [kg/m²]	Resistenza al vapore [-]	Calore specifico [J/kgK]	Resistenza [m²K/W]
	Adduttanza interna	0		5.9000				0.1695
1	Piastrelle ceramiche	15	1.3000	86.6667	34.50	205.3191	840	0.0115
2	Massetto ordinario	40	1.0600	26.5000	80.00	74.2308	1´000	0.0377
3	Soletta piana	225		1.6667	400.00	10.1579	1´000	0.6000

Strato	Descrizione	Spessore [mm]	Conduttività [W/mK]	Conduttanza [W/m²K]	Massa superficiale [kg/m²]	Resistenza al vapore [-]	Calore specifico [J/kgK]	Resistenza [m²K/W]
	laterocemento isolata							
4	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
	Adduttanza esterna	0		5.9000				0.1695

Table 17 – Characteristics of the floors. Thickness 290 mm

With a thickness of 290 mm, the total thermal resistance is equal to 1.0025 m^2K/W, which correspond to a thermal transmittance U of 0.9975 W/ m^2K. The surface resistances of the floor dividing two heated environments are 0.1695 m^2K/W because in this case the air touches the floor in the vertical, as opposed to the previous case where the air touched the outer and inner surfaces of the walls horizontally.

The last stratigraphy represented is the roof (Figure 24). It is made of asbestos tiles with a thickness of 90 mm. In table 18 are show its characteristics.

Figure 24 - Stratigraphy of the roof

Strato	Descrizione	Spessore [mm]	Conduttività [W/mK]	Conduttanza [W/m²K]	Massa superficiale [kg/m²]	Resistenza al vapore [-]	Calore specifico [J/kgK]	Resistenza [m²K/W]
	Adduttanza esterna	0		25.0000				0.0400
1	Amianto-cemento in lastre	80	0.6000	7.50000	144.00	66.5517	837	0.1333
2	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
	Adduttanza interna	0		10.0000				0.1000

Table 18 - Characteristic of the roof

With a thickness of 90 mm, the total thermal resistance is equal to 0.2876 m^2K/W, which correspond to a thermal transmittance U of 3.4768 W/m^2K. The internal resistance in this case is equal to 0.1000 m^2K/W because the roof divides an unheated environment, the attic, with the external environment, and therefore the external surface resistance is equal to 0.0400 m^2K/W.

3.5. Windows

The transparent components of the building are listed in the following table, both dimension and materials are shown. The Table 19 divides the types of windows (W for windows, DW for door windows), the number of windows sashes, the length, the height, the material of the frame, and the type of glass.

Type	W	W	DW	DW	DW	DW	W	DW		
Window sashes	1	3	1	2	2	3	1	1		
Length [m]	0.65	1.75	0.75	1.5	1.2	1.75	0.69	0.56		
Height [m]	1.5	1.5	2.4	2.4	2.4	2.4	1.46	2.34		
Flat ↓									Frame material	Glass
1			1		1	1			Wood + PVC	Single + 4-16-4
2	1	1				3			PVC	4-16-4
3	1				1	1			Wood	Single
4	1				1	1			PVC	4-16-4
5	1	1		1	3	1			Wood	Single
6			1		1	1			Wood	Single
7	1	1				3			Wood	Single
8	1				1	1			Wood	Single
9	1				1	2			Wood	Single
10	1	1			2				Wood	Single
11	1		1		1	1			PVC	4-16-4
12			1			1			PVC	4-16-4
13	1	1			1	3			Wood	Single
14	1				1	1			Wood	Single
15	1				1	2			Wood	Single
16	1	1			2				PVC	4-16-4
17	1		1		1	1			PVC	4-16-4
18			1			1			Wood	Single
19	1	1			1	3			Aluminium	4-12-4
20	1				1	1			Wood	Single
21	1				1	2	1	1	PVC	4-16-4
22	1	1		1	3	1			Wood + PVC	Single + 4-20-4

Table 19 - Transparent components of the building

It is possible to notice that some owners have already changed some windows, passing from the old wooden ones with single glazing, mounted during the construction of the building, to those in PVC or aluminium with double glazing. The n. 1 and n. 22, have some windows with single class made in wood and others in PVC with double glass. In the unit number 21 two windows have been added over the last few years.

In addition to the windows of the apartment, there are the ones in the stairwell. The dimension of these windows is 1.06 m length, and 2.65 high and made of wood and single glass.

The following tables show an example of the different types of windows installed with their properties (see attachment 1 for the properties of all windows). In this way it is possible to see the differences between old and new glass in terms of transmittance.

Door window with three doors, Wood, Single glass		
	GLASS Type = Single Area - A_g = 2.55 m² Perimeter - L_g = 17.34 m Transmittance - U_g = 5.40 W/m²K Normal solar factor - f_g = 0.85	FRAME Type = Wood Area - A_f = 1.65 m² Transmittance - U_f = 1.60 W/m²K
	Total area - A_w = 4.20 m²	
Internal surface resistance	0.13	m²K/W
External surface resistance	0.04	m²K/W
Frame area reduction coefficient	0.39	
Total transmittance - U_w	**3.9036**	**W/m²K**
Total resistance - R_w	**0.26**	**m²K/W**

Table 20 - Properties door windows with three doors, made of wood, with single glass

Door window with three doors, PVC 4-16-4, Double glass		
	GLASS Type = Double (low emissivity) Area - A_g = 2.55 m² Perimeter - L_g = 17.34 m Transmittance - U_g = 1.40 W/m²K	FRAME Type = Plastic Area - A_f = 1.65 m² Transmittance - U_f = 2.00 W/m²K Type spacers = Metal

	Normal solar factor - f_g = 0.67	Transmittance spacers = 0.06 W/m²K
	Total area - A_w = 4.20 m²	
Internal surface resistance	0.13	m²K/W
External surface resistance	0.04	m²K/W
Frame area reduction coefficient	0.39	
Total transmittance - U_w	**1.8845**	**W/m²K**
Total resistance - R_w	**0.53**	**m²K/W**

Table 21 - Properties door windows with three doors, made of PVC, with doble glass low emissivity

Door window with three doors, Aluminium 4-12-4, Double glass		
	GLASS Type = Double Area - A_g = 2.55 m² Perimeter - L_g = 17.34 m Transmittance - U_g = 2.80 W/m²K Normal solar factor - f_g = 0.75	FRAME Type = Aluminium Area - A_f = 1.65 m² Transmittance - U_f = 2.80 W/m²K Type spacers = Metal Transmittance spacers = 0.06 W/m²K
	Total area - A_w = 4.20 m²	
Internal surface resistance	0.13	m²K/W
External surface resistance	0.04	m²K/W
Frame area reduction coefficient	0.39	
Total transmittance - U_w	**3.0477**	**W/m²K**
Total resistance - R_w	**0.33**	**m²K/W**

Table 22 - Properties door windows with three doors, made of aluminium, with double glass

It can be seen that the double glazed PVC windows have a higher thermal resistance than the other two, and then a lower thermal transmittance.

3.6. Model and results

When all the previous characteristics of the building are implemented on *TerMus*, it is possible construct the model of the building. Figure 25 shows the 3D representation of the street where the building is located. The surrounding buildings are represented as blocks, and the trees represent the hill behind the condominium. The other figures show all the facades.

Figure 25 - 3D model of the street

Figure 26 - South-West facade

Figure 27 - North-East façade

a) b)

Figure 28 - a) South-East facade. b) North-West facade

Once that all is implemented on the software it is possible to run the simulation. The energy performances results are show in Table 23.

It is possible to notice that all the apartments are energy inefficient. This is because the heating generator uses diesel fuel, and most of the windows are in wood with a single glass. The two apartments with the best class are the two with the summer air conditioning, anyway the do not have a good energy class. In conclusion, the energy class of the whole building (conventional EPC) is F (Figure 29). It is therefore suggested to intervene both on the heat generator and on the thermal insulation of the entire building in order to increase the energy efficient and thus to decrease the thermal losses.

Apartment	EPC	Consumes [kWh/m2*year]	Winter	Summer
1	G	161.13	☹	☹
2	F	129.56	☹	😐
3	G	144.93	☹	☹
4	D	132.49	☹	😐
5	G	152.4	☹	☹
6	F	114.71	☹	☹
7	G	110.85	☹	😐
8	G	107.49	☹	☹
9	F	96.48	☹	😐
10	G	134.9	☹	☹
11	F	135.36	☹	☹
12	F	165.98	☹	☹
13	G	107.04	☹	😐
14	F	99.47	☹	☹
15	F	96.66	☹	😐
16	F	122.04	☹	😐
17	F	135.23	☹	☹
18	G	251.95	☹	☹
19	F	186.05	☹	😐
20	G	167.88	☹	☹
21	G	137.99	☹	😐
22	G	181.79	☹	☹

Table 23 – EPCs of the apartments

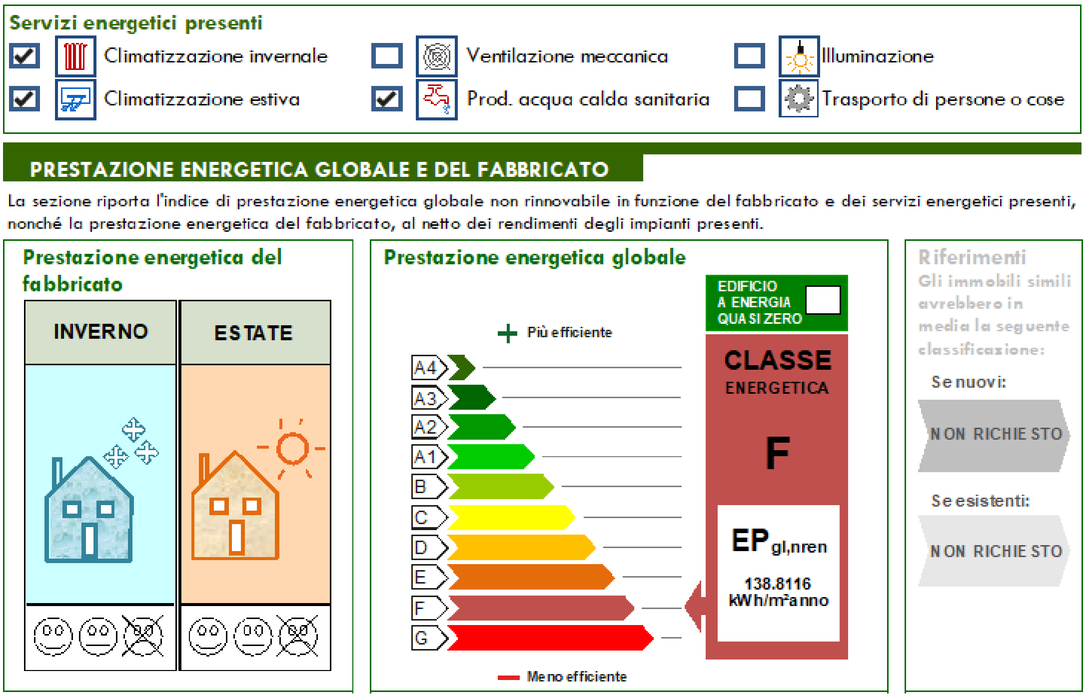


Figure 29 – Conventional EPC of the building

4. IMPROVEMENT INTERVENTIONS

As explained in chapter 2.6, to have access to the incentive, the interventions must ensure improvement of at least two energy classes. In addition to the interventions on the common parts, even those on the individual apartments can contribute to achieving this goal.

The interventions on common parts that have been considered are:

- thermal insulation of the wall;
- thermal insulation of the roof;
- substitution of the heat generator;
- installation of a photovoltaic system (panels and batteries) at the condominium's service;
- installation of charging station at the service of the condominium.

Instead, those on the single apartments can be:

- substitution of the windows, shutters and/or curtains;
- substitution of the heat generator for the DHW;
- substitution of the entrance doors;
- substitution of the heating terminals;
- installation of a private charging station.

4.1. Thermal insulation of the walls and of the roof

The thermal insulation must affect the building envelope with an incidence greater than 25% in order to access to the deduction. It was agreed with the owners that the insulation should be done on the entire envelope except on the ground floor because it is an unheated environment.

With this configuration, the gross surface area subject to intervention is 856.30 m^2, out of a total of 2220.02 m^2. The intervention therefore affects for 38.57%.

Regarding the insulation of the walls, as a first attempt it was decided to use Expanded Polystyrene (EPS) in all the facades. This material is a product of natural origin that is treated with artificial production processes. It is made up of 98% air, the remainder part is composed of carbon and hydrogen. The graphite is added in order to increase the thermal properties. At the end of the formation process is obtained a rigid and low weight product with a thermal conductivity of 0.31 W/mK. The EPS chosen is the "*RÖFIX EPS-F 031 RELAX*" from RÖFIX [17]. To respect the minimum law value for the transmittance of the walls needed to have access to the deductions (0.26 W/m^{2}K, Figure 30), a thickness of 100 mm is required (Figure 33a). This solution, however, led to a reduction in the space available on the terraces which did not work for the owners. It was therefore decided to use EPS only in the walls without terraces, and to use the aerogel where there are (Figures 14-15-16-17-18 show where the two materials are placed by means of different hatch).

Tipologia di intervento	Requisiti tecnici di soglia per la tipologia di intervento	
i. Strutture opache orizzontali: isolamento coperture (calcolo secondo le norme UNI EN ISO 6946)	Zona climatica A	≤ 0,27 W/m^2*K
	Zona climatica B	≤ 0,27 W/m^2*K
	Zona climatica C	≤ 0,27 W/m^2*K
	Zona climatica D	≤ 0,22 W/m^2*K
	Zona climatica E	≤ 0,20 W/m^2*K
	Zona climatica F	≤ 0,19 W/m^2*K
ii. Strutture opache orizzontali: isolamento pavimenti (calcolo secondo le norme UNI EN ISO 6946)	Zona climatica A	≤ 0,40 W/m^2*K
	Zona climatica B	≤ 0,40 W/m^2*K
	Zona climatica C	≤ 0,30 W/m^2*K
	Zona climatica D	≤ 0,28 W/m^2*K
	Zona climatica E	≤ 0,25 W/m^2*K
	Zona climatica F	≤ 0,23 W/m^2*K
iii. Strutture opache verticali: isolamento pareti perimetrali (calcolo secondo le norme UNI EN ISO 6946)	Zona climatica A	≤ 0,38 W/m^2*K
	Zona climatica B	≤ 0,38 W/m^2*K
	Zona climatica C	≤ 0,30 W/m^2*K
	Zona climatica D	≤ 0,26 W/m^2*K
	Zona climatica E	≤ 0,23 W/m^2*K
	Zona climatica F	≤ 0,22 W/m^2*K
iv. Sostituzione di finestre comprensive di infissi (calcolo secondo le norme UNI ENISO 10077-1)	Zona climatica A	≤ 2,60 W/m^2*K
	Zona climatica B	≤ 2,60 W/m^2*K
	Zona climatica C	≤ 1,75 W/m^2*K
	Zona climatica D	≤ 1,67 W/m^2*K
	Zona climatica E	≤ 1,30 W/m^2*K
	Zona climatica F	≤ 1,00 W/m^2*K

Figure 30 - Maximum transmittance values allowed for access to deductions [8]

The aerogel is a solid porous material with low density and extremely low thermal conductivity (between 0.012 and 0.025 W/mK [23]) that it is obtained by replacing the liquid part of a gel with a gas. The thermal conductivity is lower than that of the free air (0.026 W/mK [24]) due to the Knudsen effect: the dimension of the pores (20 nm) is lower than the main free path of the molecules in air, thus the movements are restricted and so the thermal conductivity is decreased. The excellent thermal properties permit to have low value of thermal transmittance with less thickness compared to other materials. In this case the thickness required to have a value of thermal transmittance lower than the law value is only 50 mm, and thus using half of the space with respect to the EPS (Figure 33b). The aerogel chosen is the "*AEROPAN*" from AMA COMPOSITES S.R.L. [18].

The properties of the two insulating materials are shown in Figure 31 and Figure 32. Unfortunately, this two manufacturing company are not present on the *TerMus* database, anyway there are other companies that produce the same materials with comparable properties. The walls now created are those in Table 23 and Table 24.

Dati tecnici						
SAP-Art. Nr.:	**2000916002**	**2000148256**	**2000151660**	**2000151661**	**2000151662**	**2000151663**
NAV-Art. Nr.:	137471	136686	136687	136688	136689	136690
Imballaggio						
Unità per bancale	6 pz./cf (IT)	5 pz./cf (IT)	4 pz./cf (IT)	4 pz./cf (IT)	3 pz./cf (IT)	3 pz./cf (IT)
Quantità per unità	3,5 m²/cf.	2,5 m²/cf.	2 m²/cf.	2 m²/cf.	1,5 m²/cf.	1,5 m²/cf.
Spessore	80 mm	100 mm	120 mm	140 mm	160 mm	180 mm
Larghezza	1.000 mm					
	500 mm					
Permeabilità al vapore μ	ca. 45					
Conducibilità termica $\lambda_{10,dry}$	0,031 W/mK					
Calore specifico	ca. 1,5 kJ/kg K					
Resistenza al taglio (EN 1348:1997)	ca. 0,05 kN/m²					
Resistenza a trazione trasversale	> 150 kPa					
Assorbimento acqua	< 0,05 kg/m²h					
classe di sistema	Classe di sistema I in conformità a ÖNORM 6400					
Massa volumica media	ca. 15 kg/m³					
Valore R		3,2 m²K/W	3,87 m²K/W	4,52 m²K/W	5,16 m²K/W	5,81 m²K/W
Avvertenze relative all'imballo	In fogli in PE riciclabili.					
Temperatura del supporto	> 5 - < 25 °C					
Reazione al fuoco	E (EN13501-1)					

Figure 31 - Features of the RÖFIX EPS-F 031 RELAX [17].

CARATTERISTICHE TECNICHE

DATI TECNICI	VALORI	UNITÀ	METODO DI PROVA
Formato pannello	1400x720	mm	
Spessori	6/10/20/30/40/50/60	mm	
Conducibilità termica (λ) a 10 °C	0,015	W/m·K	EN12667
Permeabilità al vapore acqueo	0,07	m	EN12086
Temperature limite di impegno	-50 +450	°C	
Resistenza alla compressione (per una deformazione del 10%)	80	KPa	EN826
Calore specifico	1.000	J/kgK	ASTM E 1269
Densità nominale	230 ± 10%	kg/m³	
Classe di reazione al fuoco	BS_1D_0		UNI-EN 13501-1:2019
Assorbimento di acqua a lungo termine per immersione parziale	Wp ≤ 0,01	kg/m²	EN 1609
Colore	bianco		

RESISTENZA TERMICA

SPESSORE	6	10	20	30	40
R (m² K/W)	0,40	0,67	1,34	2,01	2,68

Figure 32 – Features of the AEROPAN [18].

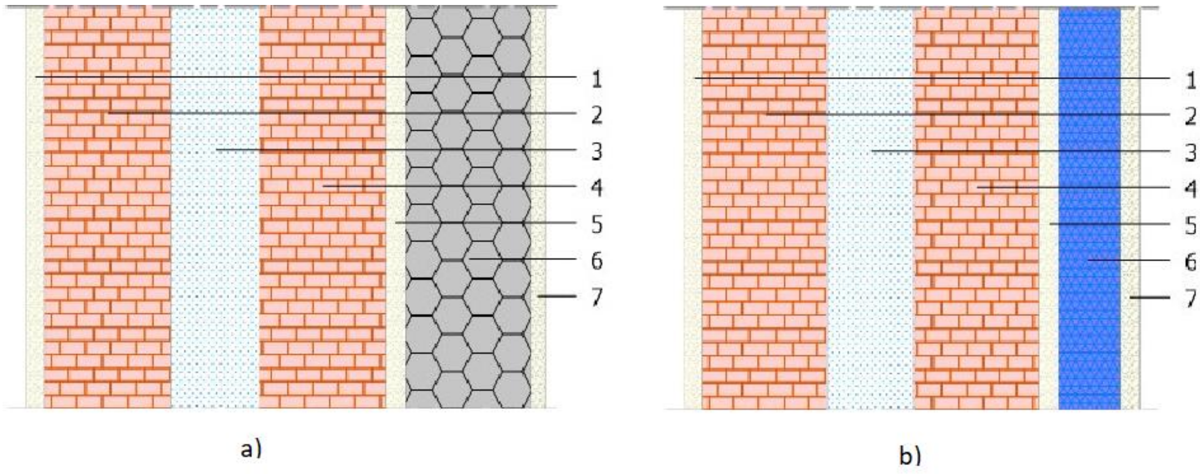


Figure 33 - Stratigraphy of a) Wall with EPS, 410 mm. b) Wall with aerogel 365 mm.

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza interna	0		7.7000				0.1299
1	Intonaco di calce e gesso	15	0.7000	46.6667	21.00	10.7222	1´000	0.0214
2	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
3	Strato d'aria verticale da 7 cm	70		5.5556	0.09	1.0000	1´008	0.1800
4	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
5	Intonaco di gesso puro	15	0.3500	23.3333	18.00	10.7222	1´000	0.0429
6	EPS - VIEROCLIMA GRIGIO 031 T100 ECO	100	0.0310	0.3100	1.50	30.0000	1´350	3.2258
7	Intonaco esterno - cp 1000	10	0.9000	90.0000	18.00	22.7059	1´000	0.0111
	Adduttanza esterna	0		25.0000				0.0400

Table 24 - Characteristic of walls with EPS

Above the addition of EPS, a layer of external plaster of 10 mm is placed. The total thickness of 410 mm, the total thermal resistance is equal to 4.0511 m^2K /W, which correspond to a thermal transmittance U of 0.2468 W/ m^2K.

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza interna	0		7.7000				0.1299
1	Intonaco di calce e gesso	15	0.7000	46.6667	21.00	10.7222	1´000	0.0214
2	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
3	Strato d'aria verticale da 7 cm	70		5.5556	0.09	1.0000	1´008	0.1800
4	Mattoni pieni, forati, leggeri - densità 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
5	Intonaco di gesso puro	15	0.3500	23.3333	18.00	10.7222	1´000	0.0429
6	Pannello Aerogel Isolante alte prestazioni	50	0.0159	0.3180	10.00	2.7571	1´000	3.1447
7	Intonaco esterno - cp 1000	15	0.9000	60.0000	27.00	22.7059	1´000	0.0167
	Adduttanza esterna	0		25.0000				0.0400

Table 25 - Characteristic of walls with Aerogel

In the case of the Aerogel, the external plaster must be thicker in order to protect the aerogel layer, so at least 15 mm are needed. The total thickness of the wall become 365 mm, the total thermal resistance is equal to 3.9755 m^2K /W, which correspond to a thermal transmittance U of 0.2515 W/ m^2K.

It is interesting to compare the diagram of the temperature through the walls when an insulant is used and when it not, by comparing Figure 22 and Figure 34. With the insulation, the temperature in the apartment is much higher (in winter) than without it, meaning that there are less dispersions. As a matter of fact, the insulant material has much lower conductivity, and the slope of the line is higher with respect to the other components of the wall, and so the temperature difference between the two faces of the insulation is larger.

In addition, since the software gives a warning on the possibility of mold in the walls, it was decided to install in each apartment two systems for mechanical controlled ventilation to avoid condensation inside the walls.

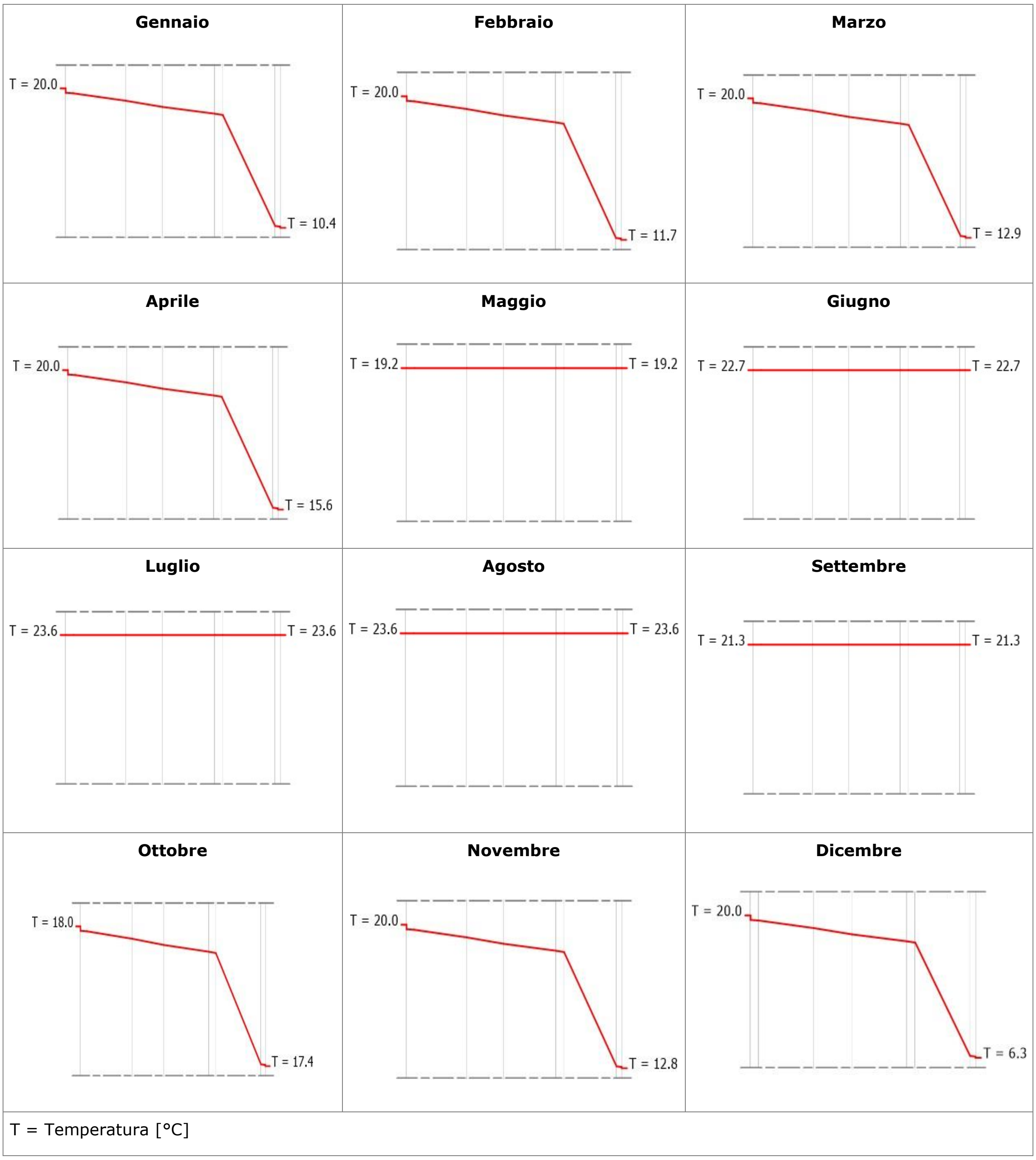


Figure 34 - Diagram of the monthly temperature

Regarding the roof, firstly it is important to remove asbestos, knowing the negative effects on human health, and then insulate it and replace the roof tiles. The insulating material chosen is the ISOTEC XL [19] which is a layer of polyurethane coated with an aluminium foil placed on a steel structure which, as well as guaranteeing fastening, allows micro-ventilation which enables humidity to be disposed during the winter season and prevents the formation of mold and condensation. The stratigraphy and the features are show in Figure 35 and Table 26 respectively.

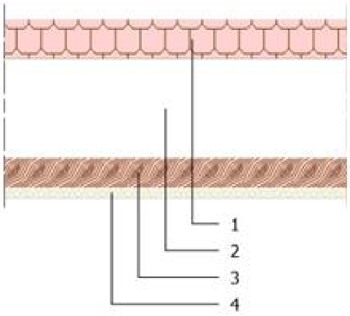


Figure 35 - Stratigraphy of the roof with ISOTEC, thickness 180 mm

Strato	Descrizione	Spessore [mm]	Conduttività [W/mK]	Conduttanza [W/m²K]	Massa superficiale [kg/m²]	Resistenza al vapore [-]	Calore specifico [J/kgK]	Resistenza [m²K/W]
	Adduttanza esterna	0		25.0000				0.0400
1	Tegole in terracotta	40	1.0000	25.0000	80.00	40.0000	800	0.0400
2	Isotec XL	100	0.0220	0.2200	3.80	50.0000	1´400	4.5455
3	Pannello di legno compensato di pino	30	0.1440	4.8000	18.00	42.8889	1´600	0.2083
4	Intonaco interno	10	0.7000	70.0000	14.00	10.7222	1´000	0.0143
	Adduttanza interna	0		10.0000				0.1000

Table 26 – Characteristic of roof with ISOTEC [19]

In addition, the horizontal roof is also replaced. This cannot be isolated because it covers an unheated environment (stairs), then a slab finished with bitumen is placed (Figure 36 and Table 27).

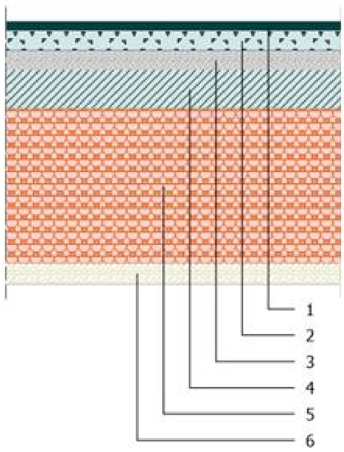


Figure 36 - Stratigraphy of the horizontal roof

Strato	Descrizione	Spessore	Conduttività	Conduttanza	Massa superficiale	Resistenza al vapore	Calore specifico	Resistenza
		[mm]	[W/mK]	[W/m²K]	[kg/m²]	[-]	[J/kgK]	[m²K/W]
	Adduttanza esterna	0		25.0000				0.0400
1	Bitume	10	0.1700	17.0000	12.00	barriera	920	0.0588
2	Massetto ordinario	20	1.0600	53.0000	40.00	74.2308	1´000	0.0189
3	Malta di cemento	20	1.4000	70.0000	40.00	22.7059	1´000	0.0143
4	Calcestruzzo armato	40	0.8500	21.2500	96.00	148.4615	1´000	0.0471
5	Blocco solaio laterizio - resistenza 0.27	160		3.7037	144.00	10.1579	1´000	0.2700
6	Intonaco interno	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
	Adduttanza interna	0		10.0000				0.1000

Table 27 - Characteristic of the horizontal roof

4.2. Thermal plant

The heat generator currently in use, utilizes diesel oil as fuel. It has a lower efficiency, and it emits more pollutants than a natural gas heat generator. Furthermore, it also requires an external tank to store the fuel and therefore more maintenance.

After all these considerations, it was decided to replace the old heat generator with a hybrid system consisting of a condensing boiler that uses natural gas and a heat pump. This system allows to choose, by means a control unit, which heat generator use according to the most convenient at that time. This idea comes from the fact that in this building there are apartments that are used as a holiday home, so there are days when the heat demand is not very high. With a hybrid system, it is possible to exploit the heat pump without the intervention of the condensing boiler.

The dimension of the condensing boiler it calculated from the sum of the thermal needs in Table 12, and then this value is oversized in order to ensure a safety margin. The power of the heat pump, that in a hybrid system cannot be larger than a half of the condensing boiler [12], was chosen considering only the owners who live in the building all year round. The powers decided are:

- 115 kW for the condensing boiler;
- 17.9 kW for the heat pump.

The reductoin in power from the 205 kW of the old heat generator to the 115 kW of the condensing boiler, also avoids having to fill the "Certificato Prevenzione Incendi" to be submitted to the fire every five years. Obviously, all the safety systems and the REI walls must be installed anyway.

The condensing boiler installed is the "MULTIINOX 116" from UNICAL [21], which features are shown in Figure 37 and Figure 38. It has a nominal power of 115 kW with an efficiency of 98% without condensation and equal to 103.9% when using the heat of the exhaust, and its energetic class (Energy related Product, ErP) is "A".

DATI DI FUNZIONAMENTO

SCHEMI ELETTRICI - IDRAULICI - IMPIANTISTICI - TERMOREGOLAZIONI scaricabili sul sito www.unical.eu alla pagina del prodotto

MULTIINOX		69	116
Categoria della caldaia		II_{2H3P}	II_{2H3P}
Rapporto di modulazione		1:2,3	1:3,8
Portata termica nominale su P.C.I. Qn	kW	69	115
Portata termica minima su P.C.I. Qmin	kW	30	30
Potenza utile nominale (Tr 60 / Tm 80 °C) Pn	kW	67,65	112,7
Potenza utile minima (Tr 60 / Tm 80 °C) Pn min	kW	29,3	30,7
Potenza utile nominale (Tr 30 / Tm 50 °C) Pcond	kW	75,3	119,5
Potenza utile minima (Tr 30 / Tm 50 °C) Pcond min	kW	32,89	32,2
Rendimento a potenza nominale (Tr 60 / Tm 80 °C)	%	98	98
Rendimento a potenza minima (Tr 60 / Tm 80 °C)	%	97,75	102,4
Rendimento a potenza nominale (Tr 30 / Tm 50 °C)	%	109,1	103,9
Rendimento al potenza minima (Tr 30 / Tm 50 °C)	%	109,6	107,6
Rendimento al 30% del carico (Tr 30°C)	%	106,9	109
Rendimento di combustione a carico nominale (*)	%	98,23	98,1
Rendimento di combustione a carico ridotto (*)	%	98,27	98,5
Perdite al mantello bruciatore funzionante (Qn)	%	0,19	0,1
Temperatura fumi netta tf-ta (min)(**)	°C	34,3	30
Temperatura fumi netta tf-ta (max)(**)	°C	34,7	38
Temperatura massima ammissibile	°C	100	100
Temperatura massima di funzionamento	°C	85	80
Portata massica fumi (min)	kg/h	50	49
Portata massica fumi (max)	kg/h	115	190
Eccesso aria	%	28,17	26,8
Perdite al camino con bruciatore funzionante (min)	%	1,7	1,50
Perdite al camino con bruciatore funzionante (max)	%	1,7	1,90
Pressione minima del circuito riscaldamento	bar	0,5	0,5
Pressione massima del circuito riscaldamento	bar	6	6
Contenuto d'acqua	l	80	80
Consumo gas metano G20 (p.alim. 20 mbar) a Qn	m^3/h	7,2	12,16
Consumo gas metano G20 (p.alim. 20 mbar) a Qmin	m^3/h	3,17	3,17
Consumo gas G25 (p.alim. 20/25 mbar) a Qn	m^3/h	8,5	14,14
Consumo gas G25 (p.alim. 20/25 mbar) a Qmin	m^3/h	3,69	3,69
Consumo gas propano (p.alim. 37/50 mbar) a Qn	kg/h	5,32	8,93
Consumo gas propano (p.alim. 37/50 mbar) a Qmin	kg/h	2,33	2,33
Massima pressione disponibile base camino	Pa	70	70
Produzione di condensa max	kg/h	8,3	18,5
Emissioni			
CO alla portata termica massima con 0% di O_2	mg/kWh	26	28
NO_x alla portata termica massima con 0% di O_2	mg/kWh	-	62
Classe di NO_x		6	6
Dati elettrici			
Tensione di alimentazione/Frequenza	V/Hz	230/50	230/50
Fusibile sull'alimentazione	A (R)	6,3	6,3
Grado di protezione	IP	X4D	X4D

Temperatura Ambiente = 20°C

(*) Temperature rilevate con apparecchio funzionante mand. 80°C / rit. 60°C

Efficienza Energetica Stagionale secondo 2009/125 CEE (<=400 kW) η_s - vedi Tabella ErP

Perdite all'arresto a ΔT 30°C - P_{stby} - vedi Tabella ErP

Consumo elettrico in stand-by - P_{sb} - vedi Tabella ErP

Figure 37 – Characteristics of condensing boiler MULTIINOX 116 [21].

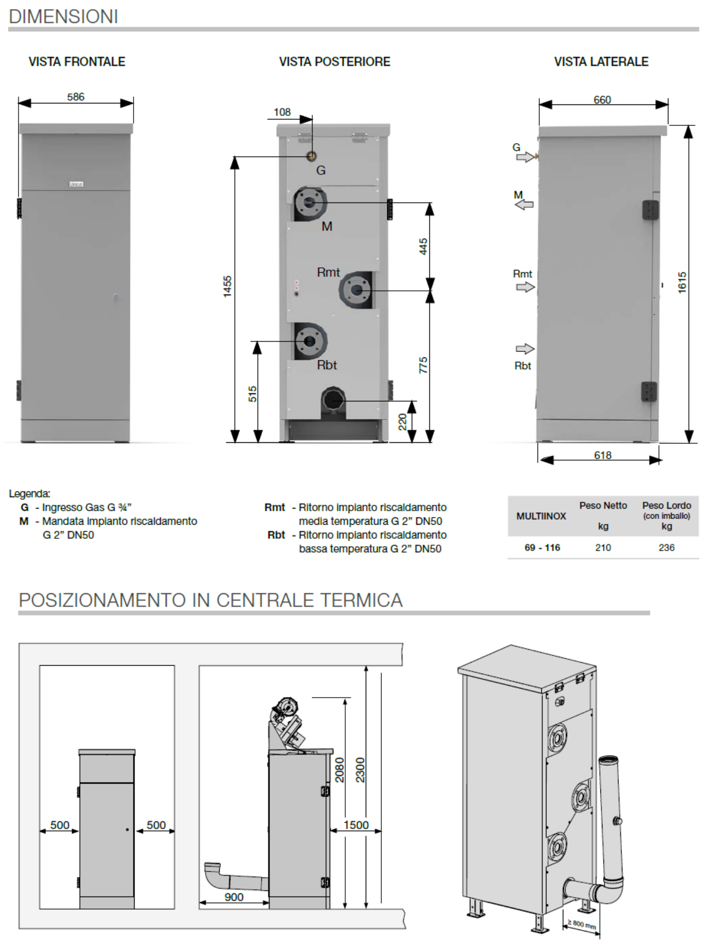


Figure 38 - Dimensions and minimum space for maintenance of MULTIINOX 116 [21].

The heat pump is a "HP_OWER ONE 180R" from UNICAL [25] and it will be used only for heating (Figure 39). It has a COP of 4.40 at 35°C or 3.52 at 45°C for a nominal power of 17.90 kW (Figure 40)

Figure 39 - Heat pump HP_OWER ONE 180R [25].

HP_OWER ONE			70R	90R	120R	140R	160RT	180R
EFFICIENZA ENERGETICA stagionale per riscaldamento (T_{out} = 35/55°C)			A+++ / A++	A+++ / A++	A+++ / A++	A+++ / A++	A+++ / A++	A+++ / A++
Raffreddamento	Potenza frigorifera (1) min-nom-max	kW	4,82 - 6,18 - 6,80*	4,91 - 7,72 - 8,49*	6,41 - 11,60 - 12,76*	9,17 - 14,00 - 14,70*	9,20 - 15,80 - 16,59*	9,09 - 17,10 - 17,96*
	Potenza assorbita (1)	kW	1,28	1,76	2,79	2,59	3,15	3,59
	E.E.R. (1)	W/W	4,82	4,38	4,16	5,40	5,02	4,76
	Potenza frigorifera (2) min-nom-max	kW	3,20 - 5,02 - 5,52*	3,80 - 6,08 - 6,69*	4,55 - 8,51 - 9,36*	6,87 - 11,48 - 12,05*	5,99 - 13,80 - 14,49*	6,86 - 15,04 - 15,79*
	Potenza assorbita (2)	kW	1,60	1,99	2,79	3,53	4,38	4,88
	E.E.R. (2) / S.E.E.R. (5)	W/W	3,14 / 4,12	3,05 / 4,25	3,05 / 4,25	3,25 / 4,62	3,15 / 4,80	3,08 / 4,91
Riscaldamento	Potenza termica (3) min-nom-max	kW	3,95 - 6,08 - 6,99*	3,95 - 7,81 - 8,98*	5,33 - 11,80 - 13,57*	7,54 - 14,10 - 15,23*	7,36 - 16,30 - 17,60*	7,30 - 17,90 - 19,33*
	Potenza assorbita (3)	kW	1,35	1,78	2,73	2,91	3,49	4,07
	C.O.P. (3)	W/W	4,51	4,38	4,32	4,85	4,67	4,40
	Potenza termica (4) min-nom-max	kW	3,82 - 5,88 - 6,76*	3,80 - 7,58 - 8,72*	5,13 - 11,47 - 13,19*	7,23 - 13,56 - 14,64*	7,06 - 15,77 - 17,03*	7,02 - 17,32 - 18,71*
	Potenza assorbita (4)	kW	1,66	2,17	3,33	3,55	4,24	4,92
	C.O.P. (4) / S.C.O.P. (6)	W/W	3,54 / 4,46	3,50 / 4,46	3,44 / 4,47	3,82 / 4,48	3,72 / 4,50	3,52 / 4,46
Dati elettrici	Alimentazione		230V/1/50Hz	230V/1/50Hz	230V/1/50Hz	230V/1/50Hz	400V/3P+N+T/50Hz	400V/3P+N+T/50Hz
	Potenza massima assorbita (vers. K)	kW	3,5 (3,6)	3,9 (4,0)	5,1 (5,2)	6,6 (6,7)	7,0 (7,1)	8,3 (8,5)
	Corrente massima assorbita (vers. K)	A	15,1 (15,6)	17,0 (17,6)	22,1 (22,7)	28,6 (29,2)	10,1 (10,3)	12,0 (12,2)
Quantità refrigerante R32 (7)		kg	1,5	1,5	2,5	3,2	3,5	3,5
Circuito idraulico	Portata acqua (2)	l/s	0,24	0,28	0,41	0,55	0,66	0,71
	Prevalenza utile nominale (2)	kPa	78,8	76,0	63,4	75,0	62,3	55,6
	Minimo volume acqua	l	40	40	60	60	70	70
Rumorosità	Potenza sonora L_w (8)	dB(A)	64	64	65	68	68	68
	Press. sonora a 1 m di distanza L_{p1} (9)	dB(A)	49,8	49,8	50,4	52,7	52,7	52,7
	Press. sonora a 10 m di distanza L_{p10} (9)	dB(A)	32,8	32,8	33,7	36,6	36,6	36,6
Peso in esercizio		kg	72	72	96	121	141	141

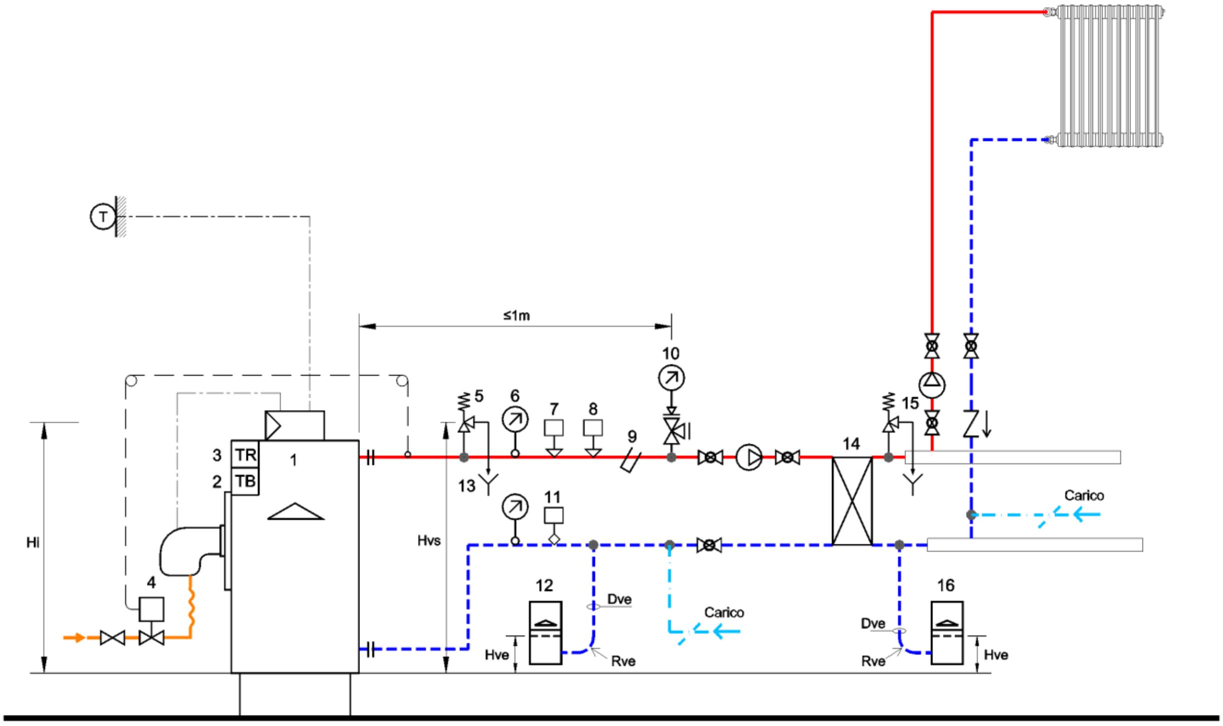
Prestazioni riferite alle seguenti condizioni:
(1) Raffreddamento: temperatura aria esterna 35°C; temperatura acqua ing./usc. 23/18°C.
(2) Raffreddamento: temperatura aria esterna 35°C; temperatura acqua ing./usc. 12/7°C.
(3) Riscaldamento: temperatura aria esterna 7°C b.s. 6°C b.u.; temp.acqua ing./usc. 30/35°C.
(4) Riscaldamento: temperatura aria esterna 7°C b.s. 6°C b.u.; temp.acqua ing./usc. 40/45°C.
(5) Raffreddamento: temperatura acqua ing./usc. 12/7°C.
(6) Riscaldamento: condizioni climatiche medie; T_{biv}=-7°C; temp.acqua ing./usc. 30/35°C.
(7) Dati indicativi e soggetti a variazione. Per il dato corretto, riferirsi sempre all'etichetta tecnica riportata sull'unità.
(8) Potenza sonora: unità a pieno carico in modalità riscaldamento secondo quanto previsto dal Regolamento UE 813/2013 per applicazioni a media e bassa temperatura. Valore determinato sulla base di misure effettuate in accordo con la normativa EN 12102-1:2017, usata in congiunzione con UNI EN ISO 9614-2 che descrive la prova con metodo intensimetrico. La tolleranza sul valore del livello di potenza sonora totale è di 2 dB(A).
(9) Pressione sonora: valore calcolato dal livello di potenza sonora utilizzando la ISO 3744:2010, considerando le unità in campo aperto.
(*) Attivando la funzione "Hz Massimi"

N.B. Le rese dichiarate ai punti (1), (2), (3) e (4) sono da intendersi riferite alla potenza istantanea secondo UNI EN 14511. Il dato dichiarato ai punti (5) e (6) è determinato secondo la UNI EN 14825.

Figure 40 - Features of heat pump HP_OWER ONE 180R [25].

Since the whole heating pipe system will not be replaced, the deposits and impurities inside it could ruin the new boiler when water passes through it. To remedy this, it was decided to insert a heat exchanger in the boiler room in order to divide the system into two circuits: one for the boiler and the heat pump (called primary circuit), and the other one to get to the floors (secondary circuit).

As said before, the safety systems must be designed. To do so, the "Edilclima" software was used, giving as result the scheme in Figure 41. Furthermore, the regulation "Raccolta R" [26] defines the mandatory devices that must be inserted in a heating system that uses hot water under pressure with a temperature not exceeding 110°C and with a power greater than 35 kW. The safety systems are positioned on the delivery circuit of boiler and heat pump, at a maximum distance of one meter from the boiler. The connection between the heat pump and the condensing boiler is done before the safety systems. Furthermore, other devices are needed for the correct functioning of the system, such as: expansion vessel (since the system is a "closed vessel"), recirculation pumps, thermometer, manometer, and valves.



N	COMPONENTI CALDAIA 1		qta
1	Caldaia		1
	Qf = 115,00 kW	Qu = 105,00 kW	
	Peg = 4,00 bar	DNa =	
	DNf = 0,0 mm	Hi = 2,00 m	
2	Termostato blocco		1
	DNtb = 1/2"M	Ttb = 98,0 °C	
3	Termostato regolazione		1
	DNtr = 1/2"M	Ttr = 60,0 °C	
4	Valvola Intercettazione combustibile		1
	DNvic = 1"FF	Gvic,e = 11,6Nm³/h	
	Dp,vic,e = 0,73 mbar		
5	Valvola di sicurezza		1
	Pt = 2,30 bar	DNvs = 1/2"	
	DNsvs = 3/4"	Hvs = 1,20 m	
6	Termometro		1
	DNt = 1/2"	Fst = 120,0 °C	

N	COMPONENTI CALDAIA 1		qta
7	Pressostato blocco massimo		1
	DNpma = 1/4"F	Ptpr,max = 2,10 bar	
8	Pressostato blocco minimo		1
	DNpmi = 1/4"F	Ptpr,min = 0,70 bar	
9	Pozzetto di controllo		1
	DNt = 0 - 120	Lp = 0,0 mm	
10	Manometro, rubinetto con flangia e riccio		1
	DNt = 1/4"	Fsm = 4,00 bar	
11	Flussostato		1
	DNfl = 1/2"	Pmax,fl = 6,00 bar	
13	Scarico visibile		1
	DN = 1/2"		

N	VASI ESPANSIONE					qta
12	Vaso espansione chiuso caldaia					1
	Vn [l]	DN	Hve [m]	Pve [bar]	Pir [bar]	
	30,0	3/4'	0,50	6,00	0,65	
	Tubo coll. Dve = 18,0mm Rve = 27,0mm					
16	Vaso espansione chiuso scambiatore					2
	Vn [l]	DN	Hve [m]	Pve [bar]	Pir [bar]	
	400,0	1'	0,50	6,00	2,12	
	400,0	1'	0,50	6,00	2,12	
	Tubo coll. Dve = 18,0mm Rve = 27,0mm					

N	COMPONENTI IMPIANTO		qta
14	Scambiatore		1
	Qn = 110,00 kW	Pes = 10,00 bar	
	DNsp = 1"	DNss =	
	Hi = 17,00 m		
15	Valvola di sicurezza		1
	Pt = 2,30 bar	DNvs = 1/2"	
	DNsvs = 3/4"	Hvs = 1,20 m	

	Tubazione Mandata Riscaldamento
	Tubazione Ritorno Riscaldamento
	Tubazione Acqua Fredda
	Tubazione Alimentazione Gas

Figure 41 - Diagram of the thermal power plant

The machines that will be installed in the condominium are not present in the software database, so comparable ones are used to size all the devices.

In the primary circuit are installed:

- the safety valve (5), which when a pressure higher than the set one is reached, opens and discharges the water in order to not exceed the pressure limits of the boiler or the other components. If the pressure in the circuit increases too much, it must be able to drain the water and thus reduce the system pressure. The calibration pressure (2.3 bars) must be lower than the maximum one of the boiler (4 bars);
- thermostats, one for set the delivery temperature (3) to 60°C and the other one (2) to prevent the fluid temperature from exceeding 98°C. Often they are already configured in the control unit on the boiler;

- maximum (7) and minimum (8) pressure switch, which stop the gas flow when the pressure is respectively higher or lower than set values;
- flow switch (11), that stops the gas flow if the water in the pipes is still;
- fuel shut-off valve (4), that stops the gas flow if some of the previous safety systems is activated.
- thermometer (6) with full-scale of 120°C and manometer (10) with full scale of 4 bar;
- inspection well (9), to check flow parameters with a probe;
- expansion vessel (12), which must allow the water to expand due to the increase in temperature. It is equal to 30 litres, deriving from the sum of the expansion vessel of 18 litres for the boiler only and that of 12 litres for the heat pump only. They were calculated with the formula $Vn \geq \frac{Ve}{\left(1-\frac{p1}{p2}\right)}$ on [26], considering:
    - Vn as volume of the vessel in litres,
    - Ve as expansion volume in litres, equal to $Va * n/100$ (Va is the total volume of water in the system, $n = 0.31 + 3.9 * 10^{-4} * Tm^2$, Tm is the maximum temperature admitted in the system),
    - p1 as pre-charge pressure of the vessel,
    - p2 as absolute calibration pressure of the safety valves plus an amount corresponding the difference in height between safety valve and vessel (0.07 bars because the difference in height is 0.7 m).

  The pipe that links the system with the expansion vessels must be equal or larger than 18 mm (the one chosen in this project) and the curves must be have a radius equal or larger than the diameter of the pipe (18 mm) times 1.5 (in this case is equal to 27 mm)
- recirculation pump;
- non-return valves and three-way valves for coupling the boiler and heat pump pipes.

The heat exchanger (14) dimension is 110 kW, it is countercurrent and made in titanium in order to avoid corrosion problems with the impurities in the pipes. The hydrostatic height of the system is 17 m (about the height of the building), and it is used to size the recirculation pump.

In the secondary circuit, the safety systems are no longer necessary since there are no flames. However, a safety valve (14) and the expansion vessels (15) need to be installed. The vessels in this case are two with a volume of 400 litres each and they are sized using the same formulas as before, obviously varying the necessary parameters.

In addition, there are there are the gas pipe for the boiler and the connection to the hydraulic network to fill the system.

In Figure 42 is represented the planimetry of the thermal plant with the positions of the heat generators, of the heat exchanger, of the expansion vessels and the pipes.

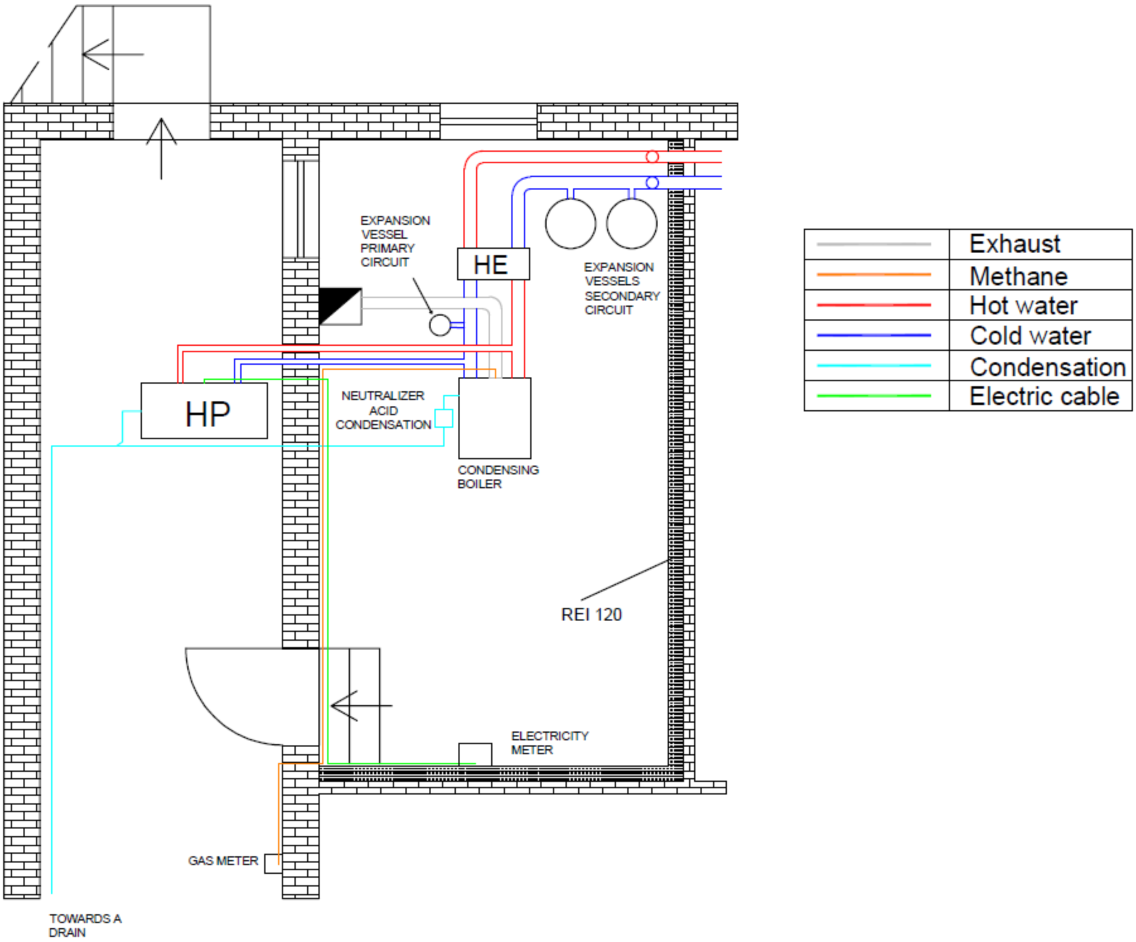


Figure 42 - Planimetry of the thermal plant

The size of the room allows the best positioning of each device, respecting the maintenance spaces of the machinery. The condensing boiler, in addition to the water delivery and return pipes, has an exhaust pipe which goes to the chimney, and a condensate pipe, which, being an acid condensate, must be neutralized in a special tray. The heat pump is external to the boiler room because it needs to exchange heat with the air. The pipes of this device join those of the boiler creating the primary circuit. The expansion tank is positioned on the cold-water pipe. In the heat exchanger, the primary circuit exchange the heat generated to the secondary circuit, which will then go to each floor. The expansion vessels are also placed on the cold-water pipe.

Condensation from the boiler and the heat pump merge and then are discharged into an external drain. Boiler and heat pump need fuel and electricity respectively. Natural gas is brought to the thermal power plant by a pipe from the external gas meter. Electricity, on the other hand, is present inside the thermal power plant and will be brought to the heat pump.

It is important to specify that REI (Resistance Entretenir Isolement) panels are needed on the walls bordering other rooms. Panel with REI 120 are used on the garage, the cellars and on the ceiling.

4.3. Photovoltaic system

With the *Superbonus 110%,* there is also the possibility to install a photovoltaic system and the storage units at the service of the condominium. As explained in chapter 2.6.1.2., since this is a condominium and it is not a building renovation, new construction, or urban renovation (it is an energy requalification), the maximum power that can be facilitated for the photovoltaic system is 20 kW. Due to this level of power, the system will be a three-phase.

To simulate the topology of the solar field on the roof, "*Solarius*" from *ACCA* was used.

From the database, the values of monthly average daily irradiations (direct plus diffuse) are obtained based on location by means "UNI 10349:2016 - Stazione di rilevazione: Capo Vado Ligure" (Figure 43 and Figure 44), with an albedo of 0.20 (conservative average value for asphalt, buildings and trees, from UNI 10349-1).

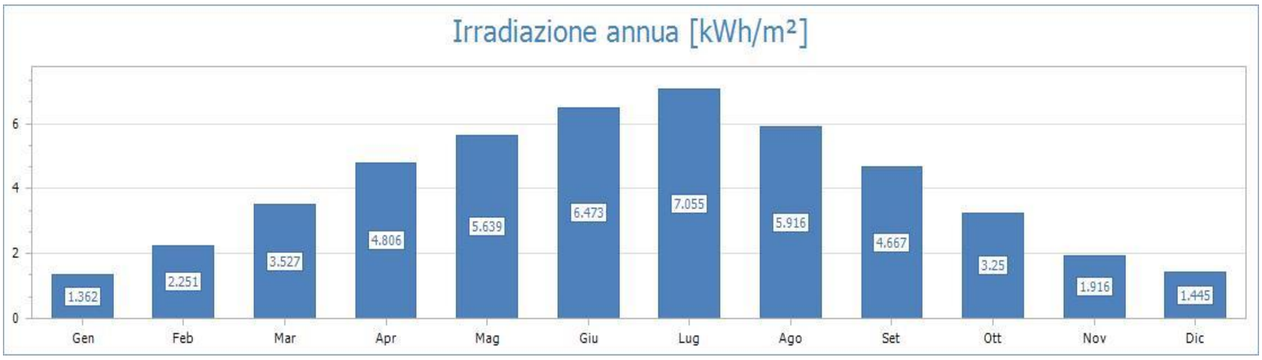


Figure 43 - Monthly average daily irradiations values

Irradiazione oraria media mensile (totale) [kWh/m²]

	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Gen									0.036	0.111	0.180	0.230	0.248	0.230	0.180	0.111	0.036							
Feb								0.011	0.099	0.198	0.286	0.348	0.370	0.348	0.286	0.198	0.099	0.011						
Mar								0.082	0.197	0.316	0.420	0.491	0.516	0.491	0.420	0.316	0.197	0.082						
Apr							0.059	0.172	0.299	0.425	0.531	0.603	0.629	0.603	0.531	0.425	0.299	0.172	0.059					
Mag						0.024	0.123	0.240	0.365	0.486	0.588	0.654	0.678	0.654	0.588	0.486	0.365	0.240	0.123	0.024				
Giu						0.057	0.165	0.290	0.423	0.550	0.654	0.723	0.747	0.723	0.654	0.550	0.423	0.290	0.165	0.057				
Lug						0.049	0.169	0.309	0.459	0.603	0.722	0.801	0.829	0.801	0.722	0.603	0.459	0.309	0.169	0.049				
Ago							0.098	0.231	0.377	0.519	0.639	0.720	0.748	0.720	0.639	0.519	0.377	0.231	0.098					
Set							0.015	0.135	0.275	0.418	0.541	0.624	0.654	0.624	0.541	0.418	0.275	0.135	0.015					
Ott								0.038	0.158	0.287	0.403	0.483	0.511	0.483	0.403	0.287	0.158	0.038						
Nov									0.061	0.160	0.251	0.316	0.339	0.316	0.251	0.160	0.061							
Dic									0.028	0.113	0.194	0.252	0.272	0.252	0.194	0.113	0.028							

Figure 44 - Monthly average daily irradiations values divided by hours

When the location is selected, the file created in *TerMus* can be imported in *Solarius*, where the position of the solar panel field is created. Since the roof is composed of four pitches, it was decided to install the photovoltaic panels on the one facing South-West as it has the largest surface area. This pitch is inclined by 21°, guaranteeing an annual irradiation of 1,580 kWh/m^2. At this latitude, the ideal inclination would be 35°, with an annual irradiation of 1.687 kWh/m^2. However, it is better to install the panels coplanar to the roof instead of providing them with a support structure.

The other information the software needs are the installed peak power, the type of photovoltaic panel, the distance between the rows and from the edges of the roof. It was decided to exploit the limit of peak power of 20 kW, by installing as many photovoltaic panels as possible. The choice of the panels is fell on "*Q.PEAK DUO ML-G9 390*" from *Q.CELLS [22]* (Figure 46), monocrystalline with a power of 390 W each and a surface of 1.895 m^2. To reach the 20 kW it is needed to install 51 panels for a total power of 19.89 kW. The distance from the edges of the roof is 0.35 m and that between the rows is 0.2 m and they are installed in vertical position.

The choice of pitch is also due to the fact that there are obstacles around the building such as taller buildings and the hill, which would create shadows on the panels if placed in other pitches. The lighter surface in Figure 45 defines the boundaries within which the panels must be installed. As a matter of fact, near the chimney there is an area where it was decided not to install any panels to prevent some cells from being shaded by the shadow of the chimney itself.

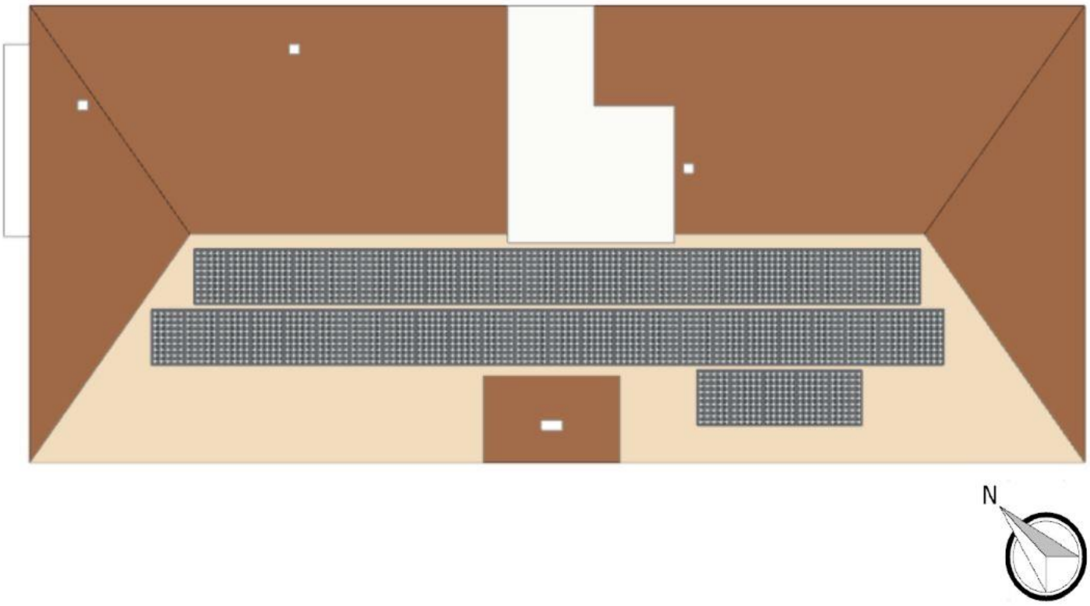
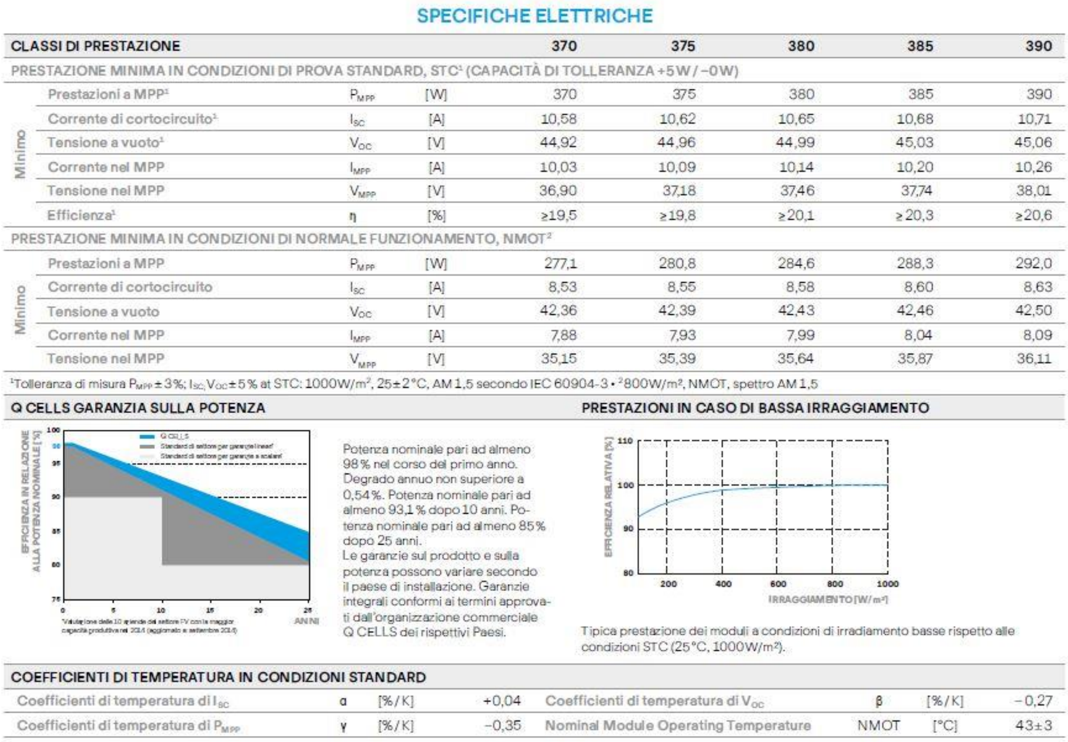


Figure 45 - Solar field on the roof



SPECIFICHE ELETTRICHE

CLASSI DI PRESTAZIONE				370	375	380	385	390
PRESTAZIONE MINIMA IN CONDIZIONI DI PROVA STANDARD, STC¹ (CAPACITÀ DI TOLLERANZA +5W / −0W)								
Minimo	Prestazioni a MPP¹	P_{MPP}	[W]	370	375	380	385	390
	Corrente di cortocircuito¹	I_{SC}	[A]	10,58	10,62	10,65	10,68	10,71
	Tensione a vuoto¹	V_{OC}	[V]	44,92	44,96	44,99	45,03	45,06
	Corrente nel MPP	I_{MPP}	[A]	10,03	10,09	10,14	10,20	10,26
	Tensione nel MPP	V_{MPP}	[V]	36,90	37,18	37,46	37,74	38,01
	Efficienza¹	η	[%]	≥19,5	≥19,8	≥20,1	≥20,3	≥20,6
PRESTAZIONE MINIMA IN CONDIZIONI DI NORMALE FUNZIONAMENTO, NMOT²								
Minimo	Prestazioni a MPP	P_{MPP}	[W]	277,1	280,8	284,6	288,3	292,0
	Corrente di cortocircuito	I_{SC}	[A]	8,53	8,55	8,58	8,60	8,63
	Tensione a vuoto	V_{OC}	[V]	42,36	42,39	42,43	42,46	42,50
	Corrente nel MPP	I_{MPP}	[A]	7,88	7,93	7,99	8,04	8,09
	Tensione nel MPP	V_{MPP}	[V]	35,15	35,39	35,64	35,87	36,11

¹Tolleranza di misura P_{MPP} ± 3%; I_{SC}, V_{OC} ± 5% at STC: 1000W/m², 25±2°C, AM 1,5 secondo IEC 60904-3 • ²800W/m², NMOT, spettro AM 1,5

Q CELLS GARANZIA SULLA POTENZA

Potenza nominale pari ad almeno 98 % nel corso del primo anno. Degrado annuo non superiore a 0,54 %. Potenza nominale pari ad almeno 93,1 % dopo 10 anni. Potenza nominale pari ad almeno 85 % dopo 25 anni. Le garanzie sul prodotto e sulla potenza possono variare secondo il paese di installazione. Garanzie integrali conformi ai termini approvati dall'organizzazione commerciale Q CELLS dei rispettivi Paesi.

PRESTAZIONI IN CASO DI BASSA IRRAGGIAMENTO

Tipica prestazione dei moduli a condizioni di irradiamento basse rispetto alle condizioni STC (25°C, 1000W/m²).

COEFFICIENTI DI TEMPERATURA IN CONDIZIONI STANDARD							
Coefficienti di temperatura di I_{SC}	α	[%/K]	+0,04	Coefficienti di temperatura di V_{OC}	β	[%/K]	−0,27
Coefficienti di temperatura di P_{MPP}	γ	[%/K]	−0,35	Nominal Module Operating Temperature	NMOT	[°C]	43±3

Figure 46 - Features of QCELLS Q.PEAK DUO ML-G9 390 [22].

The software, by providing location, time, and day data, allows to simulate the shadows that could obscure the panels. In the Figure 47 the winter solstice has been simulated (at dawn, at noon, and at sunset) since it is the day on which the shadows are the longest. It is possible to notice that the panels have been positioned in such a way as to avoid shading from surrounding objects as much as possible.

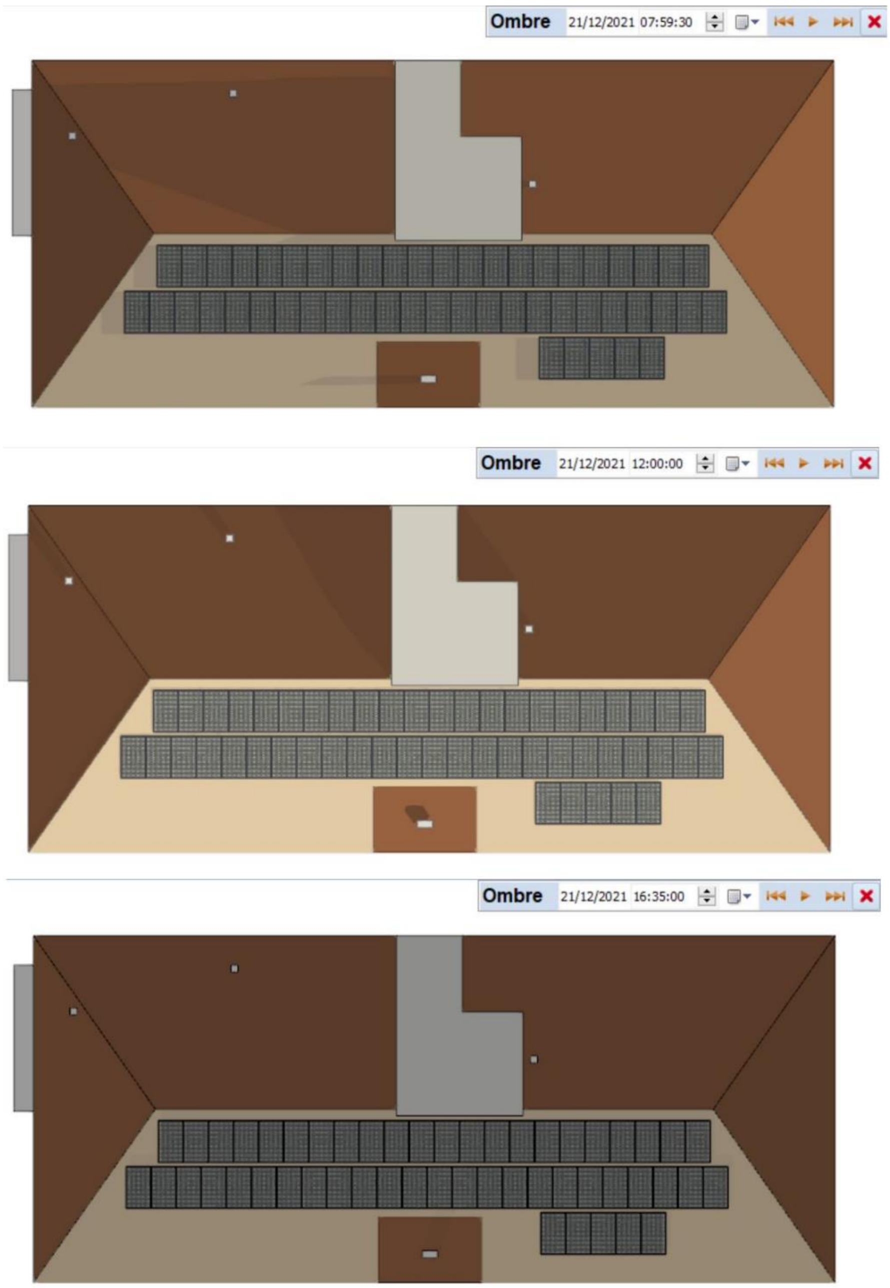


Figure 47 - Simulation of shadows in the winter solstice

The resulting energy production from this solar panel field is 23,590.50 kWh (for a field of 96.65 m^2 and 51 panels).

Furthermore, the inverter must be selected. The choice fell on the "FRONIUS SYMO 17.5-3-M" by *Fronius* [27] (Figure 48). The size is 17.5 kW because the solar panels cannot reach the peak power due to the non-ideal position and external conditions, so a power somewhat lower than the installed peak power is chosen. This system has two MPPT and the software recommends three strings of seventeen panels each, two of these will be associated with the first MPPT, while the last will be associated with the second one. In Figure 49 and Figure 50 the electric check needed are shown.

DATI DI ENTRATA

Numero di inseguitori MPP	2
Corrente di entrata max. ($I_{dc\ max}$)	33,0 / 27,0 A
Corrente di corto circuito max. campo dei moduli solari	49,5 / 40,5 A
Gamma tensioni di entrata CC ($U_{dc\ min}$ - $U_{dc\ max}$)	200 - 1000 V
Tensione di avvio alimentazione ($U_{dc\ start}$)	200 V
Tensione di entrata nominale ($U_{dc,r}$)	600 V
Gamma tensione MPP ($U_{mpp\ min}$ - $U_{mpp\ max}$)	370 - 800 V
Gamma di tensione MPP utilizzabile	200 - 800 V
Numero attacchi CC	3 + 3
Potenza max. del generatore FV ($P_{dc\ max}$)	26,3 kWpeak

Figure 48 - Features of FRONIUS 17.5-3-M [27]

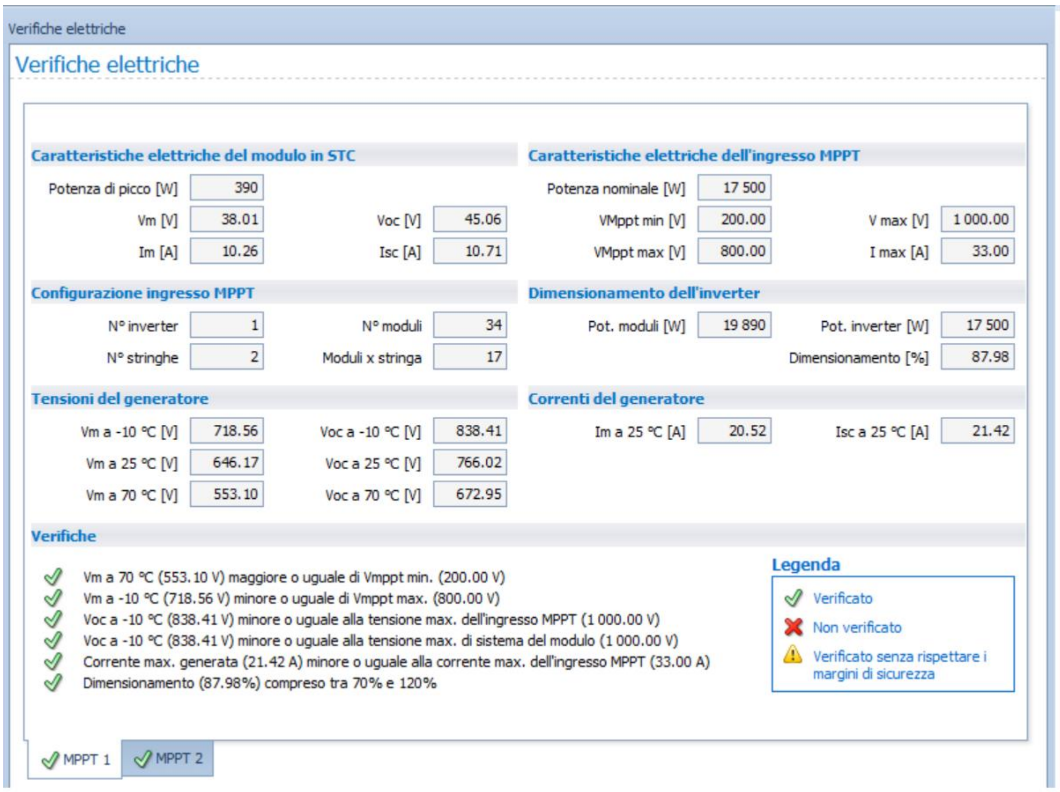


Figure 49 – Electric check of MPPT1

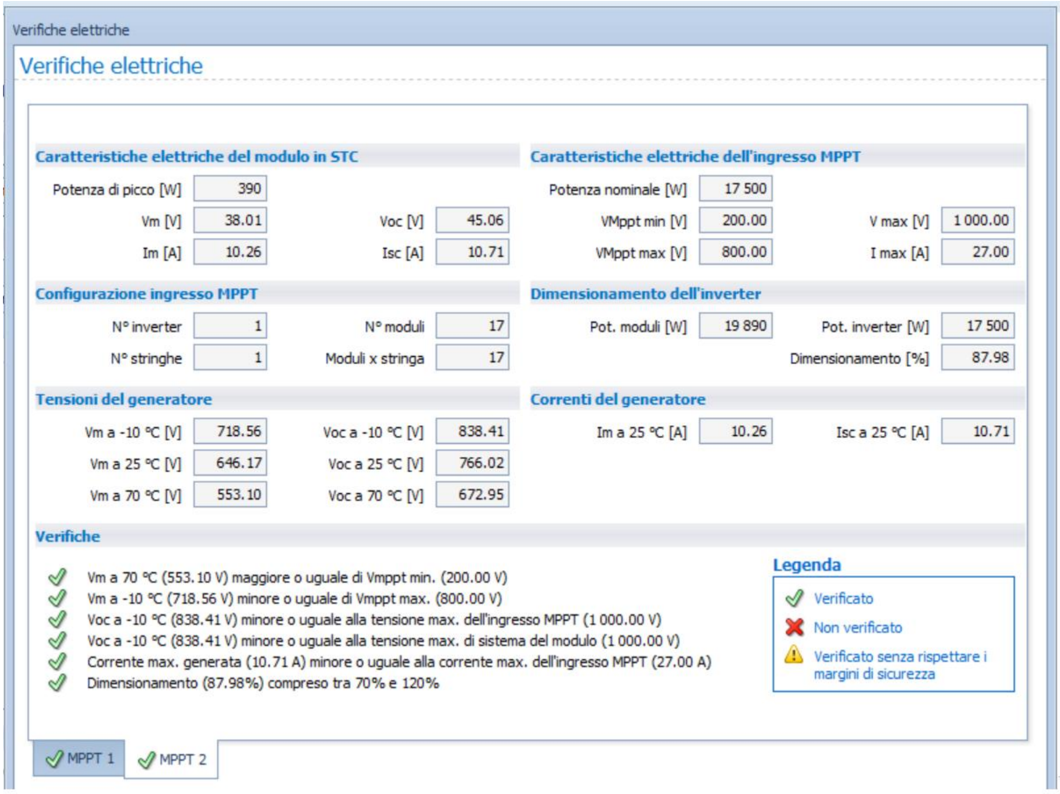


Figure 50 – Electric check of MPPT2

The last device associated to the photovoltaic is the battery. It was chosen "BATTERY-BOX PREMIUM HVM" by *BYM* [28] (Figure 51). The battery is composed by two modules of HVM 19.3 in parallel, giving a total usable energy of 38.64 kWh. This design derives from the fact that it is usually possible to use a battery that is (in kWh) almost twice the peak power of the photovoltaic system (in kW).

	HVM 8.3	HVM 11.0	HVM 13.8	HVM 16.6	HVM 19.3	HVM 22.1
Battery Module	HVM (2.76 kWh, 51.2 V, 38 kg)					
Numero di moduli	3	4	5	6	7	8
Energia Disponibile [1]	8.28 kWh	11.04 kWh	13.80 kWh	16.56 kWh	19.32 kWh	22.08 kWh
Corrente di Uscita massima [2]	40 A	40 A	40 A	40 A	40 A	40 A
Corrente di Uscita Picco [2]	75 A, 3 s	75 A, 3 s	75 A, 3 s	75 A, 3 s	75 A, 3 s	75 A, 3 s
Tensione Nominale	153 V	204 V	256 V	307 V	358 V	409 V
Tensione Operativa	120~173 V	160~230 V	200~288 V	240~345 V	280~403 V	320~460 V
Dimensioni (H/W/D)	945 x 585 x 298 mm	1178 x 585 x 298 mm	1411 x 585 x 298 mm	1644 x 585 x 298 mm	1877 x 585 x 298 mm	2110 x 585 x 298 mm
Peso	129 kg	167 kg	205 kg	243 kg	281 kg	319 kg

Figure 51 - BATTERY-BOX PREMIUM HVM [28].

In this sub-chapter it was decided to also include the condominium charging station for vehicles. It will be a "AMTRON Basic R T2S" from *MENNEKES* [29] (Figure 52). It has a maximum charging power of 7.4 kW, monophase and it needs a key for the switch.

	Start E T2S	Standard E T2S	Basic E T2S	Basic R T2S
				Protezione delle persone
			Contatore di energia digitale tarato	Contatore di energia digitale tarato
		Interruttore a chiave	Interruttore a chiave	Interruttore a chiave
	Indicatore di stato LED Pulsante di arresto	Indicatore di stato LED Pulsante di arresto	Indicatore di stato LED Pulsante di arresto	Indicatore di stato LED Tasto multifunzione
Articolo	3,7 kW 1340680 11 kW 1340681	3,7/7,4 kW 1358600 11/22 kW 1358601	3,7/7,4 kW 1353600 11/22 kW 1353601	3,7/7,4 kW 1343680 11 kW 1343681

Figure 52 - Charging station AMTRON Basic R T2S [29].

4.4. Interventions in the apartments

Private interventions contribute to achieving the double jump in energy class of the entire building. A questionnaire with all the information and all the interventions that can be done was provided to each owner. the choices made are shown in the Table 28.

	110%								50%
APARTMENTS	WINDOWS	SHUTTERS	ENTRANCE DOOR	CURTAINS	HEAT PUMP DHW	HEATING TERMINALS	THERMOSTATIC VALVES	PRIVATE CHARGING STATION	SUMMER AIR CONDITIONINIG
1	X	X	X	X	X	X	X		
2				X			X		
3							X		
4				X			X		
5	X	X		X		X	X		X
6	X	X	X	X		X	X		X
7	X	X		X			X		
8	X	X	X	X		X	X		
9	X	X	X			X	X		
10	X	X	X	X	X		X		X
11		X	X	X		X	X		X
12							X		
13	X	X	X	X	X	X	X		
14	X	X	X	X		X	X		
15							X		
16		X	X			X	X	X	X
17			X		X		X		X
18	X	X	X	X		X	X		
19	X	X	X	X			X	X	
20	X	X	X	X	X	X	X		X
21				X	X		X		
22	X	X	X	X	X	X	X		X

Table 28 - Interventions in the apartments

From the table it can be seen that three people did not express preferences (n. 3, 12, 15).

Those who have already replaced the windows in the past have decided not to change them (n. 2, 4, 11, 12, 16, 17, 21). The new windows installed are in PVC, with frame of 70 mm, certified thermal transmittance Uf = 1.3 W/m^{2}K, with double glass 4-20-4 and Argon [6]. This model is not present on *TerMus*, so a comparable window is chosen. In order to compare the new windows with the old ones, the windows with the same dimension as the one in Table 20 is shown (Table 29). The difference in terms of transmittance of the glass is null with respect to the PVC 4-16-4 windows, but in comparison to wood and aluminium is remarkable (see attachment 2 for the properties of all windows).

Door window with three doors, PVC 4-20-4, Double glass		
	GLASS	FRAME
	Type = Double (low emissivity)	Type = Plastic
	Area - A_g = 2.55 m²	Area - A_f = 1.65 m²
	Perimeter - L_g = 17.34 m	Transmittance - U_f = 1.00 W/m²K
	Transmittance - U_g = 1.40 W/m²K	Type spacers = Metal
	Normal solar factor - f_g = 0.34	Transmittance spacers = 0.06 W/m²K
	Total area - A_w = 4.20 m²	
Internal surface resistance	0.13	m²K/W
External surface resistance	0.04	m²K/W
Frame area reduction coefficient	0.39	
Total transmittance - U_w	**1.4907**	**W/m²K**
Total resistance - R_w	**0.67**	**m²K/W**

Table 29 - Door window with three doors, PVC 4-20-4, double glass

The total transmittance is 1.4907 W/m^{2}K, larger than that of the windows that will be installed, so the results will be conservative. The normal solar factor is lower then that of the other windows, this leads to a lower heating due to the sun in summer.

As for the heat pump for domestic hot water, the people who want to install it are n. 1, 10, 13, 17, 20, 21 and 22. The systems installed are "NUOS EVO 80L" from ARISTON [20] which characteristics are described in the Figure 53. This heat pump has is in the energetic class "A", it is able to work with temperature between -5°C and 42°C, so these temperatures are excellent for Varazze which is unlikely to be outside this range, and it eliminates bacteria by means an automatic water heating cycle.

Many who replace the windows also change shutters, curtains, and entrance doors.

The n. 1, 5, 6, 8, 9, 11, 13, 14, 16, 18, 20 and 22 have decided to substitute the old heating terminals with more efficient ones in alluminium.

The thermostatic valves are required by law and since they were not installed in this building, it is necessary to go and put them in all the apartments.

The private charging station for the cars is wanted only by owner n. 16 and n. 19.

DATI TECNICI		80	110
COP**		2,15	2,33
Tempo di riscaldamento**	h:min	6:42	9:03
Temperatura min/max aria	°C	-5/42	-5/42
Potenza sonora	db(A)	50	50
Potenza elettrica assorbita media	W	250	250
Quantità massima di acqua calda a 40°C**	l	99	133
Capacità nominale accumulo	l	80	110
Pressione massima di esercizio	bar	8	8
Tensione/Potenza massima assorbita	V/W	220-240/1550	220-240/1550
Potenza resistenza	W	1200	1200
Portata d'aria standard	m^3/h	100-200	100-200
Volume minimo del locale d'installazione*	m^3	20	20
Massa a vuoto	kg	50	55
Protezione elettrica		IP24	IP24
Spessore isolamento	mm	41	41
Diametro connessioni acqua	"	1/2 M	1/2 M
Minima Temperatura del locale di accumulo	°C	1	1
Dispersioni termiche (Pes)**	W	17	17
Pressione statica disponibile	Pa	65	65

Figure 53 – Features of NUOS EVO 80-110 [20].

The previous interventions can be deducted in the 110% regime, while the installation of summer air conditioning systems has a deduction of 50%. The n. 5, 6, 10, 11, 16, 17 and 20 want to install a dual-split system of 5 kW, while the n. 22 wants a trial-split system of 7.5 kW.

4.5. Results

Once all the interventions to be done have been defined, it is necessary to bring them back to the model created previously on *TerMus*. It will proceed to the addition of the thermal insulation of the roof and walls, the replacement of the oil boiler with the hybrid system, the installation of the photovoltaic system and all the interventions in the individual apartments (windows, shutters, curtains, front door entrance, water heater, thermostatic valves).

The results are shown in Figure 54 and Figure 55.

The building increases its conventional EPC from a F class to an A1 class, this means that the minimum double jump of EPC is obtained. Furthermore, the consumes are reduced of 70%. By considering each apartment it is possible to notice that the variation on consumes are significative. The one that reduces them the least is n. 14 which in every case has practically halved them. There are apartments n. 10 and n. 13 that reduce them consumes of 95%.

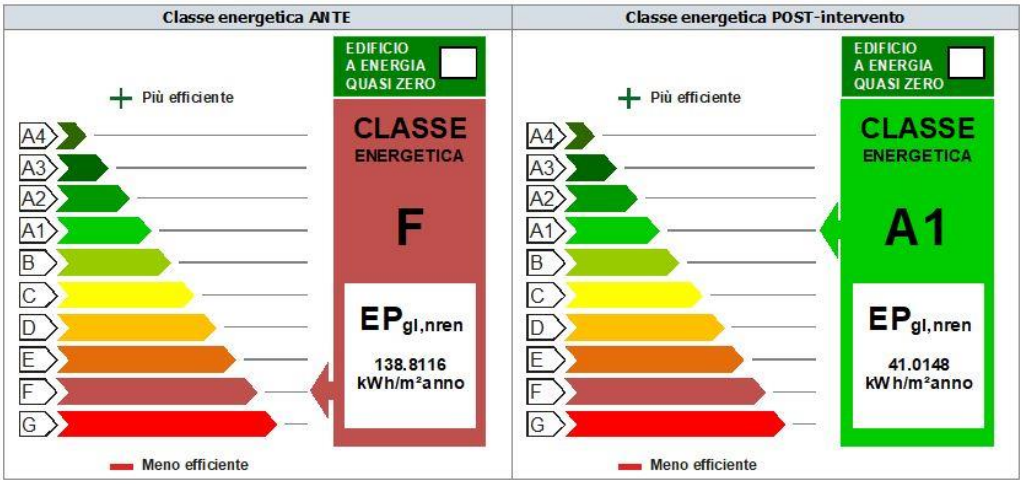


Figure 54 - Comparison EPC before and after the interventions

	BEFORE				AFTER				
Apartment	EPC	Consumes [kWh/m2*year]	Winter	Summer	EPC	Consumes [kWh/m2*year]	Winter	Summer	Variation
1	G	161.13	☹	☹	A3	23.55	☹	😐	-85%
2	F	129.56	☹	😐	B	42.71	☹	☺	-67%
3	G	144.93	☹	☹	D	53.95	☹	☹	-63%
4	D	132.49	☹	😐	A2	54.8	☹	😐	-59%
5	G	152.4	☹	☹	B	61.45	☹	😐	-60%
6	F	114.71	☹	☹	A2	38.78	☹	😐	-66%
7	G	110.85	☹	😐	A1	32.22	☹	☺	-71%
8	G	107.49	☹	☹	C	39.96	☹	😐	-63%
9	F	96.48	☹	😐	B	37.42	☹	😐	-61%
10	G	134.9	☹	☹	A4	6.7	☺	☺	-95%
11	F	135.36	☹	☹	A2	48.54	☹	☹	-64%
12	F	165.98	☹	☹	C	64.95	☹	☹	-61%
13	G	107.04	☹	😐	A4	5.55	😐	☺	-95%
14	F	99.47	☹	☹	D	52.9	☹	😐	-47%
15	F	96.66	☹	😐	C	40.75	☹	😐	-58%
16	F	122.04	☹	😐	A3	35.56	😐	☺	-71%
17	F	135.23	☹	☹	A4	18.9	☹	☹	-86%
18	G	251.95	☹	☹	C	89.43	☹	☹	-65%
19	F	186.05	☹	😐	A1	53.5	☹	☺	-71%
20	G	167.88	☹	☹	A3	34.38	☹	😐	-80%
21	G	137.99	☹	😐	C	50.95	☹	😐	-63%
22	G	181.79	☹	☹	A3	37.9	☹	😐	-79%

Figure 55 - Comparison of the EPC of each apartment

In winter the colour of the EPC is still red even after all the interventions carried out. This is due to the fact that the useful energy performance index Eph,nd calculated is still higher than the limit one. To improve it, it would be necessary to isolate more and therefore further decrease the dispersions. In the summer case, on the other hand, the colour has improved because the thermal performance index useful for cooling Epc,nd is lower than its limit. This is mainly due to the new windows and shutters which have a lower solar factor than the previous ones.

5. ECONOMIC ANALYSIS

All the intervention proposed allow to reach the requirement for the improvement of at least two energy classes. Now it is important to understand the costs of the interventions and the advantages of the intervention in terms of money.

5.1. Assessment of economic convenience

First of all, the cost of operation of the old heat generator was analysed by looking at the bills issued in previous years for the purchase of diesel oil (Table 30). The VAT (Value Added Tax) is equal to 22%.

Bills	Litres	Price/litres	VAT	Costs	Seasonal consumption
02/10/2018	5,000	€ 1.430	€ 1,572.87	€ 8,722.27	€ 16,659.65 Litres 10,000
23/01/2019	5,000	€ 1.301	€ 1,431.33	€ 7,937.38	
19/11/2019	4,500	€ 1.325	€ 1,311.60	€ 7,273.43	€ 13,795.30 Litres 8,500
04/02/2020	4,000	€ 1.336	€ 1,176.08	€ 6,521.88	

Table 30 – Costs and consumptions of diesel oil

Then the data of the electricity consumptions are evaluated from the bills of the last three two-months of the 2020 and the first three of the 2021, divided in the time slots (measured in kWh). The condominium has two POD, so the sum of the two consumption registered was carried out in Table 31.

	2020			2021			
POD IT001E136077180	**4th BIM**	**5th BIM**	**6th BIM**	**1st BIM**	**2nd BIM**	**3rd BIM**	**Tot [kWh]**
Consumption F1	98	117	102	98	105	90	610
Consumption F2	84	94	78	73	78	69	476
Consumption F3	149	154	128	143	119	130	823
Tot Consumption	*331*	*365*	*308*	*314*	*302*	*289*	*1,909*
POD IT001E136077171	**4th BIM**	**5th BIM**	**6th BIM**	**1st BIM**	**2nd BIM**	**3rd BIM**	**Tot [kWh]**
Consumption F1	41	42	61	95	103	61	403
Consumption F2	26	25	54	68	90	54	317
Consumption F3	64	64	64	65	69	64	390
Tot Consumption	*131*	*131*	*179*	*228*	*262*	*179*	*1,110*

Tot Consumption EE [kWh]	*462*	*496*	*487*	*542*	*564*	*468*	*3,019*

Table 31 – Electricity consumptions and costs

With all these data it is possible to create the energetic consumption profile of the building. To do so, it was assumed a consumption of 9,000 litres of diesel oil and a fuel cost of 1.35 Euros/litre (without VAT, that become 1.647 Euros/litre considering the VAT at 22%). Both values are estimated on the base of the season 2018/2019 and 2019/2020 values.

The Table 32 shows a monthly estimate of the energy consumption of the condominium and the relative costs. The 9,000 litres of diesel oil are distributed among the months of the heating season. The diesel consumption was converted in kWh considering that 1 litre of diesel produce 9.17 kWh [13], and then it was multiplied by the efficiency of the heat generator equal to 85%. Furthermore, the cost for running and maintaining the thermal power plant is included and equal to 1,300 Euros/year. Regarding the cost of electricity, the system charges are not taken into account, considering a cost equal to 0.25 Euros/kWh. The consumptions are the sum of consumptions of the two POD divided by two since the bills are referred to two-months.

QUANTITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Total
Diesel consumptions [litres]	2,250	1,260	1,080							900	1,260	2,250	**9,000**
Boiler efficiency	0.85	0.85	0.85							0.85	0.85	0.85	
Thermal energy to the building [kWhth]	17,538	9,821	8,418							7,015	9,821	17,538	**70,151**
Electricity consumptions [kWhel]	271	271	282	282	234	234	231	231	248	248	244	244	**3,020**
F1	97	97	104	104	76	76	70	70	80	80	82	82	**1,013**
F2	71	71	84	84	62	62	55	55	60	60	66	66	**793**
F3	104	104	94	94	97	97	107	107	109	109	96	96	**1,213**
COSTS													
Diesel cost [€]	3,638 €	2,037 €	1,746 €							1,455 €	2,037 €	3,638 €	**12,150 €**
Electricity cost (variable only) [€]	68 €	68 €	71 €	71 €	59 €	59 €	58 €	58 €	62 €	62 €	61 €	61 €	**755 €**
O&M cost of the system [€]	108 €	108 €	108 €	108 €	108 €	108 €	108 €	108 €	108 €	108 €	108 €	108 €	**1,300 €**
Total energy cost [€]	**3,814 €**	**2,214 €**	**1,925 €**	**179 €**	**167 €**	**167 €**	**166 €**	**166 €**	**170 €**	**1,626 €**	**2,207 €**	**3,807 €**	16,608 €

Table 32 – Montlhy energy consumptions and relative costs

As result, in one year, the cost for the electricity for the common part of the building and for the heating is € 16,608.

Now the costs with the hybrid system have to be estimated. Actually, only the operation of the heat pump is considered without the intervention of the condensing boiler because, as said before, many apartments are empty for a large part of the year. In this way it is possible to understand that the thermal requirements can be satisfied by the heat pump alone (Table 33).

In order to compare the results, the thermal energy sent to the building is maintained equal to the one produced by the old heat generator. The COP of the heat pump is equal to 3.52 at the outlet temperature of 45°C. By dividing the thermal energy by the COP, the electricity needed for the heat pump is obtained. Furthermore, the electricity production of the photovoltaic system is the one calculated in chapter 4.3 (23,591 kWh). Now it is possible to calculate the electricity that has to be purchased for the heating system by subtracting the electricity required to run the heat pump and the electricity produced by the photovoltaic system. Obviously, the electricity consumptions for the common parts remain the same as the case of the old heat generator. Regarding the electricity costs, as before the price of electricity is assumed equal to 0.25 Euros/kWh, and so the cost for the heating system and for the common parts are evaluated. Moreover, the operation and maintenance cost of the heating system and the photovoltaic system are respectively equal to 1,800 Euros/year and 300 Euros/year.

QUANTITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Total
Thermal energy to the building [kWhth]	17,538	9,821	8,418							7,015	9,821	17,538	**70,151**
Heat pump COP (T=45°C)	3.52	3.52	3.52							3.52	3.52	3.52	
Electricity needs for Heat Pump [kWhel]	4,982	2,790	2,391							1,993	2,790	4,982	**19,929**
Elecricity production from PV panels [kWhel]	807	1,121	1,822	2,259	2,601	2,855	3,213	2,832	2,285	1,783	1,130	883	**23,591**
Elecricity purchased [kWhel]	4,175	1,669	570							209	1,660	4,099	**12,382**
Electricity consumptions [kWhel]	271	271	282	282	234	234	231	231	248	248	244	244	**3,020**
F1	97	97	104	104	76	76	70	70	80	80	82	82	**1,013**
F2	71	71	84	84	62	62	55	55	60	60	66	66	**793**
F3	104	104	94	94	97	97	107	107	109	109	96	96	**1,213**
													-
COSTS													-
Electricity cost for heating [€]	1,044 €	417 €	142 €							52 €	415 €	1,025 €	**3,096 €**
Electricity cost (variable only) [€]	68 €	68 €	71 €	71 €	59 €	59 €	58 €	58 €	62 €	62 €	61 €	61 €	**755 €**
O&M cost of the heating system [€]	150 €	150 €	150 €	150 €	150 €	150 €	150 €	150 €	150 €	150 €	150 €	150 €	**1,800 €**
O&M cost of the PV system [€]	25 €	25 €	25 €	25 €	25 €	25 €	25 €	25 €	25 €	25 €	25 €	25 €	**300 €**
Total energy cost [€]	**1,287 €**	**660 €**	**388 €**	**246 €**	**234 €**	**234 €**	**233 €**	**233 €**	**237 €**	**289 €**	**651 €**	**1,261 €**	5,951 €

Table 33 – Estimation of energy costs for heating with only the heat pump

Finally, the total cost for one year of services is € 5,951, resulting in a saving of 64% compared to the case of the diesel boiler. This cost can be further reduced considering that in the summer there is a production of electricity from the photovoltaic panels which is stored in the battery and then can be used to cover the electricity needs of the building and the one in excess can be fed into the network.

5.2. Cost of the interventions

The final part of this work is the "bill of quantities" (in Italian Computo Metrico Estimativo – CME). It is a table that assemble all the interventions of a construction work and estimates the total costs of it. The table is divided in different columns regarding the code of the interventions, its description, its dimensions and the relative unit of measurement, its quantity, and its cost.

To decide the cost of the interventions, some price lists are used. They are called "Prezzario DEI" and usually are used both the national one and the regional one (in this case that of Liguria) in order to have a comparison and to have more types of possible interventions since in many cases the regional one is not complete. An important observation is that due to Covid-19, many companies supplying raw materials for construction have stopped or have slowed down production causing difficulties in findiing materials and the price increases of them. The latest elaborations of the ANCE, which compare the situation of November 2020 with that of the last few months, show an increase of: + 243% for rebar steel, + 128% for polyethylene, + 38.6% for copper, + 73.8% for PVC, + 76.1% for coniferous wood, + 25.2% for bitumen [14], making difficult the compilation of the bill of quantities.

The document is written on "*PriMus*" software, also produced by *ACCA*. This software allows to import the price lists and then to drag the item chosen on the worksheet. Since there are many items of calculation, it has preferred to include the most relevant ones in this dissertation. In any case, the total costs provided are the real ones. The items are divided in the following macro categories:

1. **"Trainanti" interventions on common parts, deduction 110% (Total cost € 625,000).**

Inside this category fall the cost for the thermal insulation and the substitution of the heat generator.

In the thermal insulation part, in addition to the cost of the actual materials, there are also all the costs regarding the construction site. For example: work area fencing, scaffolding (for 8 months it is about € 48,000), construction site signage, roof cover, personal protective equipment (DPI, Dispositivi di Protezione Individuale), anti-theft devices, workers' rooms, covid-19 protection material (sanitization, gel, masks), waste disposal and transport. The total cost is around € 109,500. For only the insulation part, the cost of the preparation of the external surface of the walls and the roof, in order to install the insulant, is about € 171,300. Furthermore, the cost for each insulant material is: € 32,341 for EPS (the cost for 1 m^2 is around € 88.7, the interested surface is about 365 m^2), € 92,271 for the Aerogel (the cost for 1 m^2 is around € 186.5, the interested surface is about 495 m^2) and € 25,566 for the ISOTEC for the roof (the cost for 1 m^2 is around € 64.77, the interested surface is about 395 m^2). Moreover, € 76,110 are used for the installation, in each apartment, of two system for the controlled mechanical ventilation that is needed in order to avoid the formation of mold and interstitial condensation, and they can be deducted at 110% as clarified by ENEA [15]. The previous interventions give a total cost for this part of about € 507,000, that is lower than the maximum ceilings available of € 950,000 (€ 40,000 for each real estate unit up to the eight and then € 30,000 for each apartment from the ninth onwards, also considering the pertinences, therefore twenty-one unit).

The heating system includes the cost for the dismantling of the old generator and the reclamation of the diesel tank, for a total of € 5,800 (it also includes manual labour), the cost for the connection of the methane network is € 3,500 and the new Hybrid system cost is about € 44,500. Furthermore, the cost of the installation of pipes, valves, safety systems, building works accounts for € 36,700. The cost of replacing the terminals of the owners who have chosen to change them falls in this set of expenses and it is about € 14,200 for twelve apartments. The total cost for the substitution of the heat generator is around € 118,000, that is lower than the maximum ceilings of € 475,000 (€ 20,000 for each real estate unit up to the eight and then € 15,000 for each apartment from the ninth onwards, also considering the pertinences, therefore twenty-one unit)

2. "Trainati" interventions on common parts, deduction 110% (Total cost € 79,850).

These types of interventions are those related to the photovoltaic system. In particular, the cost for the photovoltaic panels is about € 43,400 (€ 2,182 for each kW, in this case 19.98 kW), the cost for the battery is € 35,100 (€ 909 for each kWh, in this case 38.6 kWh) and the cost of the charging station for cars is € 1.363.

The costs of these interventions are lower than their maximum ceilings: for photovoltaic € 48,000, for the battery € 1,000 for each kWh installed for a total of € 38,600, and for the charging station € 1,500 since the installed charging station are lower than eight.

3. "Trainati" interventions on single apartment, deduction 110% (Total cost € 375,000).

This category regards the substitution of the heat generator for the DHW (€ 31,250 for seven apartments), the substitution of windows, shutters, curtains, and entrance doors (€ 2,549,299 for nineteen apartments), the installation of building automation (thermostatic valves for all twenty-two apartments (€ 91,570) and the private charging station (€ 2,728 for two apartments). The Table 34 shows the interventions and the total cost for each apartment.

APARTMENT	WINDOWS	SHUTTERS	ENTRANCE DOOR	CURTAINS	HEAT PUMP DHW	THERMOSTATIC VALVES	PRIVATE CHARGING STATION	TOTAL
1	X	X	X	X	X	X		€ 21,104
2				X		X		€ 10,757
3						X		€ 4,117
4				X		X		€ 7,164
5	X	X		X		X		€ 29,649
6	X	X	X	X		X		€ 15,447
7	X	X		X		X		€ 25,439
8	X	X	X	X		X		€ 15,961
9	X	X	X			X		€ 16,587
10	X	X	X	X	X	X		€ 23,852
11		X	X	X		X		€ 11,764
12						X		€ 4,033
13	X	X	X	X	X	X		€ 34,359
14	X	X	X	X		X		€ 15,961
15						X		€ 4,033
16		X	X			X	X	€ 11,153
17			X		X	X		€ 10,246
18	X	X	X	X		X		€ 12,991
19	X	X	X	X		X	X	€ 31,606
20	X	X	X	X	X	X		€ 21,271
21				X	X	X		€ 13,399
22	X	X	X	X	X	X		€ 33,840

Table 34 – Interventions and costs of each apartment, deduction 110%

The ceilings of these intervention are those in Table 10, more precisely for windows, shutters, entrance doors and curtains the ceiling is € 54,545.45, for the heat pumps and thermostatic valves the ceiling is € 27,272.72, giving a total ceiling of € 81,818.17, respected by all the apartments.

4. Façade renovation, deduction 90% (Total cost € 99,970).

The interventions on unheated rooms cannot be deducted at 110% and therefore will be counted in the facade bonus at 90%. These parts are the walls of the stairs for what concern the isolation, the interventions on the terraces, the horizontal roof, and the ground floor for only the painting and plastering. Therefore, the owners must pay € 9997 divided by thousandth share ownership of common parts.

5. **Renovation works on common parts, deduction 50% (Total cost € 7,150).**

The windows of the stairs are deducted at 50%. Therefore, the owners must pay € 3,575 divided by thousandth share ownership of common parts.

6. **Renovation works on private parts, deduction 50% (Total cost € 47,100).**

These interventions are the installation of the splits in eight apartments. Each owner must pay his own share as shown in Table 35. Even if the machines installed are the same in most of the apartments, the cost is different due to the different length of pipes of the system.

APARTMENT	SUMMER AIR CONDITIONING	TOTAL	DEDUCTION 50%
1			
2			
3			
4			
5	DUAL SPLIT	€ 6,061	€ 3,031
6	DUAL SPLIT	€ 5,389	€ 2,695
7			
8			
9			
10	DUAL SPLIT	€ 5,677	€ 2,839
11	DUAL SPLIT	€ 5,677	€ 2,839
12			
13			
14			
15			
16	DUAL SPLIT	€ 5,677	€ 2,839
17	DUAL SPLIT	€ 5,677	€ 2,839
18			
19			
20	DUAL SPLIT	€ 5,389	€ 2,695
21			
22	TRIAL SPLIT	€ 6,928	€ 3,464

Table 35 – Cost of the summer air conditioning system, deduction 50%

Summing up all the costs, is found a total of € 1,234,000. In Figure 56 it is possible to notice the weight of the different interventions. The most important is the thermal insulation, followed by the interventions on private apartments.

The Figure 57 shows the 110%, the 50% and 90% deduction parts. As can be seen, almost all of the interventions are deducted at 110%, making this type of concession important for the energy requalification of buildings.

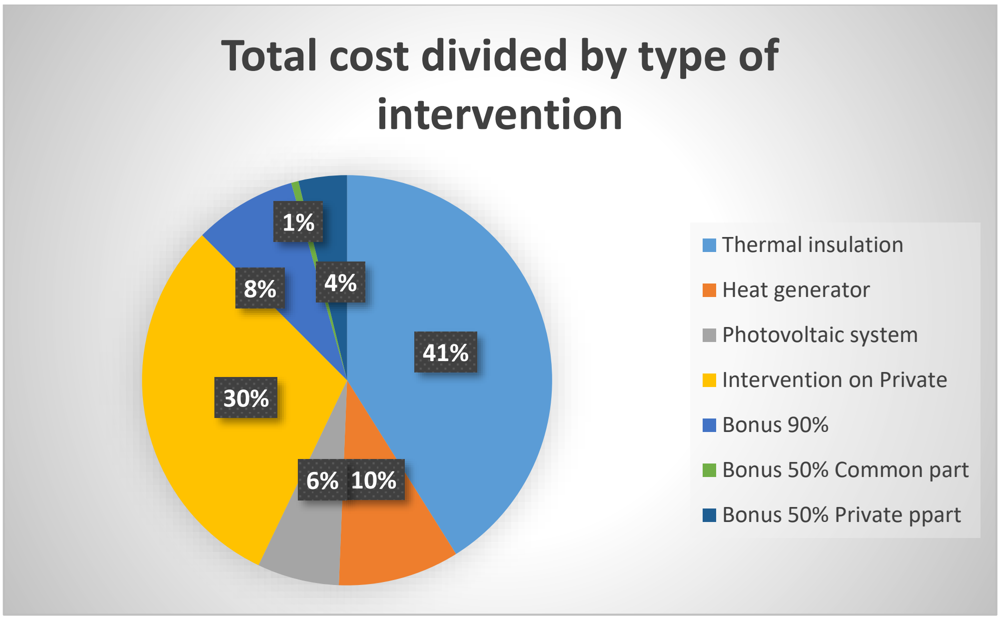


Figure 56 – Total cost divided by type of intervention

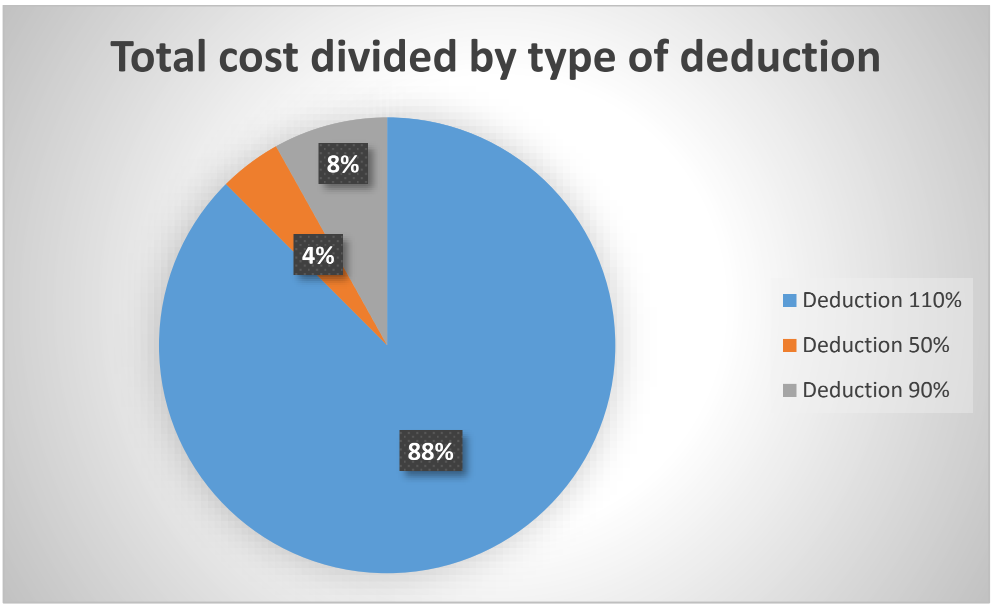


Figure 57 – Total cost divided by type of deduction

6. CONCLUSIONS

The European building stock is energy inefficient and highly polluting. New buildings must necessarily get as close as possible to the NZEB (Nearly Zero Energy Building), but the real challenge is the energy requalification of existing buildings.

The purpose of this dissertation was to highlight the importance of the energy requalification of buildings to reduce heat loss and therefore to reduce polluting emissions emitted by heat generators powered by fossil fuels.

The interventions on which action must be taken are certainly the replacement of boilers that use diesel oil as fuel, which are very polluting and not very efficient, with new generation condensing boiler methane fuelled. Even better would be to switch to technologies that do not use any type of fossil fuel, but rather electricity, such as heat pumps, in particular if the latter are powered with electricity produced on site from renewable sources such as photovoltaic panels.

Another important type of intervention is the insulation of the building envelope, using materials that allow to maintain constant internal comfort, avoiding heat loss, and therefore reducing the heat power required by the heat generator.

Although these interventions are necessary, it is also true that the cost of an energy redevelopment is very high. Funds are therefore needed from governments in order to reduce the individual citizens' expenses as much as possible. In addition, stricter rules and laws are needed to avoid fraud and excessive price increases of materials and components.

In this dissertation, all the interventions mentioned have been implemented, enabling the EPC of a building constructed in the 70s to be increased from F to A1. The total cost of the intervention is around € 1,234,000, which means that without financing, each owner would have had to pay an average of about € 54,000, a cost that most people would never have incurred. Thanks to the *Superbonus 110%*, these costs are reduced and the owners must pay only for the private parts deducted by 50% (installation of SPLIT, about € 3000 each for eight apartments) or for the common ones deducted by 90% (windows, stairs and balconies, about € 620 each for all the apartments).

In conclusion, the energy requalification of the national and European building stock is possible and very effective, but it can only take place quickly if supported by Governments' funding.

7. REFERENCES

1 - IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/

2 - National Oceanic and Atmospheric Administration, Global Monitoring Laboratory, Eart System Research Laboratories, https://gml.noaa.gov/ccgg/trends/global.html

3 - Google Maps

4 - Eurostat Statistic Explained. Energy consumption in households. June 2021. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

5 - De Paolis Dino, Superbonus 110%, Roma, Legislazione Tecnica, (Febbraio 2021), pp 13-84

6 - COMETAL, Finestre D'autore. https://www.cometalserramenti.it/serramenti-pvc-lombardia-piemonte-liguria/

7 - Meliță, Larisa & Croitoru, Cristiana. (2019). Aerogel, a high performance material for thermal insulation – A brief overview of the building applications. E3S Web of Conferences.

8 – Gazzetta ufficiale. Valori di trasmittanza massimi consentiti per l'accesso alle detrazioni. https://www.gazzettaufficiale.it/do/atto/serie_generale/caricaPdf?cdimg=20A0539400500010110001&dgu=2020-10-05&art.dataPubblicazioneGazzetta=2020-10-05&art.codiceRedazionale=20A05394&art.num=1&art.tiposerie=SG

9 – EPA, United States Environmental Protection Agency. Global Greenhouse gas Emissions Data. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

10 – EPA, United States Environmental Protection Agency. Understanding Global Warming Potentials. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

11 –European Commission. In focus: Energy efficiency in buildings. 17 February 2020. https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en

12 – GSE, Incentivazione della produzione di energia termica da impianti a fonti rinnovabili ed interventi di efficienza energetica di piccole dimensioni, REGOLE APPLICATIVE DEL D.M. 16 FEBBRAIO 2016. https://www.gse.it/documenti_site/Documenti%20GSE/Servizi%20per%20te/CONTO%20TERMICO/REGOLE%20APPLICATIVE/REGOLE_APPLICATIVE_CT.pdf

13 – Energia Regione Emilia-Romagna. Fattori di conversione. https://energia.regione.emilia-romagna.it/come-fare-per/allegati-banche-dati/nota-metodologca-e-i-fattori-di-conversione

14 – Il Sole 24 ore. Edilizia, il caro materiali mette in pericolo i cantieri. https://www.ilsole24ore.com/art/edilizia-caro-materiali-mette-pericolo-cantieri-AE1b4Lc

15 – Enea, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile. https://www.efficienzaenergetica.enea.it/detrazioni-fiscali/ecobonus/faq-ecobonus/d-impianti-termici-comma-347.html

16 – Elemens. Una strategia per la decarbonizzazione dei sistemi di riscaldamento degli edifici in Italia. April 2021. https://www.legambiente.it/wp-content/uploads/2021/04/StrategiaDecarbonizzazioneRiscaldamento.pdf

17 – RÖFIX, Sistemi per costruire. RÖFIX EPS-F 031 RELAX. https://www.roefix.it/prodotto/roefix-eps-f-031-relax

18 – AEROPAN, Nanotech Thermal insulation. https://www.aeropan.it/it/prodotti/aeropan/

19 – ISOTEC, Isolamento e ventilazione per coperture sia nuove che esistenti https://isotec.brianzaplastica.it/download/it/Isotec_Tetto.pdf

20 – ARISTON, Comfort sostenibile per la tua casa, NUOS EVO 80-110. https://www.ariston.com/it-it/prodotti/pompe-di-calore/acqua-calda/nuos-evo-80-110

21 – UNICAL, MULTIINOX 69-116. https://www.unicalag.it/prodotti/professionale-300/light-commercial-inox/2664/multiinox-116

22 – QCELLS. https://www.q-cells.it/prodotti/moduli-fotovoltaici/moduli-fotovoltaici-qantum-duo-z.html

23 - Alyne Lamy-Mendes et al. (2021), Progress in silica aerogel-containing materials for buildings' thermal insulation. Construction and Building Materials 286, pp. 122815-122846.

24 – Material Prof. Monica Ferraris.

25 – UNICAL, HP_OWER ONE 180R. https://www.unicalag.it/prodotti/domestico-50/pompe-di-calore/4028/hp_ower-one-r

26 – Caleffi Hydronic Solutions. Raccolta R Ed. 2009 commentata. https://raccoltar.caleffi.it/pdf/raccolta_r_commentata_caleffi.pdf

27 – FRONIUS, Solar Energy. FRONIUS Symo 17.5-3-M. https://www.fronius.com/it-it/italy/energia-solare/installatori-e-partner/dati-tecnici/tutti-i-prodotti/inverter/fronius-symo/fronius-symo-17-5-3-m#

28 – BYD. BATTERY-BOX PREMIUM HVM. https://bydbatterybox.com/downloads

29 – MENNEKES. AMTRON Basic E 3.7/7.4 T2S. https://www.chargeupyourday.it/pd/amtron/AMTRON-Basic-E-3-77-4-T2S-1353600/

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