Breaking down the barriers of the energy efficiency market through Digital Marketing, BIM and Building Automation

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Index

1 Preface 11
1.1 Digitalization and energy renovation of buildings 11
1.2 The multi-disciplinary approach of the thesis 12
1.3 The thesis' structure 13
1.4 Acknowledgments 17

1st Part

2 The composition of Italian real estate assets 21
2.1 Introduction 21
2.2 Real estate consistence 21
2.3 Real estate heritage and Energy Classification 24
2.4 Current energy consumption 25
3 Economic incentives for buildings renovation 27
3.1 Introduction 27
3.2 The commitment of EU member states 27
3.3 PNIEC - The Integrated Energy and Climate National Plan 27
3.4 New Thermal Account 2.0 31
3.5 Ecobonus 32
3.6 White certificate – TTE 35
4 The results of Italian incentive policy 37
4.1 Introduction 37
4.2 Incentivized interventions in 2018 37
4.3 The building energy classification 41
4.4 The new nZEB normative 42
4.5 The transition from natural gas to renewable energy in buildings 43

2nd Part

5 Renovation of the public buildings stock: the role of New Thermal Account 2.0 and EPCs 49
5.1 Introduction 49
5.2 EPC contracts for the energy upgrading of public buildings 49
5.3 The Project Feasibility Assessment Methodology - PFAM 50
5.4 The case study 58
5.5 Conclusion 62
5.6 Annex 1 63
5.7 Annex 2 64
6 Renovation of private buildings: the effectiveness of Ecobonus 65
6.1 Introduction 65
6.2 The case study 65
6.3 The typology of interventions in the renovation of buildings 67
6.4 The renovation hypotheses 67
6.5 Transfer of Tax Credits from Ecobonus 74
6.6 Conclusion 75

7 New nZEB buildings: the impact of BIM design and Building Automation ... 79
7.1 Introduction ... 79
7.2 The case study ... 79
7.3 Photovoltaic and energy storage ... 86
7.4 Building automation: framework ... 88
7.5 Conclusion ... 90
7.6 Annex 1: ... 92
7.7 Annex 2: Functional diagram of the thermal generation plant with storage ... 94
8 The barriers of the energy renovation market ... 97
8.1 Introduction ... 97
8.2 Classification of barriers ... 97
8.3 The decision-making process in renovation of buildings ... 99
9 The WEB to break down the barriers of awareness and knowledge ... 103
9.1 Introduction ... 103
9.2 The potential of Digital Marketing for energy requalification of buildings ... 103
9.3 Analysis of web search volume of words related to energy upgrading in Italy ... 104
9.4 Analysis of the type of web content for research related to energy renovation in Italy ... 105
9.5 The funnel applied to the renovation market ... 107
9.6 Conclusion ... 109
10 Actions necessary to strengthen the energy efficiency plan ... 111
10.1 Introduction ... 111
10.2 Adequacy of economic incentives ... 111
10.3 The need of a new project development approach ... 112
10.4 The impact on decision making process ... 112
10.5 The need for a Decision Support System in the early stages of decision-making ... 113

3rd Part

11 The developed Decision Support System (DSS) platform ... 117
11.1 Introduction ... 117
11.2 The Applications present in the DSS-RRE ... 119
11.3 The portal RRE Software architecture ... 120
11.4 Front End and Database ... 121
11.5 The structure of the applications computer programs ... 125
11.6 Economic and financial analysis tools ... 126
11.7 CRM ... 129
11.8 Comparison between RRE platform and existing DSSs ... 129
12 The thermal energy demand of a building ... 131
12.1 Introduction ... 131
12.2 The Italian legislation ... 131
12.3 The primal heat demand relationship ... 133
12.4 Thermal exchange by transmission ... 135
12.5 Thermal loss for ventilation ... 137
12.6 Extra thermal flow for infrared radiation to the celestial vault ... 139

12.7 Internal gains ... 140
12.8 Solar heat gain through glazed surface ... 141
12.9 Solar heat gain through opaque surfaces ... 145
12.10 The Utilization Factor of thermal gain ... 145
12.11 The monthly thermal energy demand ... 149
12.12 Thermal demand required by the generator ... 150
12.13 Conclusion ... 151
Appendix 1: Thermal characteristics of envelope reference elements ... 153
13 The energy consumption of the climate generator ... 159
13.1 Introduction ... 159
13.2 Traditional and condensing boilers efficiency evaluation ... 160
13.3 Gas (absorption) Heat Pumps efficiency evaluation ... 162
13.4 Electric (compression) Heat Pump efficiency evaluation ... 164
13.5 The Bin Hourly Method ... 169
13.6 The definition of Degree-Hours ... 170
13.7 Energy Consumption according to the integration algorithm ... 172
13.8 Conclusion ... 173
14 Towards the nZEB building ... 175
14.1 Introduction ... 175
14.2 Renewable and non-renewable primary energy ... 176
14.3 The Reference Building ... 178
14.4 Definition of the Energy Class for Buildings ... 178
14.5 Requirements for nZEB buildings ... 179
14.6 A model for calculating renewable energy production from a photovoltaic plant ... 184
14.7 Energy consumption computing algorithm of a heat pump powered by photovoltaic plant ... 186
15 The validation of the DSS-RRE model ... 191
15.1 Introduction ... 191
15.2 Geometric model data ... 194
15.3 The accuracy of the DSS-RRE model ... 195
15.4 Applying the DSS-RRE model to a complex case ... 201
15.5 The DSS-RRE tools to asses renovation interventions ... 205
15.6 Bringing the Town-Hall into NZEB ... 217
15.7 Conclusions ... 219
16 Conclusions and future developments ... 221
17 References ... 225

Index of Figures

Figure 2-1: Real estate unit in Italy 22
Figure 2-2: Housing Unit in Italy........ 22
Figure 2-3 Italian real estate park, for use in thousands of buildings........ 22
Figure 2-4: Residential buildings in Figure 2-3 22
Figure 2-5: Residential Housing Units in Figure 2 2........ 22
Figure 2-6: Housing Units types In Italy 23
Figure 2-7: Buildings type in Italy........ 23
Figure 2-8: Tertiary buildings. 2018 23
Figure 2-9: Dwellings in residential buildings for the time of construction. 24
Figure 2-10: Non-residential buildings........ 24
Figure 2-11: Residential buildings........ 24
Figure 2-12: Final energy consumption by sector in Europe in 2000 and 2015 in Mtoe 25
Figure 2-13: Energy consumption in Europe in 2000........ 25
Figure 2-14: Energy consumption in Europe in 2015........ 25
Figure 2-15: Energy consumption in Italy 2000 25
Figure 2-16: Energy consumption in Italy 2015 25
Figure 2-17: Energy consumption in the residential sector 26
Figure 2-18: Electricity consumption by sector in Italy (TWh) – 2015 26
Figure 3-1: Expected savings 2021-2030 in Mtoe by sector 30
Figure 3-2: Expected savings 2021-2030 in Mtoe by incentives 30
Figure 3-3: Comparison of expected savings for the period 2021-2030 and savings obtained for the 2014-2018 period..... 30
Figure 3-4: Comparison of allocated resurces 2021-2030 (source: PNIEC) and incentives deliverd (source: ENEA, 2019).... 30
Figure 3-5: Average prices of TEE 2006-2017 36
Figure 3-6: Number of TEE applications submitted in 2018 36
Figure 4-1: Number of interventions in Italy in the civil sector in 2018 divided by type of incentive mechanism........ 38
Figure 4-2: Number of interventions and incentives delivered in Italy in 2018 divided by type of incentive mechanism..... 38
Figure 4-3: incentive interventions involving the thermal coat promoted in 2018 by Ecobonus and Thermal Account 38
Figure 4-4: Distribution of Ecobonus, Thermal Account and White Certificates in number in 2018........ 39
Figure 4-5: Distribution of Ecobonus, Thermal Account and White Certificates as a percentage in 2018 39
Figure 4-6: Number of Interventions vs. Investments in 2018 - Ecobonus........ 40
Figure 4-7: Investments (Mil€) in 2018 - Ecobonus 40
Figure 4-8: Number of Interventions Vs average investment in 2018- Ecobonus 40
Figure 4-9: Number of interventions in 2018- Ecobonus........ 40
Figure 4-10: Energy savings in 2018- Ecobonus 41
Figure 4-11: Energy savings (MWh) in 2018 - Ecobonus........ 41
Figure 4-12: Additional cost to rase the energy class level from A1 to nZEB........ 43
Figure 4-13: Heat generators sold in 2011-2018 in Italy........ 45
Figure 4-14: Heat generators sold in 2018 in Italy........ 45
Figure 4-15: Distribution of fuels and plants in Italy........ 45
Figure 5-1: Cumulative cash flow........ 52
Figure 5-2: IT tool working phases 55
Figure 5-3: PFAM Flow Chart 57
Figure 5-4: Front of the building used for the case-study........ 59
Figure 5-5: Comparison between quasi-steady vs dynamic method........ 59
Figure 5-6: Comparison between quasi-steady vs dynamic method considering realistic operating conditions......... 59
Figure 6-1: Building views 65
Figure 6-2: The developed BIM Energy Model........ 66
Figure 6-3: Montlhy primary energy demand........ 67
Figure 7-1: Building front view........ 80
Figure 7-2: Geometric data and significant tables 81
Figure 7-3: Construction system with disposable formworks........ 82
Figure 7-4: Photovoltaic plant of 42 kW + 15 x 3 kW installed on the roof. 82
Figure 7-5: Section across the cavedium for the placement of technological networks 82
Figure 7-6: Left side ot the thermal power plant (the right side is symmetrical) 83
Figure 7-7: Technological network inside the cavedio........ 83
Figure 7-8: Left side ot the technological network allocated through the false ceiling........ 83
Figure 7-9: Monthly thermal energy needs of the building from dynamic analysis 85
Figure 7-10: Electricity consumption for condominium services [kWh] 85
Figure 7-11: Electricity required from the building and produced by the photovoltaic plant........ 85

Figure 7-12: Subdivision of costs 87
Figure 7-13: Architecture of a BA plant 88
Figure 8-1: Effect of barriers on the decision-making process of investing in an EEM. 101
Figure 8-2: Barriers to energy efficiency – average values 101
Figure 8-3: Involvement of different categories of actors in the energy efficiency decision-making process 101
Figure 9-1: Monthly volume in Italy for words related to Queries. 104
Figure 9-2: Ownership of the sites dealing with energy requalification 106
Figure 9-3: : Pages type dealing with energy requalification 106
Figure 9-4: : Pages type & Ownership of the sites dealing with energy requalification 106
Figure 9-5: : topics that commercial sites deal with 106
Figure 9-6: Average SERP position of the contents based on the site to which they belong 106
Figure 9-7: Monthly visits in the energy renovation Price Comparator sites 107
Figure 9-8: Monthly visits in the commodity Price Comparator sites 107
Figure 9-9: funnel marketing framework 108
Figure 11-1: Platform's home page 117
Figure 11-2: Screenshot ot main menu 118
Figure 11-3: The platform's Software architecture 120
Figure 11-4: Formidable form front-end example 122
Figure 11-5: WP Table table and chart example 123
Figure 11-6: AM Charts library based graphical example 1 - Electrical consumption monitoring system 123
Figure 11-7: AM Charts library based graphical example 2 - Electrical consumption monitoring system 124
Figure 11-8: Economic-financial parameters and incentives input form 127
Figure 11-9: Economic-financial parameters and incentives output 128
Figure 12-1: Horizontal angle, α 142
Figure 12-2: β = vertical overhang corner; γ = horizontal overhang corner 142
Figure 12-3: Hourly profile of the two components of the heating/cooling load for a typical day 146
Figure 12-4: The Utilization Factor for the winter period 147
Figure 12-5: The Utilization Factor for the summer period 148
Figure 13-1: Boiler efficiency relationships 161
Figure 13-2: The normal distribution of Gauss 171
Figure 14-1: Example of a label for an energy performance certificate 175
Figure 14-2: representation of exposure factors 185
Figure 14-3: Self-consumption in Italy in 2017 187
Figure 14-4: Annual self-consumption by Italian region in 2017 188
Figure 15-1: The reference case for RRE real application: the Town-Hall 192
Figure 15-2. Screenshot of RRE input data # 1 – geometric data: Town-Hall case 193
Figure 15-3: Geometry of the Test Building 197
Figure 15-4. Screenshot of the RRE of the Test Building input data 198
Figure 15-5: DSS-RRE model Accuracy Assessment: Test Building – monthly values 199
Figure 15-6: DSS-RRE model Accuracy Assessment: Test Building – Annual values 200
Figure 15-7 Town-Hall: CAD representation used in the BIN analysis 202
Figure 15-8: Town-Hall: Heat demand – graphs 204
Figure 15-9. Screenshot of RRE input data # 2 – requalification work: Town-Hall case 206
Figure 15-10. Screenshot of RRE input data # 3 - economic-financial data: City-Hall case 207
Figure 15-11. Building data 208
Figure 15-12. Cost and profitability 209
Figure 15-13. Comparison between energy consumptions and operating costs 210
Figure 15-14. Results in detail: Status quo 211
Figure 15-15. Results in detail: The benefits of the energy efficiency intervention 212
Figure 15-16. Results in detail: Climate system operating data 213
Figure 15-17. Results in detail: Heating data analysis 214
Figure 15-18. Results in detail: Cooling data analysis 215
Figure 15-19. Results in detail: Finance 216

Index of Tables

Table 1-1: Primary Energy Consumption in the EU in 2017 in Mtoe 11
Table 3-1: Comparison of PNIEC objectives and results achieved to 2018 by the incentives currently in force in Italy. 29
Table 3-2 Example of Tax Credit Transfer 34
Table 3-3 Financial costs for buying Ecobonus 34
Table 3-4: The real cost of the Tax Credits Transfer 35
Table 5-1: Typical factors governing the funding available through the regional and natonal incentives 54
Table 5-2: Main feature of the “New Thermal Account 2.0” 58
Table 5-3: Summary of obtained results in term of energy consumption 60
Table 5-4: : Investment alternative scenarios exploiting the “New Thermal Account 2.0” 61
Table 5-5: Incentives obtainable through the “New Thermal Account 2.0” (VAT included) for the Case Study 61
Table 5-6: New Thermal Account 2.0” Incentives for Climatic Zone E and requalification in Energy Class B 63
Table5-7: “New Thermal Account 2.0” Incentives for Climatic Zone E and requalification in *nZEB* 64
Table 6-1: Replacement of the heat generator only 69
Table 6-2: Case of application of the external thermal coat and replacement of the windows 69
Table 6-3: Cash flow calculation and profitability 70
Table 6-4: calculation of cash flows and profitability in the case of Ecobonus 73
Table 6-5: comparison of costs and economic-financial results for the case study 74
Table 6-6: Comparison between traditional and nZEB intervention 76
Table 7-1: Summary of the building costs 80
Table 7-2: Electricity consumption for private use and condominium services 86
Table 7-3: photovoltaic plant installed horizontally on the roof of the building 86
Table 7-4: Incentives and duties related to BA in Italy 89
Table 7-5: BA regulations based on the scope of application 89
Table7-6: Analysis of the building's functions 90
Table 7-7_A: Function analysis uni en 15232 92
Table 7-8_B: Function analysis uni en 15232 93
Table8-1: le barriere al mercato dell’efficienza energetica nel settore civile. Barriers to the adoption of EEMs 100
Table8-2: The decision-making model for building energy requalification 102
Table9-1: Statistics on the use of internet and social media in the world, in Europe and in Italy. 103
Table10-1: BIM and BA impact on the decision-making model for building energy requalification in Table8-2 113
Table10-2: DM and DSS impact on the decision-making model for building energy requalification in Table8-2 114
Table 11-1: Comparison between DSS-RRE and other similar already available platforms 130
Table 12-1: Definition of winter heating period 133
Table 12-2: Construction element transittance values 138
Table12-3: air exchange depending on type of use 138
Table 12-4: Values of gains depending on the type of user 141
Table 12-5: Exposure factor for glazed surfaces: Table 20 of the UNI / TS 11330-1 144
Table 12-6: Total solar energy transmitting values for normal incidence used, Prospetto B.5 dell’ UNI/TS 11330-1 144
Table 12-7: Reduction Factors for Certain Tent Types 144
Table 12-8: Reduction factor for mobile shielding, Prospectus 21 UNI-TS 11300 - 1 144
Table 12-9: Thermal capacity per casing surface unit, Cm (Source: UNI TS 11300-1:2008) 149
Table 12-10: Values of regulation, emission and distribution efficiencies 151
Table 12-11: Standard wall 153
Table 12-12: Mediocre wall 153
Table12-13 Standard roof covery 154
Table 12-14:Building elements mediocre coverage 154
Table 12-15: Standard ground slab construction elements 155
Table 12-16: mediocre concrete slab floor vs. land 155
Table 12-17: Standard window door technical features 156
Table 12-18: Standard window technical features 156
Table 12-19: Poor window door technical features 157
Table 12-20: Poor window technical features 157
Table 13-1: Output temperatur Tp as function of the season and of the conditioning system 159
Table 13-2: Minimum Performance Values for Water Heat Generators, DPR 74/2013 161
Table 13-3: Minimum Performance Values for Water Heat Generators 162
Table 13-4: Minimum performance coefficient values (GUE) for gas heat pumps 162
Table13-5: *GUE* Robur gas heat pump 163
Table 13-6: Minimum performance coefficient values (COP) for electric heat pumps 165
Table 13-7: heat pump full load performance data - Original Figures 166

Table 13-8: Corrective air/water heat pump coefficient for CR = 100% 168
Table 14-1: Primary energy conversion factors 177
Table 14-2. Thermal end electric yearly demand for a building 177
Table 14-3: standard technologies of the *reference building* 178
Table 14-4; Energy Class for Buildings 179
Table 14-5 Limit values of the global average thermal exchange $\boldsymbol{H'T, lim}$ coefficient 180
Table 14-6: Limit values for the ratio between equivalent summer solar area and building useful area 180
Table 14-7: Average efficiencies of the subsystems used by the *reference building* for services of H, C, W 181
Table 14-8: Average efficiencies of the *reference building* thermal generation subsystems 182
Table 14-9:indexes to describe energy efficiency performance according to nZEB requirements 183
Table 14-10: implemented $\boldsymbol{F} \propto$ values 185
Table 15-1 Alternative selections for RRE input data # 1 194
Table 15-2: Geometric relationships in the RRE geometrical building model 196
Table 15-3: DSS-RRE model Accuracy Assessment: Test Building - Numeric values 199
Table 15-4 Town-Hall: Heat demand – Numeric results 203
Table 15-5. APE building class in the redevelopment works for the Town-Hall 217
Table 15-6 Synthesis of the alternative redevelopment works for the Town-Hall 218
Table 16-1: Simple renovation of the facade vs. renovation of the facade with a thermal coat 222

1 Preface

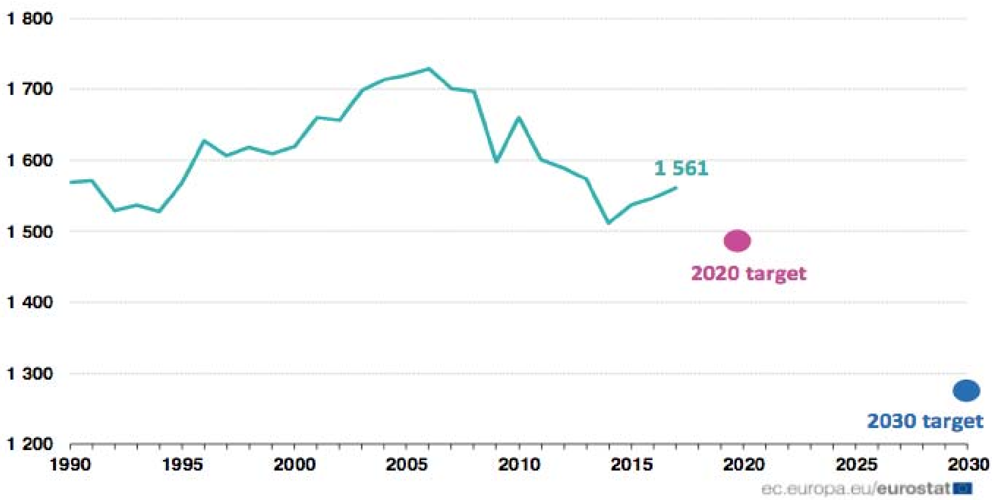
1.1 Digitalization and energy renovation of buildings

Almost on a daily basis we are informed about catastrophic meteorological phenomena all over the world apparently connected to the climate change and caused by global warming. Almost the totality of the scientific community states that these extreme events are due to the excessive production of CO_2 resulting from the use of fossil fuel used in the energy production industry (Cox, Betts, Jones, & Spall, 2000).

Following the agreements of Kyoto protocol signed in the 1997 and with the directive 2009/29/EC, the European Union (EU) committed itself to reduce its primary energy consumption by 20% by 2020, i.e. not more than 1'483 Mtoes (The EU Parliament and the Council of EU, 2009). Subsequently, with the Paris Agreement in 2014, the international community reviewed the objectives of the Kyoto Protocol, by setting the more challenging goal containing global warming within 2°C compared to pre-industrial levels. As a result, the EU has set the goal of reducing primary energy consumption to 1,273 Mtoes by 2030 (Paris Agreement, 2016) .

On the contrary, however, the Table 1-1 points out that energy consumption has steadily increased in the EU from 2015 to 2018, which it apparently makes it impossible to achieve the goals set (Eurostat, Energy consumption increased by 1%, Gap to energy efficiency target for 2020 continued to widen, 2019).

Table 1-1: Primary Energy Consumption in the EU in 2017 in Mtoe



Source: (Eurostat, Energy consumption increased by 1%, Gap to energy efficiency target for 2020 continued to widen, 2019)

In order to reverse the trend, the EU believes that a significant contribution to achieve the objectives can be provided by the energy renovation of buildings for civil usage (residential and tertiary segment). In fact, energy consumption for air conditioning in buildings represents around 40% of total consumption (Odyssee-mure, 2019) and has a high potential for reduction due to age and inefficiency of the existing building stock (Dall'O, Belli, Brolis, Mozzi, & Fasano, 2013).

Moreover, air-conditioning is not linked to the production of wealth, unlike for the industrial production, but represents a real source of waste that can be significantly reduced with proper insulation of buildings and with the use of more efficient heating and conditioning plants, preferably totally or partially powered by renewable energy such as, for example, through electric heat pumps powered by photovoltaic systems installed on site.

For these reasons, the European Directive 31/2010/EC introduced the concept of nearly Zero Energy Buildings (*nZEB*) and requires that all newly built public buildings, starting from 2019, be built in compliance with specific energy consumption limits. This obligation is also extended to private buildings starting from 2021. In addition to the requirements of excellent thermal insulation, these buildings also require that the energy demand should be met by very efficient systems, mainly powered by renewable sources on site (The EU Parliament and the Councile of the EU, 2010).

With the DLGS of 4.06.2013, Italy has fully implemented the European Directive by extending the application also to the renovation of existing public and private buildings (Ministero Economia e Finanza, 2013). Furthermore, in order to support the achievement of these energy efficiency objectives, the national government has issued a series of regulations that consistently reduce the cost of the intervention through various incentives.

Currently the energy efficiency market in buildings is experiencing an interesting growth: in between 2015 and 2018, in Italy annual investments rose up to +7%, for a total amount of €4.3 billion Euros (Energy & Strategy Group, 2018). On the other hand, less than 10% of the 400'000 incentivized interventions concerned a renovation including the envelope (see Chapter 4). In the vast majority of cases, these are often isolated interventions (boiler change, window changes, etc.), which are certainly not sufficient to satisfy the nZEB requirements, as well as to grant a consistent energy saving.

At this regard, the nZEB market has yet to be deciphered: the 2013 decree merely introduced the definition, while only two Regions (Lombardia and Emilia Romagna) anticipated the time to apply the standard, then there are few data about it. Anyway, from 2015 to date (ENEA, 2018) and (Energy & Strategy Group, 2017) estimated no more than 1'400 nZEB buildings (Italian real estate stock amount to 13 million), of which only 130 derived from the renovation of existing ones.

The renovation of the whole building-plant system is not important only to reduce emissions, but it is also necessary to facilitate the transition to the electrification of buildings: indeed, only well-insulated buildings allow a capillary widespread diffusion of technologies such as electric heat pumps. The latter, if combined with photovoltaic energy produced on site, would make possible to permanently switch from the natural gas energy production for heating and domestic hot water (DHW) purposes. Currently, however, the evidence shows a ratio of at least eight natural gas boilers installed for each heat pump.

Typically, in order to make the renovation of buildings attractive (and in particular the global renovation compliant with nZEB requirements) a crucial role is entrusted to the development of more effective financing and incentive methodologies.

On the other hand, If correctly used, available incentives are able to cut costs up to 50-70%: this is useful to make the overall profitability of the interventions acceptable (PBT = 8-10 years), but probably not enough to resolve all the remaining barriers. At the same time, it is not possible to state that incentives should finance all the interventions entirely.

In order to make the renovation projects attractive it is still necessary: 1) to lower construction costs by using innovative design methods, materials and systems; 2) to further optimize the management costs (and management easiness); 3) to increase market awareness to showcase the greater value in terms of energy efficiency, comfort and safety.

In this sense a key role can be covered by the "Digitalization".

According to what is reported in the synthetic formalism of a dictionary (Wikipedia): "digitalization is the conversion process which, applied to the measurement of a physical phenomenon, determines the passage from the field of continuous values to that of discrete values. This process is now commonly summarized in terms of the transition from analog to digital ".

Simplifying this concept, digitalization in the construction sector is today synonymous with "*design and management of processes through the widest sharing of information in electronic, organized and processable form"* .

The term collects numerous approaches and trends, but in recent years the construction sector is experiencing a growing interest specifically in 3 aspects related to this topic:

1. Building Information Modeling (BIM), in order to optimize design and construction phase;
2. Building Automation (BA), in order to optimize the management of the building, verify the correspondence between the project and the actual use and provide additional integrated services;
3. Digital Marketing, in order to increase awareness, culture and education about economics and non-economic benefits of renovations.

This thesis aims to study the impact that Digitalization (understood as Building Automation, BIM and Digital Marketing) can have on the barriers of building energy renovation market and, eventually, to give a contribution in breaking down some part of them.

To achieve this goal, the first and second part of the thesis adopts a transversal technical, economic and financial approach to deepen the current criticalities through market research and some case studies. Then, the third part develops an original research study which resulted in a digital tool capable of identifying, first of all, a correct engineering solution and, at the same time, assessing its economic valuation, taking into account all existing forms of incentives and financing. Among the points of greatest interest, the speed and ease of use that allows to drastically reduce the time of execution of an analysis (from a few days to minutes) and the possibility of use even by non-experts.

1.2 The multi-disciplinary approach of the thesis

For over 30 years researchers have been wondering about the so-called "Energy Efficiency Gap", that consists in the significant difference between the potential of existing energy efficiency and the interventions that are actually carried out (Hirst & Brown, 1990) (B.Jaffe & N.Stavins, 1994). This phenomenon is due to the fact that the energy efficiency market is characterized by a significant number of barriers, which greatly limit its diffusion (Sorrell, Mallett, & Nye, 2011).

It is due to the huge complexity of energy renovation process: this complexity derives from its extremely transversal nature, which requires different skills and sensibilities.

Firstly, engineering skills are needed: these competences do not only concern a specific area (i.e. energy consumption), as it is necessary to take into consideration also structural, architectural and plant aspects.

In addition, it is also necessary to consider the fundamental importance of the economic-financial aspects: sustainability cannot in fact refer only to environmental issues, since any requalification intervention requires a certain financial sustainability to be pursued.

As extensively discussed during this thesis, the technical and economic issues are strongly linked: just think of the impact that a technical standard imposed to contain the building consumption can have on the costs of the project and, therefore, on its profitability, especially if the consequent increase in comfort is not adequately assessed in the business plan.

This complexity also has repercussions on how potential (non-technical) customers perceive the opportunities associated with a renovation projects: to make the benefits of renovation more appealing, it is necessary to study immediate and easy-to-understand communication methods able to draw the attention of the mass market.

The more interesting aspect of this thesis precisely lies in this very multidisciplinary approach, that is typical of management engineering discipline in which this research project is developed.

1.3 The thesis' structure

In light of the above, different types of activities have been carried out during my PhD:

1. market analysis, in which it has been tried to identify future developments of renovation market;
2. applied research, in which innovative technical design methods and financial analysis tools were applied in three different case studies.
3. finally, the research included the development of an innovative web platform meant to: a) carry out informative and training function, in order to spread awareness and knowledge about energy renovation opportunities; b) Develop web tools able to provide technical support to the decision-making process of customers and technicians.

Similarly, the thesis resumes all such activities into three parts.

The **1st Part** of the thesis aims to provide a detailed analysis of the Italian market. This overview has been elaborated cross-checking seven different documents/reports published by six different national agencies. The objective is to provide an in depth description of the Italian real estate assets in terms of number, types of buildings and consumptions, and to subsequently compare it with the main national energy strategy, in terms of incentives and obligations that has been planned to reduce the energy consumption for the next decade.

More specifically:

- **Chapter 2 *The composition of Italian real estate assets*** analyzes the Italian real estate segment, cross-checking the data about buildings (ISTAT, 2011), House Units (Agenzia delle Entrate, 2018) and consumptions (Odyssee-mure, 2019). It shows that condominiums and tertiary represent the most relevant targets, as they are responsible for 29% of national consumptions (more than the industry segment), while they represent only 14% of total buildings. These consumptions are mainly due to heating and air conditioning;
- **Chapter 3 *Economic incentives for buildings renovation*** reports an analysis about the Italian energy strategy contained into the PNIEC (National Integrated Plan for Climate and Energy), from which is evident that Ecobonus[1] will continue to be the most important incentive mechanism for the renovation of private buildings, while the so-called "New Thermal Account[2]" is the only mechanism dedicated to the renovation of public buildings;
- **Chapter 4 *The results of Italian incentive policy*** shows that current mechanisms are mainly adopted to incentivize single interventions with poor energy results, while they struggle to encourage more energy-savings interventions (thermal coat interventions or nZEB renovations).

[1] Ecobonus (see chapter 3) is the incentive plan dedicated to private buildings with which it is possible to carry out any type of intervention to make energy consumption more efficient, from just replacing the heat generator to the complete renovation of the building. The incentive is granted as tax deductions to all taxpayers who are subject to income tax of private persons (IRPEF) or legal (IRES) for renovations of their property

[2] The New Thermal Account 2.0 (see chapter 3) is an incentive mechanism that has two main purposes: a) Disseminating technologies based on the use of renewable sources among businesses and private subjects (ie private persons, condominiums, business owners), encouraging the creation of small plants for the production of thermal energy; b) Supporting Public Administrations to carry out interventions to increase energy efficiency (building envelope and heating systems), as well as the production of thermal energy from renewable sources.

The **2nd Part**, instead, is characterized by a more practical approach. The goal of this section is on one hand to apply innovative design methods, on the other hand to test the new incentives that the Italian Government is making available to enhance current supporting mechanisms. In light of the previous market analysis, the case studies concern the renovation of a public office building, the renovation of a condominium and the new construction of an nZEB condominium. In particular:

- **Chapter 5** ***Renovation of the public buildings stock: the role of New Thermal Account 2.0 and EPCs*** presents a new methodology for the design of renovation interventions: the innovative aspect resides in the integration, in a single methodology, of existing models and techniques used to evaluate the feasibility of renovation projects, by taking into account both technical, regulatory and financial aspects. This methodology is then applied in a real case study (a medium size public building) to analyze the impact of the recent nZEB regulation and the role of New Thermal Account and Energy Performance Contracts in this type of intervention;
- **Chapter 6** ***Renovation of private buildings: the effectiveness of Ecobonus*** reports a case study aiming to analyze the Ecobonus mechanism on the renovation of a typical Italian condominium and the impact of the so-called "Transfer of Credit", i.e. the possibility of transferring the tax deduction linked to the Ecobonus to suppliers who have carried out the renovation;
- **Chapter 7** ***New nZEB buildings: the impact of BIM design and Building Automation*** shows a third case study related to a newly constructed nZEB residential building; the objective is to present an innovative building system entirely designed in BIM in order to optimize design and construction costs through the integrated design and the industrialization of the construction site. This system also allows the reduction of management costs through the use of a Building Automation system, whose impact in terms of cost/benefit will be studied;
- **Chapter 8** ***The barriers of the energy renovation market*** based on the results of the previous 3 case studies, propose an analysis of the current barriers of the energy efficiency market, focusing on the importance of the decision-making process in renovation projects. More specifically, a new decision-making model was developed in order to describe the decision-making process based on 3 different end-users. The analysis highlights the fundamental role performed by lack of awareness and education;
- **Chapter 9** ***The WEB to break down the barriers of awareness and knowledge*** discusses the potential of spreading informative content through the web channel in Italy, reporting the study conducted to assess the interest shown by users through the analysis of searches on "Google.it" for building energy efficiency related topics.
- **Chapter 10** ***Actions necessary to strengthen the energy efficiency plan*** draws the general conclusions of the second part.

In this analysis is shown that the informative content available online is useful in the early stages of awareness generation, to make users aware of the possible opportunities that the renovation market can offer. However, the energy renovation of a building requires specialized technical skills that a potential customer does not possess and that he cannot hope to acquire simply through informative contents, without a solid technical background.

From here, the need to develop a Decision Support System (DSS) able to simultaneously analyze all the main problems related to the intervention (from the technological choice to the financial cost) using the various specialist calculation procedures.

In light of the above, the **3rd Part** presents the DSS developed in this research which aims to make up for the lack of qualified information and provide a single platform, accessible to all, able to accompany the decision to perform energy efficiency interventions.

Chapter 11 ***The developed Decision Support System (DSS) platform*** presents the architecture of the platform and the technological choices used for software development. Currently, the portal has three main functions:

1. Carry out informations and training functions able to spread awareness of the opportunities for energy upgrading of buildings, highlighting both their economic and environmental benefits.

2. Provide analysis tools able to support, from the early stages of the decision-making process, the main technical, economic and financial issues.

3. Technical and economic dimensioning of energy efficiency interventions by providing a turnkey cost for the supply and installation, taking into account the tax incentives.

This involved, among other things, the development of numerous fast calculation tools that required a considerable study to simplify the engineering analysis used in the design practice and make them sufficiently simple to use and accurate in the results.

Of interest, from an engineering point of view, is the procedure that was developed to:

1. first calculate the thermal energy demand of a building
2. and, therefore, identify the interventions necessary to reduce energy consumption required by the thermal generator for satisfying the energy demand,

3. then, determine the cost to carry out the energy efficiency intervention and the economic savings obtained from it;
4. and, finally, to evaluate the best economic-financial strategy for the realization of the intervention.

Regarding this last point, technical and economic aspects are closely related because the economic convenience varies according to:

- the cost of the plant, depending on the size and the ancillary costs (installation, auxiliary components...), which often represent more than half of the costs;
- baseline energy costs, that are function of level of comfort, building characteristics, climatic data operation of the system, ….;
- future energy costs, that are function of technologies adopted, sizing, ….;
- and incentives, that are function of awareness of the designer, awareness of the customer, costs for fulfilling the practices, ….

The calculation of profitability therefore requires non-trivial technical assessments, which often are not conducted in the early stages of drawing up a project due to the high costs they require (assuming that technicians are able to carry them out correctly - Chapter 8).

For this reason, it was considered essential that the DSS allowed, in addition to sizing the solutions, also to calculate the main profitability indicators mentioned above (NPV, IRR, PBT), considering:

- the turnkey cost of the interventions, which is calculated on specific market analyzes carried out starting from literature data and/or with the development of specific price lists developed in collaboration with installers and technology suppliers;
- all the incentives currently available in Italy, including those discussed and tested in Chapters 5 and 6 and of which there is still no consolidated literature (e.g. Transfer of Credit);
- the possibility of financing the residual part of the interventions through bank financing, as discussed in particular in Chapter 6.

All the applications concerning the air conditioning of buildings present in the DSS-RRE platform use a single calculation procedure to determine the Thermal Requirement and, therefore, the Energy Consumption required to satisfy it. This procedure fully complies with the quasi-steady method UNI/TS 11300 as adopted by the current Italian legislation listed in Section 12.2. However it contains the following important peculiarities:

a. Drastic reduction of input data so as to allow an easy and immediate use of the application even by privy users without any particular knowledge of thermotechnics.
b. Full implementation of the method also to the Summer period for cooling.
c. Integration on time based on the "*bin hourly method*" instead of the conventional method based on the monthly average air temperature.
d. Coupled calculation Electric Heat Pump with Photovoltaic Electric Generation System.

All this is documented in the following Chapters:

Chapter 12 *The thermal energy demand of a building* reports the method enforced by the UNI TS 11300 to calculate the heat requirement necessary to maintain constant comfort the climate conditions over time. This documentation work was initially conceived only to indicate the assumptions that made it possible to drastically reduce the data to be provided to the calculation. It turned out to be a complete description and, apparently, simple and essential, to the entire "quasi-steady" theory. If this were confirmed, it would be in itself a result by no means trivial, considering the difficulty of finding a complete and easy reference on the subject.

Chapter 13 *The energy consumption of the climate generator* describes the mathematical method for calculating the Energy Consumption required by the heat generator to meet the Thermal Energy demand of the building. Of interest is the comparative description between the standard Monthly Based Method contained in the UNI TS 11300 and the more innovative BIN Hourly Based Method. In particular it is mathematically proved that:

- The monthly values of the Energy Demand calculated by the two methods (monthly and hourly time integration) are mathematically identical;
- In the general case of thermal generators with variable efficiency as a function of the external temperature, the two methods must necessarily calculate different values of the Energy Consumption and those obtained with hourly-time discretization must be considered more accurate. In the particular case of thermal generators with constant efficiency, the two methods coincide.

Chapter 14 *Towards the nZEB building* provides the technical requirements necessary for a building to be qualified as nZEB , highlighting that, in addition to an excellent thermal insulation, it is necessary that at least half of the energy still required is produced on site and renewable. For this purpose, according to the recent PNIEC (National Integrated Plan for

Climate and Energy), one of the most interesting solutions in the residential field is to combine a heat pump with a photovoltaic system. For this reason it was considered essential to develop an algorithm able to:

- calculate the heat pump and the photovoltaic coupled system,
- determine the achievable Energy Class,
- compute the installation and, then, the operating costs.

Chapter 15 ***The validation of the DSS-RRE model*** aims to demonstrate the reliability in the calculations and usefulness of the RRE-simulator. For this purpose we have studied both simple cases, in which it is possible to precisely verify the mathematical accuracy of the results, and a very complex real case of restructuring a historic building. For this real case, the project was extended to reach the nZEB level with the use of a heat pump powered electrically by a photovoltaic system.

From the comparison with other certified specialist softwares available on the market, it turned out that the calculation procedure UNI TS 11300 is correctly implemented and, despite the significant simplification of the input data, If properly used, the model applied to complex project can obtain results very close from those calculated with the complete theory.

This is extremely interesting if we consider that these results can be obtained by “non-technicians” with a few minutes of work while to obtain the exact results (according the complete UNI TS 11300 theory) with other specialist SW it took about 5 work-days of a specialized technician. Furthermore, the results provided by the RRE-simulator are not limited to those strictly technical engineering, but also provide an analysis of the costs and the profitability of the investment.

Chapter 16 ***Conclusions and future developments*** reports the conclusions and the future developments of this research work.

1.4 Acknowledgments

"È un segno di mediocrità quando dimostri la tua gratitudine con moderazione".

[R.Benigni]

Nel 2015, quando consegnavo la tesi magistrale, scrivevo:

"Caro Dario del futuro, quando tra qualche anno rileggerai la tesi che in questi ultimi mesi ti ha preso così tanto, spero che sarai rimasto simpatico, diventato ricco e tornato magari un po' più in forma, ma, soprattutto, spero che ti sarà rimasta la riconoscenza verso chi, fino ad oggi, ti ha accompagnato in questo percorso bello, lungo, sicuramente difficile e, a meno di incredibili sfighe nella presentazione, a lieto fine….".

In questi 5 anni credo di essere rimasto simpatico, non sono diventato ricco, ma sono certamente più in forma. Ma più di tutti, sono orgoglioso di poter dire che nel mio percorso personale e professionale continuo ad essere accompagnato da persone eccezionali che non mancano mai di sostenermi ed ispirarmi, ai quali riserverò sempre la mia più sincera gratitudine.

Innanzitutto ritengo doveroso ringraziare e dedicare questo traguardo a chi davvero lo ha reso possibile, ovvero mio padre Amintore, per il suo imprescindibile apporto e per averci creduto più di tutti.

Un infinito grazie ai miei *Supervisor*, i Professori Marco Marengo e Davide Chiaroni, per l'eccezionale contributo, competenza e disponibilità che mi hanno riservato.

Ringrazio i due Referee del lavoro, i Professori Claudio Del Pero e Secondo Rolfo per le preziose revisioni alla Tesi e tutta la Faculty di Bergamo e Pavia per il percorso di questi anni.

Ringrazio ovviamente tutta la mia famiglia, e in particolare mia mamma Lisa e mio fratello Fabio per il supporto incondizionato e per esserci sempre.

Ringrazio di cuore e con il cuore Elena, che non mi ha lasciato nemmeno durante tutti i mesi in cui, per scrivere questa Tesi, non sono stato certamente simpatico come mi sono definito all'inizio. Anche a lei una dedica speciale, con la speranza di poter condividere insieme tutti i nostri futuri traguardi personali e professionali.

Infine un ringraziamento a C.Malvasi, per la sua encomiabile fibra morale, per me continua fonte di ispirazione.

1st PART

2 The composition of Italian real estate assets

2.1 Introduction

The energy consumption of a building change significantly depending on the use: for this reason, the reports relating to energy consumption of a country/region usually subdivide it based on the type of use, i.e. residential, tertiary, industrial. For example, the (Odyssee-mure, 2019) project, created by the EU to monitor trends and policies on energy efficiency, shows consumption divided by use for all European countries. However, these type of reports rarely contain an in-depth description of the real estate assets responsible for such consumption.

As known, real estate stock consists of **buildings** which could be made up of several real estate **housing units** (HU). By definition a housing unit is one of a house, residential apartment, office, mobile home, group of rooms or single room that is occupied or intended as separate living quarters. The separate living quarters that define a housing unit are those where the occupants live and eat, or work, separately from other residents in the structure or building, and have direct access from the building's exterior or through a common hallway.

A building can therefore be composed of HU with different intended use (residential or/and tertiary) and, consequently, with very different energy consumption. The knowledge of the real estate stock, in terms of both buildings and their HU composition, is essential to define and understand the effectiveness of any initiative (public or private) in the buildings renovation matter.

In the Italian case, the publicly available data does not immediately make evident how real estate stock is set up. On the one hand, a series of databases and extracts deriving from the 2011 census are available online (ISTAT, 2011) in which, however, only information about the buildings are reported, while there are no indications related to their HU composition. On the other hand, annual reports of the "*Revenue Agency*" (Agenzia delle Entrate, 2018) reports data concerning only about housing units, while there are no indications relating to the buildings they belong to.

In this Chapter, a cross analysis of the aforementioned sources is presented: in particular, it is shown that condominiums and tertiary represent the strategically most relevant targets, as they are responsible for 29% of national consumption (more than industry), while they represent only 14 % of total buildings. These consumptions are mainly due to heating and air conditioning.

2.2 Real estate consistence

Figure 2.1 reports the results of our analysis performed of the data based on the latest report published by the "*Revenue Agency*"[3] (Agenzia delle Entrate, 2018). It appears that the Italian building stock consists of 68,286,430 real estate units, of which:

A. 59% (or about 40 million) are Housing Units (HU), where for HU we mean a real estate unit dedicated to the non-occasional presence and which therefore needs heating to ensure comfort during human activities, such as homes, shops, offices, hospitals etc

B. the remaining 41% is made up of Service Units such as garages, cellars, appliances, etc.

The HU in A for the vast majority (87%) belong to the residential sector and the remaining to the tertiary sector (10%) and industry (3%), being the share regarding the public administration practically negligible, Figure 2-2.

As previously mentioned, different type of HU can belong to the same building but this information is not available in the published data. To make an estimation, we notice that from the last ISTAT[4] census (ISTAT, 2011) reported in Figure 2-3 that the buildings reach a total of 14'515'795.

Specifically, the number of residential buildings amounts to about 12 million: in particular, defining a building with more than 4 HU as a "Condominium", residential building are divided as shown in Figure 2-4 according to the number of HU contained in them.

Hence, from the data in Figure 2-4 **and** Figure 2-5**, it appears that the residential housing units are 17'317'886, distributed in 1'431'019 buildings. With regard to the entire Italian building stock,** Figure 2-6 **and** Figure 2-7 **show that condominiums represent 43% of Housing Units and 10% of buildings.**

Finally, Figure 2-8 shows the subdivision of the buildings of the tertiary sector by intended use: they essentially consist of Shops, Workshops and Laboratories (69%), Offices (17%) and commercial buildings (6%).

[3] The Revenue Agency (or "Agenzia delle Entrate") is an agency of the Italian public administration dependent on the Ministry of Economy and Finance which performs the functions related to tax assessments and controls and to the management of taxes.

[4] The National Statistical Institute (Istat) is an Italian public research institution. Its activities include: population censuses; censuses on industry, services and agriculture; sample surveys on families; economic investigations.

Figure 2-1: Real estate unit in Italy

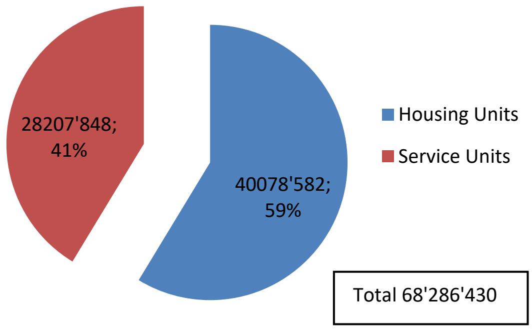
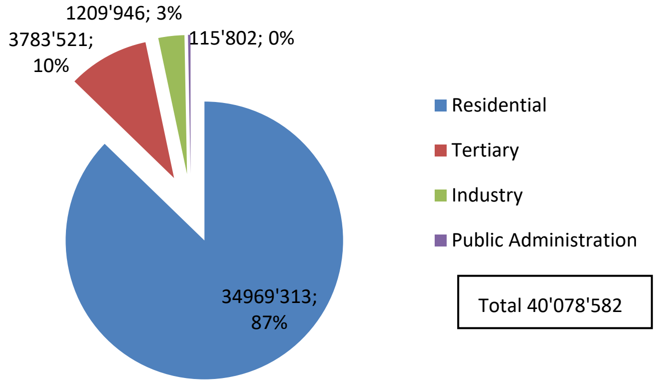
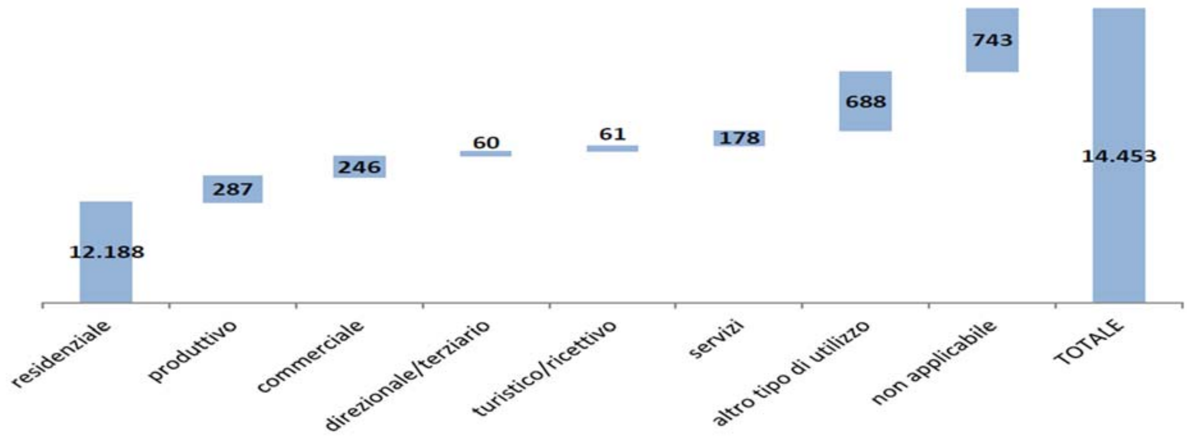


Figure 2-2: Housing Unit in Italy



Source: Data Processing from (Agenzia delle Entrate, 2018)

Figure 2-3 Italian real estate park, for use in thousands of buildings



Source: (ISTAT, 2011) – Original Figure

Figure 2-4: Residential buildings in Figure 2-3

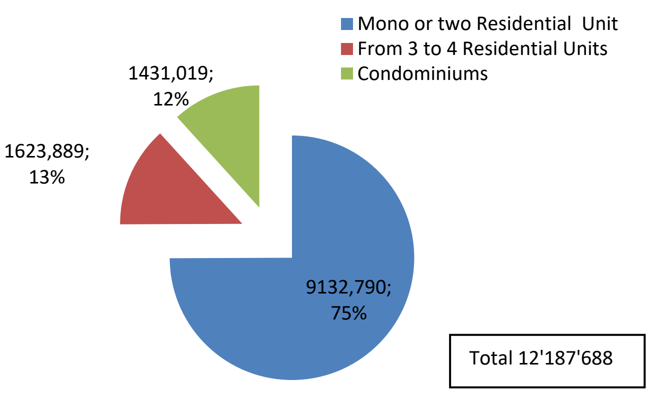
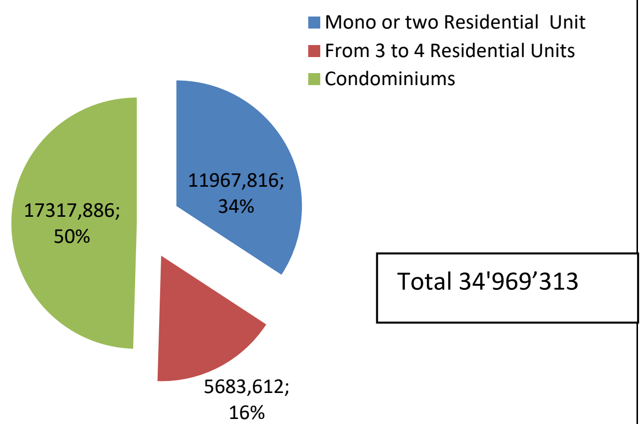


Figure 2-5: Residential Housing Units in Figure 2 2



Source: Data Processing from (ISTAT, 2011) and (Agenzia delle Entrate, 2018)

Figure 2-6: Housing Units types In Italy

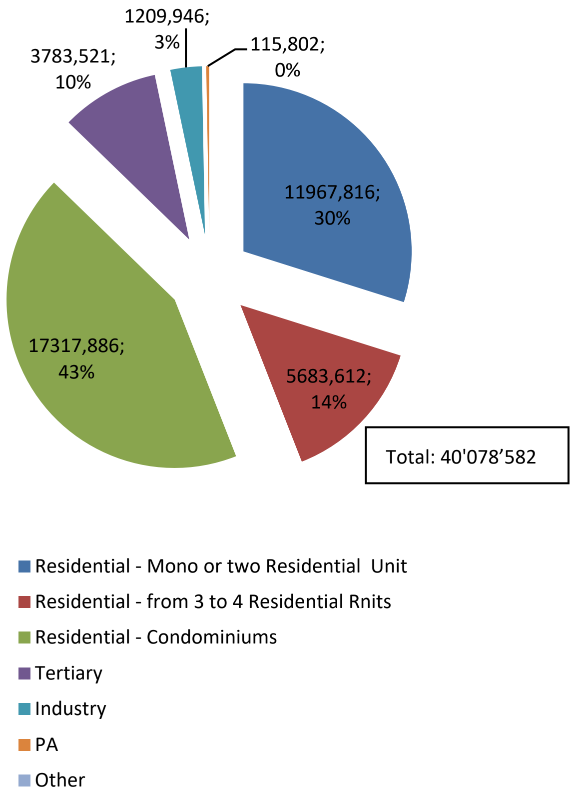
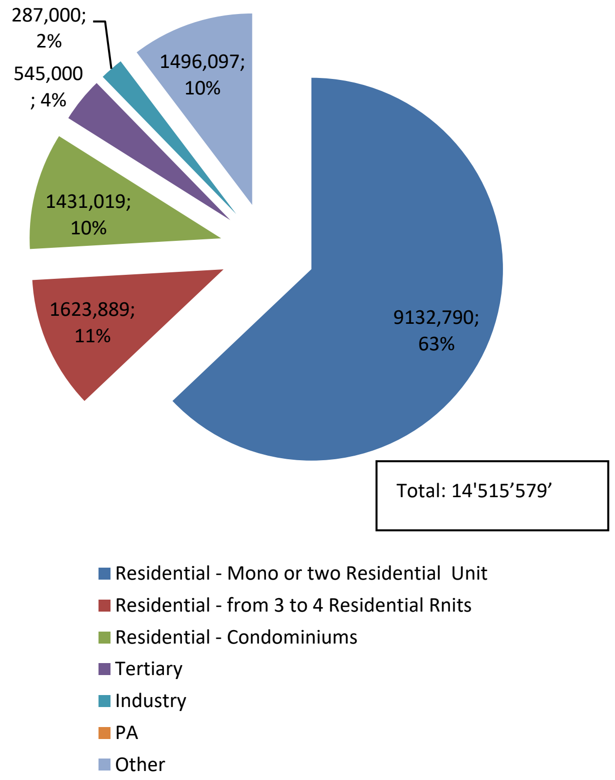
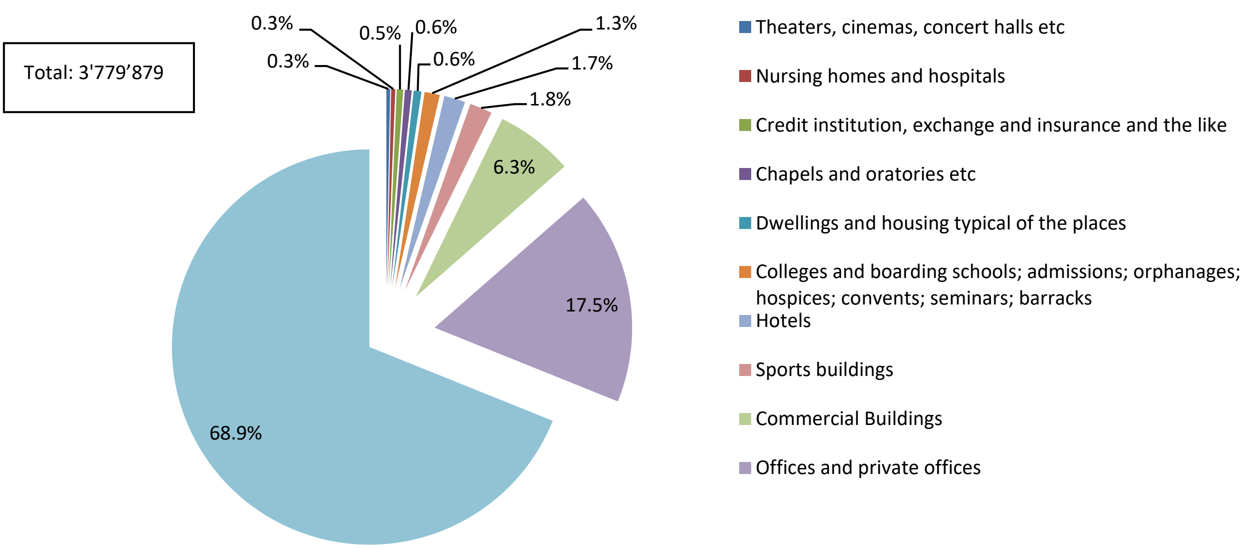


Figure 2-7: Buildings type in Italy



Source: Data Processing from (Agenzia delle Entrate, 2018) and (ISTAT, 2011)

Figure 2-8: Tertiary buildings. 2018

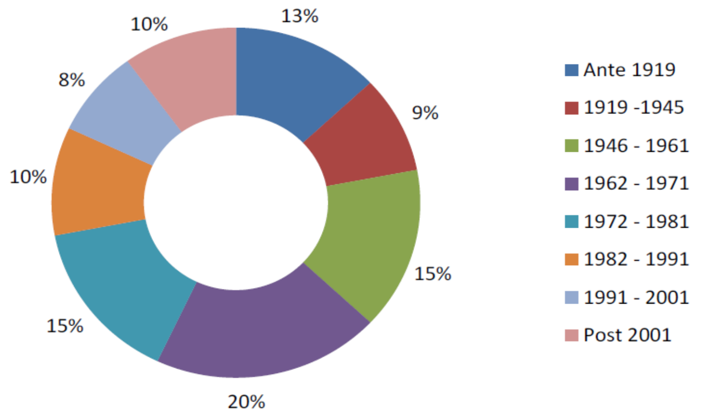


Source: Data Processing from (Agenzia delle Entrate, 2018)

2.3 Real estate heritage and Energy Classification

Still taking the data from the ISTAT 2011 census, Figure 2-9 shows that around 60% of the buildings were built before 1976, the year in which the first legislation on energy saving was introduced.

Figure 2-9: Dwellings in residential buildings for the time of construction.

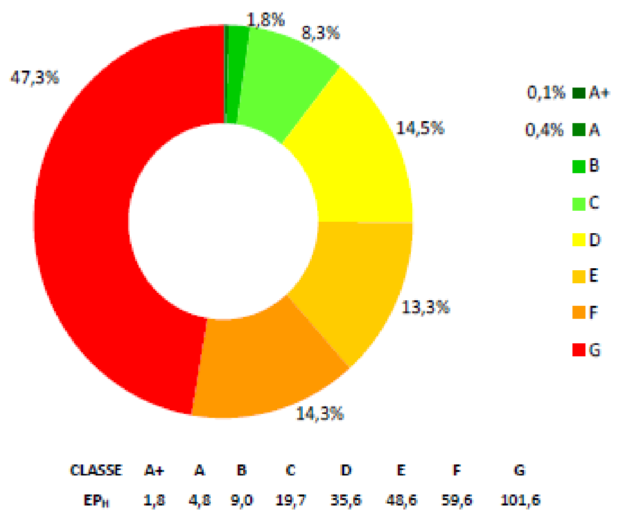


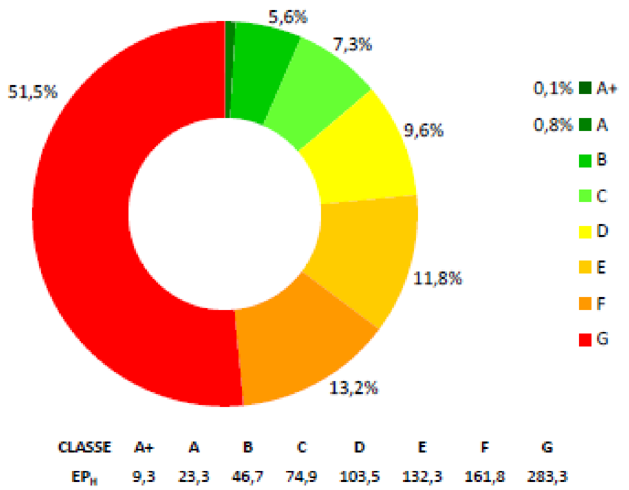
Source: ISTAT 2011 census

This would suggest that the energy performances of these buildings is much poorer than the standards now required by the European directives. In fact, from the register of energy certificates of CENED (Regione Lombardia, 2012), it results that half of the buildings in Lombardia (the richest region of Italy, and therefore probably with the best maintained real estate) presents the worst Energy Class (Figure 2-10 and Figure 2-11), according to the criteria defined by the European legislation contained in 2002/91 / CE and implemented in Italy by legislative decrees n. 192/2005 and n. 311/2006 (now updated by Ministerial Decree 15 June 2015 based on directive 2010 / 317EU).

Figure 2-10: Non-residential buildings | **Figure 2-11: Residential buildings**

Distribution of ACEs by Energy Class and average EPH value expressed in kWh/mq





Source: (Regione Lombardia, 2012)

2.4 Current energy consumption

In order to provide a complete monitoring of energy consumption, trends and energy efficiency policies for all member countries, the EU has created the Odyssee-Mure project (Odyssee-mure, 2019). Taken from the results of this project, Figure 2-12 shows that energy consumption has slightly decreased in the last 25 years.

Figure 2-12: Final energy consumption by sector in Europe in 2000 and 2015 in Mtoe

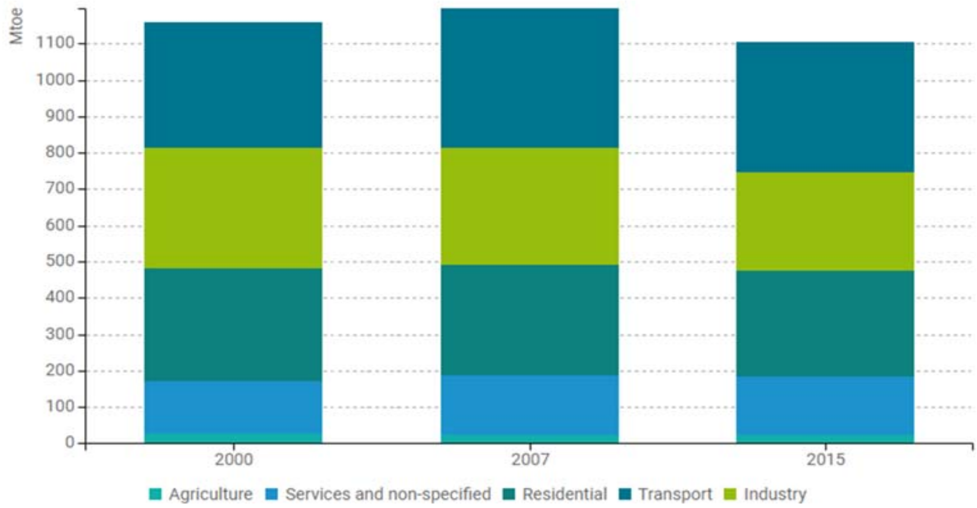


Figure 2-13: Energy consumption in Europe in 2000

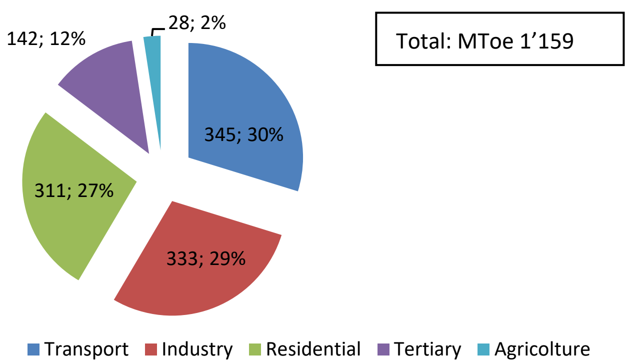
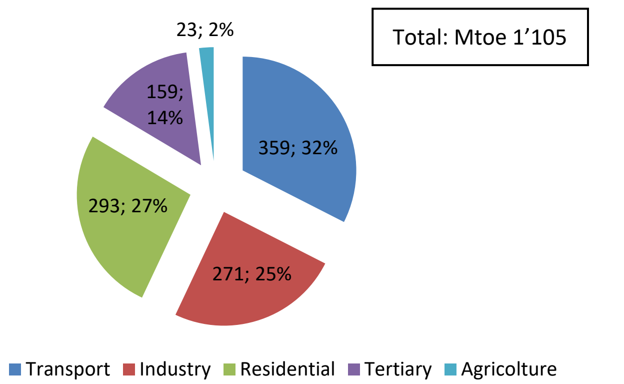


Figure 2-14: Energy consumption in Europe in 2015



Source: (Odyssee-mure, 2019)

Figure 2-15: Energy consumption in Italy 2000

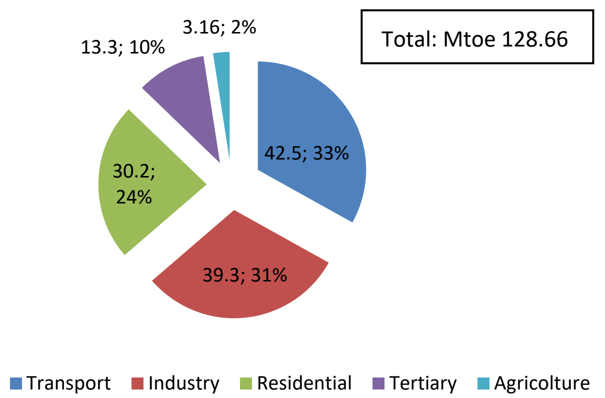
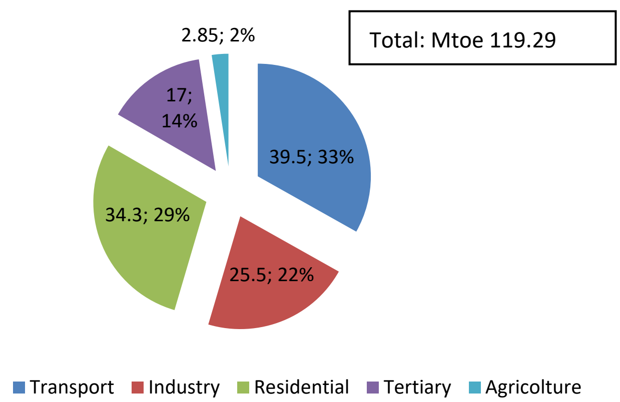


Figure 2-16: Energy consumption in Italy 2015



Source: (Odyssee-mure, 2019)

However, Figure 2-13 and Figure 2-14 show that the reduction in consumption is attributable only to industrial sector while that linked to the civil sector remained constant: in particular, the residential sector dropped from 311 to 293 Mtoe (-6%), while the tertiary sector raised from 142 to 159 Mtoe (+ 12%). Today the energy consumption of buildings for civilian use in Europe covers 41% (= 27% residential + 14% tertiary) of the total.

Figure 2-15 and Figure 2-16 show that Italy has had a similar trend over the last 15 years, with a reduction of the total energy consumption due entirely to the industrial sector while the civil sector has increased significantly (+ 18%). In particular, the residential sector has increased from 30.2 to 34.3 Mtoe (+ 14%) e the tertiary sector has increased from 13.3 to 17.0 Mtoe (+ 28%). Currently Italy has a consumption distribution quite similar to the European average, where the civil sector covers 43% (= 29% residential + 14% tertiary) of the total.

Then, relating the data in Figure 2-16 **with those reported in** Figure 2-7**, it results that 14% of the buildings (condominiums = 10% + tertiary = 4%) accounts for 29% (tertiary= 14% + condominiums = 14,5%) of the entire national consumption, i.e. more than the entire industrial sector.**

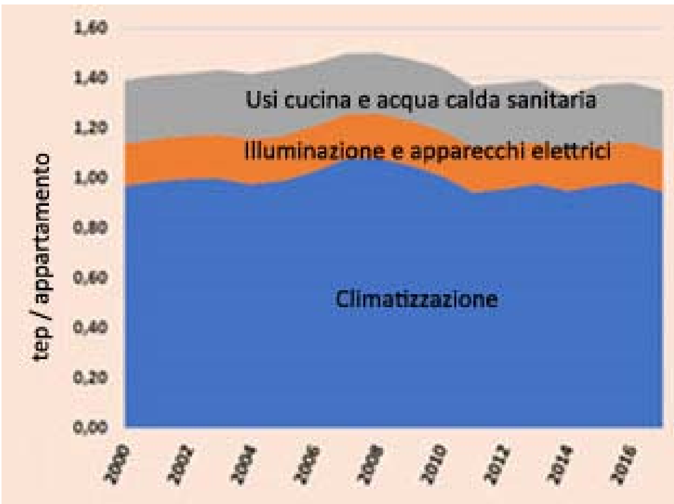
In buildings for civilian use, air conditioning represents the most part of energy consumption:

- in residential buildings Figure 2-17 shows that it covers about 70% of total consumption;
- In the buildings of the tertiary sector, it stands at around 50-57%, as lighting and, above all, the possible presence of server rooms or data centers take on greater importance. (ENEA & Assoimmobiliare, 2018).

It is of interest to note from the Figure 2-18 that the electricity consumption in the tertiary sector is higher than in the residential one (35% vs. 22%): this is because in addition to a greater consumption due to lighting and server rooms, air conditioning is mostly produced with electrically powered appliances (such as heat pumps, chillers, etc.) so as to serve both for heating and cooling. On the other hand, air conditioning in the residential sector is mainly for heating and the systems used are almost all boilers powered by hydrocarbons.

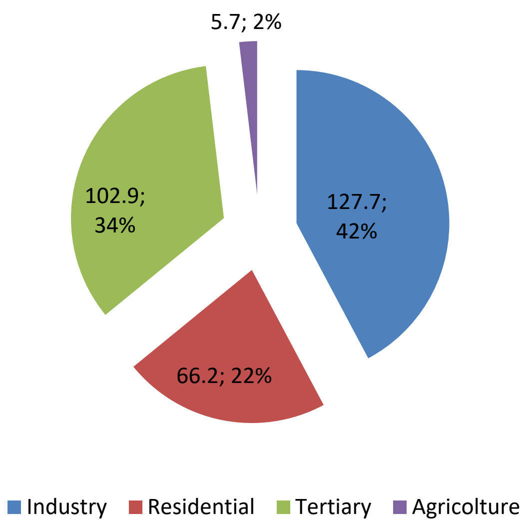
From this analysis it is therefore evident that the consumption reduction necessarily involves the renovation of the condominiums and the tertiary buildings, with the aim of reducing the need due to air conditioning.

Figure 2-17: Energy consumption in the residential sector



Source: (ENEA, 2019) - Original figure

Figure 2-18: Electricity consumption by sector in Italy (TWh) – 2015



Source: (TERNA, 2016)

3 Economic incentives for buildings renovation

3.1 Introduction

By 31 December 2019, each EU country are required to send to the European Commission a Plan containing the objectives and measures for the decade 2021-2030, with which it undertakes to contribute to the reduction of global warming in compliance with the obligations signed with the protocol of Paris (Paris Agreement, 2016).

In December 2018, the Italian Government sent the first Proposal of the so called PNIEC (Integrated Energy and Climate National Plan), with which it has been decided to confirm and strengthen all the incentives currently in force (Ministero dello Sviluppo Economico, 2018): Ecobonus, New Thermal Account and White Certificates.

In this Chapter an analysis of the PNIEC objectives is proposed, focusing on those related to energy efficiency in civil use buildings.

The analysis has been carried out by cross checking the data indicated in the PNIEC with the historical data collected and published ENEA and GSE, ie the two government agencies that manage the incentive mechanisms. The main purpose is to evaluate the expected results in terms of energy savings and capital allocations for the period 2021-2030 with the results achieved so far.

From this study, it appears that the Ecobonus will continue to be the most important incentive mechanism for the renovation of private buildings, while the New Thermal Account will be mainly dedicated to the renovation of public stock.

Furthermore, a detailed description of each of the available incentives is given, with particular attention to some mechanism recently introduced to favor the dissemination of interventions both on private and public building stock.

3.2 The commitment of EU member states

In the absence of public incentives, investments in the energy renovation market are mostly not profitable in strictly financial terms.

This is because the price of energy takes into account correctly only the real cost substained by the industry for its production and transport, while the environmental damage is not adequately considered (Bergh & Botzen, 2015).

Taking into account only the economic savings due to the lower bill cost , the renovation involves costs repayable in more than 20 years, especially if the project also involves the application of the thermal coat: this is what is already widely known in the literature and that will be widely discussed especially in the first two case studies addressed in this thesis reported in Chapter 5 and 6. But a correct economic analysis should also take into account the considerable collective benefit that a redevelopment is able to produce since it can reduce the introduction of harmful gases into the atmosphere by more than 70%.

The public policies therefore represent the necessary compensation for this gap: the Governments, through taxation on energy consumption, on the one hand can discourage the excessive use of energy and, on the other, creates the economic resources in support of those who undertake to reduce environmental damage by reducing its consumption. For this reason Art. 7 of the EED Directive (2012/27/EU) commits all Member States to introduce in their legislation a mandatory national energy efficiency and/or alternative policy measures (incentives or taxes).

Most EU countries have introduced a combination of mandatory efficiency schemes and alternative measures, such as:

- Energy or carbon taxes;
- Financial instruments or tax incentives;
- Voluntary regulations or agreements;
- Standards and rules;
- Labeling and diagrams, compliant with the EU Framework Directive on labeling 2010/30 / EU and the principle of the EU energy label, which establishes the requirements for energy-related products

Most of the measures (40%) proposed by the various member states are of financial nature, mainly in the form of grant schemes and low-interest loans (ENEA, 2019).

3.3 PNIEC - The Integrated Energy and Climate National Plan

In December 2018, as before mentioned in the introduction of this Chapter, Italy sent to the European Commission the first Proposal of the Plan - Integrated Energy and Climate National Plan (PNIEC), currently in public consultation, with which, the Italian Government commits itself to confirm and strengthen all the incentives currently in force (Ministero dello Sviluppo Economico, 2018):

- Ecobonus, already active for 11 years;
- New Thermal Account 2.0, already active for 6 years;
- White Certificates, (also known as TEE) already active for 13 years;
- National Energy Efficiency Fund (FNEE) not yet operational.

There are also various other types of incentives made available by local authorities (Regions, metropolitan cities) in the form of calls, some of which can also be combined with other forms of incentive. Normally, part of their economic endowment derives from contributions made directly by the European Community through specific programs, that aim to stimulate the various local realities in order to identify energy improvement paths based on their territorial, cultural and productive realities.

Specifically, with the PNIEC Italy aims to obtain energy savings for about 54 Mtoes, of which 14 Mtoes for the transport sector only while for the remaining 40 Mtoes it is expected the distribution reported in Table 3-1 and illustrated in the following figures:

- Figure 3-1: in terms of sector, about 85% of savings is expected from the Residential and Tertiary sectors, i.e. from uses mainly related to air conditioning of buildings; at the same time the industrial sector is not considered to have significant margins of intervention;
- Figure 3-2: in terms of incentive mechanisms, the main incentive source will be the Ecobonus, closely followed by White Certificates, and finally to a much lesser extent by Thermal Account and FNEE.

Table 3-1 it has been created by cross checking PNIEC data and those published by ENEA and GSE for the purpose of comparing the results in terms of energy savings and allocations expected by the new PNIEC for the period 2021-2030 with the results achieved so far.

Figure 3-3 and Figure 3-4 seem to suggest that the calibration of expectations was correctly carried out on the basis of the results obtained so far, placing more trust in the incentive channels that have been most successful.

Undoubtedly, the Ecobonus was the most used incentive in private buildings and, with the improvements introduced in the last few months and dealt in the next Section, it is reasonable to share the predominant role given by the PNIEC. Just as it is reasonable to share the noticeable expectations placed on the Thermal Account considering the fact that in the 2018 it has been an increase in requests equal to 122% of those received in previous years (2013-2017), as reported in Table 3-1.

On the other hand, the expectation placed on TEEs is not easily justifiable, since after a significant initial success, today it appears rather stagnant, probably due to problems linked to a recent revision of the incentive allocation mechanism. In addition, it is not immediately simple to understand the fact that, despite an expectation that triples the energy savings achieved so far, the funds provided appear to have been drastically reduced.

The National Fund for Energy Efficiency (FNEE) is the only incentive mentioned in the PNIEC that is not yet operational: it is a revolving fund, with the dual purpose of granting guarantees on individual financing transactions and granting loans at subsidized rates. It can be combined with other incentives and therefore aims solely to facilitate access to credit for the residual part of the intervention cost.

In addition to the aforementioned incentives, other measures are currently in force, mainly aimed at encouraging generic investments for industries: they can therefore also be used to finance Energy Efficiency Interventions.

Among these measures, the most important are:

- Super-amortization and iper-amortization: these are incentives aimed at supporting companies that invest in new capital goods, in tangible and intangible assets (software and IT systems) functional to the technological and digital transformation of production processes.
- Sabatini Law: this is a measure supports investments financing part of the interest due to credit institutions.

Unfortunately, at the moment, there are no official sources able to attest the performances obtained so far: for this reason the following analysis does not include the.

Table 3-1: Comparison of PNIEC objectives and results achieved to 2018 by the incentives currently in force in Italy.

TEE (White Certificates)	Type of incentive	White certificates (TEE) issued by the Energy Markets Operator (GME) in favor of individuals who achieve energy savings of 1 TEE / 1 TOE
	Present value	Convertible title in the specific market (stock exchange) of the TEE: currently about € 260 / TOE (Source: GME)
	Main beneficiary	Industry (Source: PNIEC)
	Allocated resources 2021-2030	6.83 Bln€ (Source: PNIEC)
	Estimate of mobilized investments 2021-2030	13.7 Bln€ (Source PNIEC)
	Expected savings period 2021-2030	15.02 Mtoe (Source: PNIEC)
	Expected cost 2021-2030 period	0.5 Bln€/Mtoe (Source: processing data PNIEC)
	Incentives paid 2007-2017	7 Bln€ (Source: ENEA
	Investments mobilized for 2007-2017	12 Bln€ (Source:ENEA)
	Savings obtained 2014-2018	5.335 Mtoe (Source: ENEA)
	Average cost obtained	0.5 Mtoe (Source: ENEA)
	Number of Interventions in 2018	0
	Incentives paid in 2018	ND
Ecobonus	Type of incentive	Incentive calculated as a percentage of the investment cost and disbursed in the form of tax relief
	Present value	House Unit: 50% ¸65% cost of the intervention
		Condominiums 70% ¸ 75% cost of the intervention
	Main beneficiary	Residential (Source: ENEA)
	Allocated resources 2021-2030	45.4 Bln€ (Source: PNIEC)
	Estimate of mobilized investments 2021-2030	82.5 Bln€ (Source PNIEC)
	Expected savings period 2021-2030	18.15 Mtoe (Source: PNIEC)
	Expected cost 2021-2030 period	2.5 Bln€/Mtoe (Source: processing data from PNIEC)
	Incentives paid 2007-2017	20.5 Bln€ (Source: ENEA)
	Savings obtained 2014-2018	1.13 Mtoe (Source: ENEA)
	Average cost obtained	1.12 Bln€/Mtoe
	Number of Interventions in 2018	334'369
	Incentives paid in 2018	2.1 Bln€ (+0.1% compared to 2018) (Source: Processing data from ENEA)
New Thermal Account	Type of incentive	Contribution calculated as a percentage of the investment cost and disbursed in the form of a capital payment
	Present value	Up to 65% intervention cost
	Main beneficiary	Residential and Public Administration
	Allocated resources 2021-2030	7.5 Bln€ (Source: PNIEC)
	Expected savings period 2021-2030	3.85 Mtoe (Source: PNIEC)
	Expected cost 2021-2030 period	1.9 Bln€/Mtoe (Source: Processing data from PNIEC)
	Incentives paid 2007-2017	0.5 Bln€ (Source: GSE)
	Savings obtained 2014-2018	0.156 Mtoe (Source: ENEA)
	Average cost obtained	2.67 Mtoe (Source: ENEA)
	Number of Interventions in 2018	0
	Incentives paid in 2018	0.3 Bln€ (+98% compared to 2018) (Source: Processing data from GSE)
National energy efficiency fund	Type of incentive	The Fund has a revolving nature and is divided into two sections that operate for the granting of guarantees on individual financing operations and the provision of subsidized loans.
	Present value	Guarantee on financing up to 80% of the cost and / or fixed rate mortgage 0.25%
	Main beneficiary	Companies, ESCO and Public Administrations
	Allocated resources 2021-2030	0.9 Bln€ (Source: PNIEC)
	Expected savings period 2021-2030	2.75 Mtoe (Source: PNIEC)
	Expected cost 2021-2030 period	0.3 Bln€ /Mtoe (Source: Processing data from PNIEC)
	Incentives paid 2007-2017	0
	Savings obtained 2014-2018	0
	Average cost obtained	0
	Number of Interventions in 2018	0
	Incentives paid in 2018	0

Source: data processing from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019) (ENEA, Rapporto Annuale Efficienza Energetica, 2019) (GSE, Rapporto attività 2018, 2018) (GSE, Rapporto annuale Certificati Bianchi, 2018) (Ministero dello Sviluppo Economico, 2018)

Figure 3-1: Expected savings 2021-2030 in Mtoe by sector

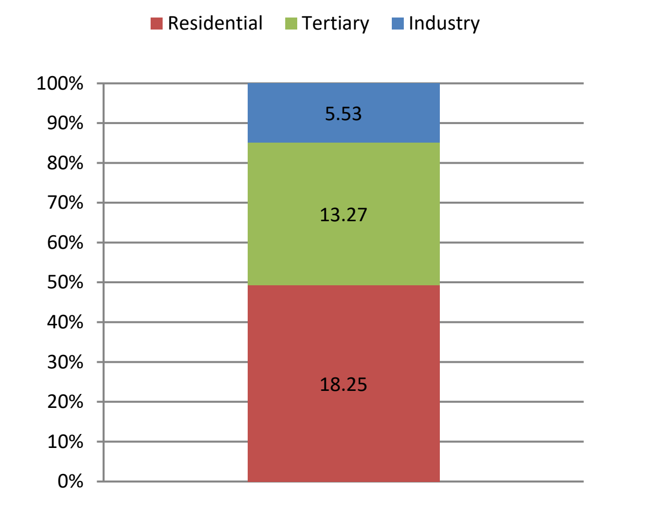


Figure 3-2: Expected savings 2021-2030 in Mtoe by incentives

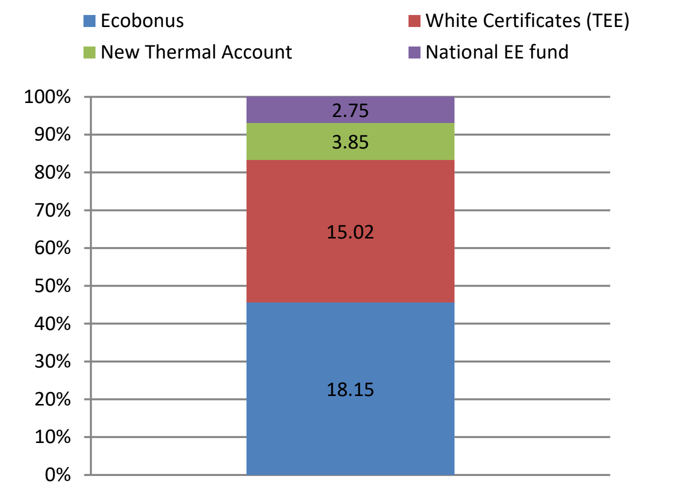


Figure 3-3: Comparison of expected savings for the period 2021-2030 and savings obtained for the 2014-2018 period

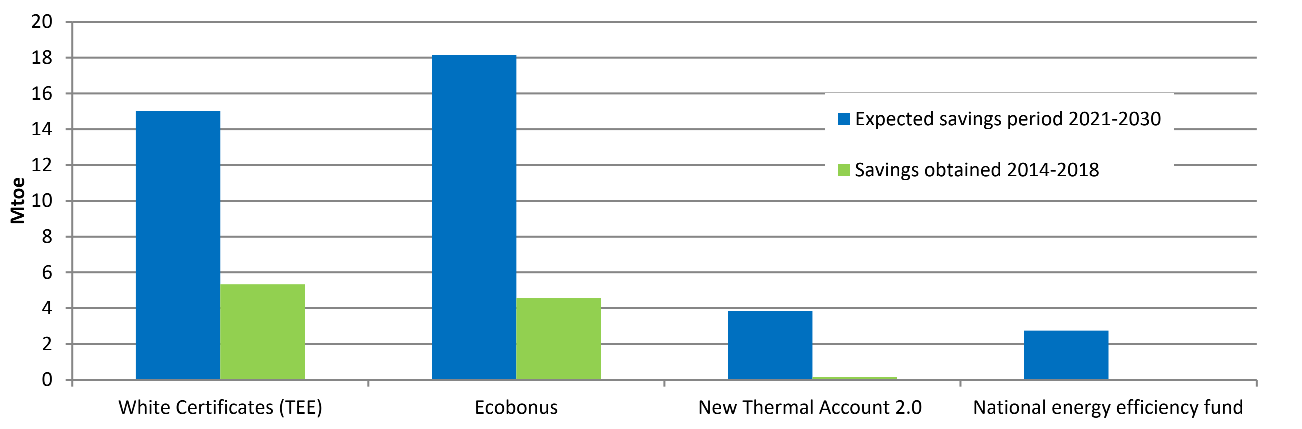
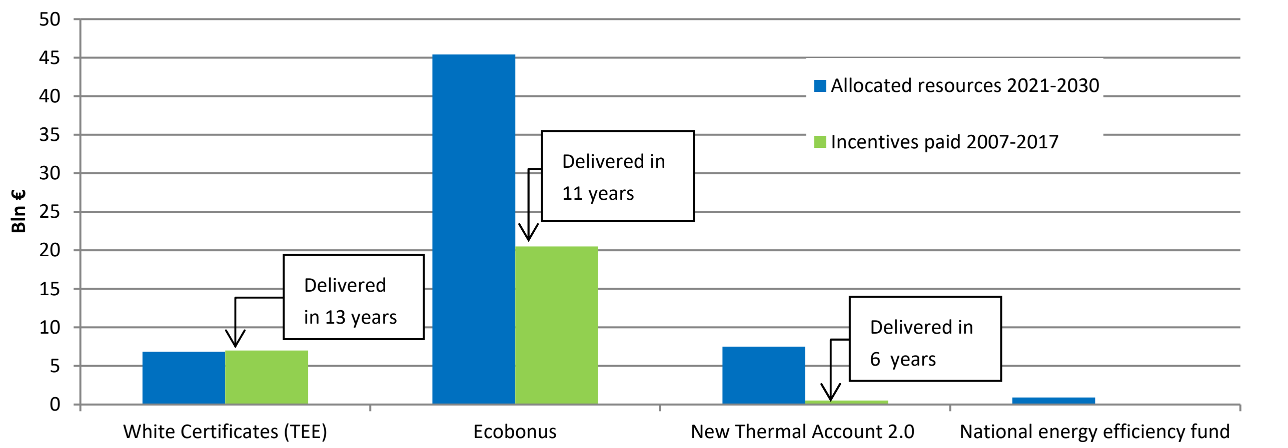


Figure 3-4: Comparison of allocated resurces 2021-2030 (source: PNIEC) and incentives deliverd (source: ENEA, 2019)



Source: data processing from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019) (ENEA, Rapporto Annuale Efficienza Energetica, 2019) (GSE, Rapporto attività 2018, 2018) (GSE, Rapporto annuale Certificati Bianchi, 2018) (Ministero dello Sviluppo Economico, 2018)

3.4 New Thermal Account 2.0

The New Thermal Account 2.0 has two main purposes:

1. To support technologies based on the use of renewable sources among businesses and private subjects (ie private persons, condominiums, business owners), encouraging the creation of small plants for the production of thermal energy.
2. To support Public Administrations to carry out interventions to increase energy efficiency (building envelope and heating systems), as well as the production of thermal energy from renewable sources.

The amount of the incentive varies from 40% to 65% depending on the type of intervention carried out, and specifically:

a) up to 65% for the renovation in nearly zero-energy buildings (*nZEB*);

b) up to 40% for wall insulation and roofing interventions, for the replacement of fixtures with more efficient ones, the installation of solar shading, the replacement of lighting bodies, the installation of technologies building automation and the replacement of traditional boilers with condensing boilers;

c) up to 50% for thermal insulation interventions in E/F climate zones and up to 55% if combined with the replacement of the heating system (condensing boiler, heat pumps, solar thermal);

d) up to 65% for the replacement of traditional systems with heat pump systems, boilers and biomass appliances, hybrid heat pump systems and solar thermal systems.

For companies and private persons, the incentive is limited to the interventions reported in point 1 regarding the replacement of pre-existing thermal energy plants with others powered by renewable sources, while the Public Administration has the entire range of possibilities available.

Similarly to Ecobonus, the Thermal Account also sets a limit on the incentive payable for each type of intervention. Unlike the Ecobonus, the Thermal Account also provides for a maximum limit to the unit cost that can be incentivized.

On the basis of the provisions of the new Thermal Account 2.0 (DM 16.02.2016 and DM 186/2017), the fund is fuelled by a government allocation of 900 million euros per year, of which 700 for private individuals and companies, while the remaining 200 for public administrations, the privates or social cooperatives and public heritage companies.

In general, incentives are paid as follows:

- For amounts up to € 5,000 the incentive is paid in a single instalment disbursed within 90 days of the date;
- For higher amounts the incentive is paid in constant annual instalments for a duration of 2 or 5 years, depending on the type of intervention.

For the realization of the intervention, it is possible to use an ESCo (Energy Service Company) through:

- in the case of a private party, the stipulation of an "Energy Service Contract", or "Energy Service Contract Plu"s, or an "Energy Performance Contract".
- in the case of a PA, the stipulation of an Energy Performance Contract (Energy Performance Contract - EPC);

In this case, the ESCO can partially or totally participate in the financing of the intervention, carry out it and be repaid on the basis of a service fee established in the stipulated contract:

A. In an "Energy Service Contract", the user (a condominium, a municipality, a company, etc.) buys an energy service (heating, cooling, etc.) in its entirety. Therefore, the costumer does not buy only the energy carrier (electricity, heat, ...) or the plants that use it: the user pays a fee to the ESCo to cover both the purchase of energy and the actual financing for the purchase of the plant. The contract can last up to 10 years, during which the plants remain in the property of the ESCo. At the end, the user becomes the owner of the systems and can decide whether to manage the plants independently or whether to stipulate a new Energy Service Contract with an ESCo (not necessarily the one with which he has signed the first contract). Legislative Decree 102/2014 introduced the obligation for the contractor to implement energy renovation measures aimed at reducing energy consumption by at least 5%.

B. An "Energy Plus Service Contract" differs from the one indicated above in that it explicitly requires the implementation of energy renovation measures aimed at reducing energy consumption by at least 10% for the first contract stipulation and 5% for any subsequent renewals.

C. In an EPC, the amount of the service fee is calculated according to the amount of energy savings achieved thanks to the improvement in energy efficiency obtained from the intervention carried out.

In cases where the ESCo directly supports the costs of carrying out interventions on buildings of the final customer, and the service contract explicitly provides for it, the incentives can be paid directly to the ESCO to partially cover the loans made by them.

The operational request for the incentives must take place through the GSE, the Italian national agency Agency for Energy Services, and it can be carried out in 2 ways:

1) DIRECT ACCESS: for the interventions carried out by Individuals and Public Administrations, the request must be submitted within 60 days of completion of the works.

   A simplified procedure is possible for interventions concerning the installation of one of the small-sized appliances (for generators up to 35 kW and for solar systems up to 50 square meters) contained in the Catalogue of household appliances, made public and periodically updated by the GSE .

2) RESERVATION: for interventions still to be carried out by Public Administrations and ESCos operating on their behalf, provision of a first deposit on start-up and the settlement on completion of the work.

The booking request must be accepted by the GSE. In this case, the latter proceeds to commit, in favour of the applicant, the sum corresponding to the incentive due.

3.5 Ecobonus

Ecobonus is the incentive plan devoted to private buildings with which it is possible to carry out any type of redevelopment intervention to save energy: from just replacing the heat generator up to the complete renovation of the building. The incentive is granted as tax deductions to all taxpayers who are subject to income tax of private persons (IRPEF) or legal persons (IRES).

These are very relevant incentives which, for example in the case of condominiums, can reach 75% of the costs incurred for interventions for only energy efficiency that, in case interventions reduces also the seismic risk, it can be extended up to 85% (Sismabonus). Specifically, depending on the applicant (individual owner or condominium) and the type of intervention envisaged, the amount of the contribution varies as follows:

1 on individual real estate units or on common parts of condominiums:

   a. 50% for

      - replacing windowed closures with more efficient ones,
      - installation of solar shading and photovoltaic systems;
      - the replacement of traditional boilers with biomass and condensing boilers in class A.

   b. 65% for

      - wrapping insulation interventions,
      - replacement of traditional boilers with heat pump systems and condensing boilers equipped with an advanced regulation system;
      - installation of hybrid heat pump systems, solar thermal systems;
      - installation of micro-generators technologies building automation;

2 on common parts of condominiums:

   a. 70% for insulation interventions of the envelope with an area of more than 25% of the dispersing surface;

   b. 75% for insulation interventions of the envelope as in 2.a and if the intervention is aimed at improving the energy performance both in winter and in summer;

3 80% for insulation interventions of envelope as in 2.a and reduction of a seismic risk class.

4 85% for interventions of insulation of the envelope as in 2.b and reduction of a seismic risk class.

For each type of intervention, the Ecobonus provides a maximum for the payable contribution.

The Ecobonus mechanism requires that the taxpayer first pays in full the cost of the work carried out to the supplier and, based on that, the value of the Ecobonus can be calculated. For each of the following ten years the taxpayer can deduct from the taxes due (IRPEF) up to one tenth of the calculated value of the Ecobonus. In the event that the taxes due by the taxpayer in that year are lower than the share of the Ecobonus, the excess part is lost forever.

This is requirement that has significantly hindered the use of Ecobonus. Technically this requirement is called “fiscal capacity” (capienza fiscale), that is the capability of the taxpayer to reduce the income tax using the Irpef deductions of that year. The case in which the amount of the deductions exceeds the tax due is called “fiscal incapacity” (incapienza fiscale).

Obviously, this mechanism unfavorably affects the less well-off classes and in particular the pensioners, or those who would need it most. In the case of condominiums, however, the consequences extend to all condominiums as the less well-off subjects, being unable to bear the redevelopment costs, block the approval.

3.5.1 Transfer of Tax Credits from Ecobonus

A novelty introduced by Law 205/2017 (fully operational only from May 2018, (Agenzia delle entrate, 2018)) provides, as an alternative to the deduction, the possibility of transferring the corresponding credit to the suppliers who carried out the works. This allows:

1. to overcome any "fiscal incapacity";
2. monetize the incentive immediately (at least in large part) without having to wait 10 years;
3. and, consequently, to significantly reduce the initial capital necessary to carry out the intervention.

Obviously this reduction in initial capital facilitates also the access to bank credit and reduces the financial costs associated with it.

In practice, the "Transfer of the credit" allows the customer to "sell" his incentive to the contractor who, therefore, can discount the agreed price. Clearly purchase price cannot be equal to the entire amount of the deduction as the contractor must take into account the monetary cost due to the anticipation of a capital that will be returned over a period of 10 years.

In this way, all taxpayers, even those who do not have sufficient "fiscal capacity", can benefit from the bonus in cash and in a single solution.

The possibility of assigning tax credits consequently creates the problem of finding who is able to purchase them. In Italy the subjects carrying out energy efficiency works are typically artisans and small businesses and, as such, have a limited fiscal capacity which, in the case of the purchase of the tax credit, quickly runs out with some work contracts.

To aggravate the problem is that many of these subjects are obliged to buy the material to do the job with 22% VAT while, for the legislation in force, they can invoice it to their customers with a VAT reduced to 10% if not 4%. Therefore, they mostly already have tax credits for having anticipated (concretely) the excess VAT and, furthermore, they are often in financial difficulty because the State delays in returning the amount paid in excess.

The law excludes that tax credits can be purchased from financial institutions but grants the possibility to the supplier to transfer them to a subcontractor involved in the service provided that generated the tax credit. However, the latter cannot anymore sell them.

So, those who are actually able to purchase these tax credits are only a few large companies that can retain these amounts from taxes would have to pay to the state anyway as, for example, the withholding taxes for their employees or levied VAT the sale of their products.

Recently DL. 34/2019 (converted into Lgs. 58/2019, 29 June 2019) has introduced new changes to this mechanism which, apparently, provides a further great competitive advantage to large utilities operating in the energy field to the detriment of all other market operators such as ESCO, small-medium enterprises, artisans etc. This has caused a vehement protest by many trade associations (CAN, Angaisa, Confartigianato, Assoclima and Assotermica, Unicmi) and, in November 2019, the Antitrust confirmed that these changes can actually provide a further great competitive advantage to large utilities operating in the energy field to the detriment of all other market operators such as ESCO, small-medium enterprises, artisans etc. Therefore it is expected that the rule will be further modified in the near future.

However, starting from year 2019, various subjects began to propose themselves as final buyers of the Ecobonus Tax Credit. Typically they are large multi-utilities that provide two or more public services such as, for example: supply of water, gas and electricity.

The first major multi-utilities to offer itself concretely on the market for the purchase of tax credits deriving from energy efficiency works was ENI followed, sometime later, by ENEL. Significant is the fact that both have the Italian State as their reference shareholder. More recently, many other multi-utilities have followed their example, gradually forming a real market with differentiated proposals for the purchase of credit.

The reason lies in the fact that more than 60% of their revenues are in fact taxes they collect from their customers on behalf of the State. Therefore the purchase of tax credits results for these companies an extremely advantageous financial means for transferring to the state of these large sums collected on its behalf.

The main differentiating element is the percentage of the value of the tax credit that the buyer recognizes to the transferor. For example, in the case of condominium works for a cost of € 100,000, the cost that the condominiums must actually bear after the assignment of the credit can be calculated as

Table 3-2 Example of Tax Credit Transfer		
A	**Total cost of the work**	100'000 €
	Ecobonus (Tax Credit)	
B1	- Rate on the total cost of the work	70,0%
B2 = A x B1	- Value	70'000 €
B3 = B2 / 10	- Annual refund	7'000 €
	Cost for the purchase of the Ecobonus	
C1	- Commission on Ecobonus value	35,0%
C2 = B2 x C1	- Amount withheld by the buyer	24'500 €
	Revenue for the Ecobonus sale (Tax Credit transfer)	
D2 = B2 - C2	- Value	45'500 €
D1 = D2 / A	- Rate on the total cost of the work	45,5%
D3 = D2 / B2	- Rate on Ecobonus value	65,0%
	Total cost of the work net of the Tax Credit transfer	
E1 = A - D2	- Value	54'500 €
E2 = E1 / A	- Rate on the total cost of the work	54,5%
E3 = (A - E1) / A	- Discount on total cost of the work	45,5%

where C1 is a value established by the buyer to cover his expenses for buying the Ecobonus and, whereby, the seller receives from the buyer the D3 percentage of the Ecobonus nominal value.

3.5.2 The real cost of the Tax Credits Transfer

For the buyer, the purchase of the Tax Credit means, from a financial point of view, an immediate cash outflow equal to D2 followed by 10 annual income of equal value B3. Through the C1 commission the buyer covers the financial cost of this D2 issue and its own operating costs. For example, the C1 commission value shown in Table 3-3 is equivalent to the financial cost that would result from taking out a ten-year mortgage of the B2 value at the interest rate of X1.

Table 3-3 Financial costs for buying Ecobonus		
B2	Ecobonus	70'000
X1	Mortgage Interest Rate	5.87%
X2	Mortgage Duration	10
T1 = f(B2, X1, X2)	Mortgage payment	€ 9'452
T2 = T1 x 10	Capital returned	84'523
	Mortgage financial cost	
T3 = T2 - B2	- Value	24'523
T4 = T3 / B2	- Rate on Ecobonus value	35.0%

From the seller's (condominium) point of view, the tax credit transfer allows an immediate monetizing the tax credit and , thus, a reduction by D2 of the cost A to be incurred for the restructuring. Table 3-4 shows the costs that the condominium should bear in the following two alternating hypotheses:

1. Reference case (indicated as Ref in the Table 3-4). Having fiscal capacity, the condominium solves the problem of paying the restructuring costs by taking out a ten-year bank loan of an amount equal to A and, for the following X2 years, pays the installment of the bank loan and reduces by D2 the payment of its taxes. Financially this means a cash flow lasting X2 years of an annual amount equal to S3, resulting from a constant exit S1 and a constant income S2.
2. Tax credit transfer case. The same as reported in Table 3-2.

Table 3-4: The real cost of the Tax Credits Transfer			
	Case	Ref	
A	Total cost of the work	100'000 €	100'000 €
B2	Ecobonus (Tax Credit)	70'000 €	
D2	Revenue for the Ecobonus sale (Tax Credit transfer)		45'500 €
E1 = A - D2	Total cost of the work net of the Tax Credit transfer	100'000 €	54'500 €
X1	Mortgage Interest Rate	5.87%	5.87%
X2	Mortgage Duration	10	10
X3	Discount rate	2.0%	2.0%
S1 = f(E1, X4, X5)	Annual mortgage payment	13'503 €	7'359 €
S2 = B2 / X2	Annual tax deduction	7'000 €	
S3 = S1 - S2	Total annual cost	6'503€	7'359 €
	Discounted total cost		
S4 = g(S3, X2, X3)	- Value	58'416 €	66'105 €
S5 = S4 – S4(Ref)	- Value increase on case Ref		7'689 €
S6 = S4 / S4(Ref)	- Percentage increase on case Ref		13.2%

The values shown in this Table assume:

A. A bank loan with the same duration and interest rate as the case in the Table 3-3
B. A reduction in the value of money equal to X3 for which the cash flow that will take place in year *t* today has a reduced value equal to

$$S4 = \mathrm{g}(S3, \mathrm{X}2, \mathrm{X}3) = \sum_{t=1}^{X2} \frac{S3}{(1+X3)^t}$$

Hence the real cost of the immediate monetizing of the tax credit is equal to S6..

3.6 White certificate – TTE

Compared to Ecobonus and Thermal Account, TEEs have the following main differences

- they are available to encourage works owned by both private and public subjects;
- access to incentives is allowed for any type of intervention granting energy savings as long as this can be measured with certified instruments;
- incentives can be requested not only to replace existing plants but also to create new ones;
- there is no limits on the payable contribution;
- instead there is a minimum energy saving threshold to be obtained to access the incentive;
- the value of the contribution is based on the actual energy savings obtained;
- The disbursement period is limited to a maximum of 5 years.

The White Certificates are titles that the GSE issues only to subjects accredited by them. A white certificate is equivalent to the saving of a TOE which is equal to the amount of energy released from the combustion of a ton of crude oil and is worth about 42 GJ.

The TEE are negotiable on the Energy Efficiency Certificates Exchange, managed by the Electricity Market Operator (GME) and are therefore subject to fluctuations in this market (Figure 3-5).

The TEE market arises from the obligation imposed by the legislation on electricity and natural gas distributors to annually reach energy efficiency targets, whose entity is calculated for each individual distributor according to its size. These objectives can be achieved both through the direct implementation of energy efficiency projects and the consequent issuing of TEEs, or by purchasing TEE from other subjects. TEEs have a limited validity period (max 5 years): so to maintain a stable offer it is necessary for GSE to promote an adequate number of new projects annually.

Figure 3-5: Average prices of TEE 2006-2017

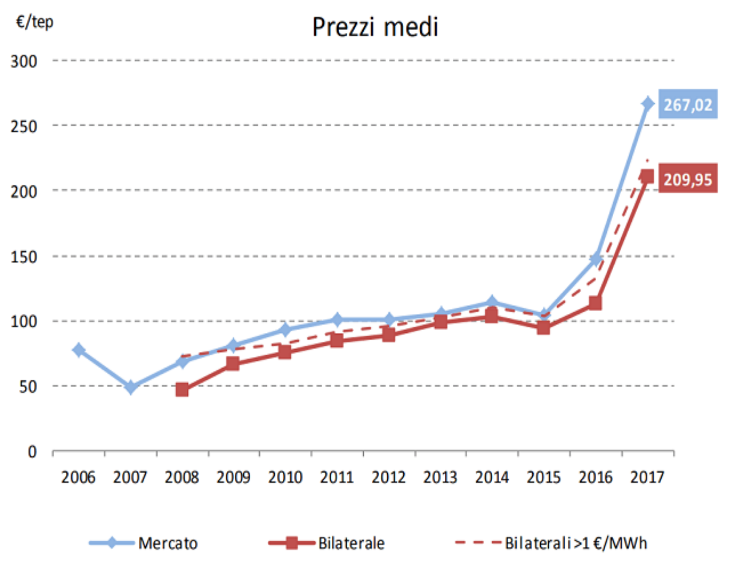
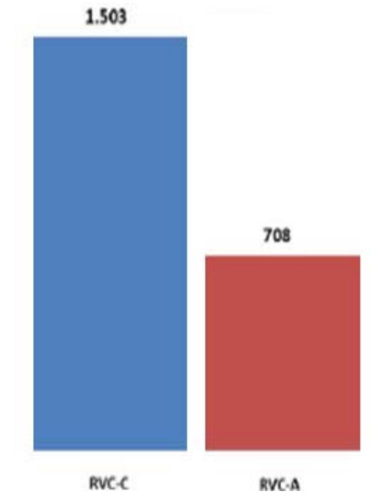


Figure 3-6: Number of TEE applications submitted in 2018



RVC-A: Richieste di Verifica e Certificazioni Analitiche
RVC-C: Richieste di Verifica e Certificazioni a Consuntivo

Source: (GSE, Rapporto annuale Certificati Bianchi, 2018) - Original figures

Since 2016 onwards, TEE price has a wide volatility. At the end of 2016 the price was around 100 and 140 euros, but already at the beginning of 2017 the price had jumped to 280 euros. In 2017, the average TEE price increased by more than 80% compared to the previous year and, in February 2018, the weighted average price of TEEs was around € 427.

This price spike is mostly due to the Ministerial Decree 11/01/2017 with which the GSE has changed the mechanism for recognizing the TTEs so that, in the face of an expected reduction of new TEEs, a rush to the available titles has taken place. Further changes were therefore made with the Ministerial Decree 11/01/2018 in which the GSE makes available Energy Efficiency Certificates at € 260 (whose actual repayment is actually € 250) that can be purchased by the last day of year.

Regulatory uncertainty, complicated presentation and evaluation mechanisms of the demand, probable speculation by the operators and the expectation of a decline in supply have led to a climate of uncertainty in the market with the consequence that in 2018 the incentive applications fell by 67% (GSE, 2018).

4 The results of Italian incentive policy

4.1 Introduction

All the obligations introduced by the European Directive 31/2010/EC will soon be fully enforced throughout Europe: in particular, this directive has introduced the concept of nearly Zero Energy Buildings (*nZEB*) and requires that all newly built public buildings, starting from 2019, have to be constructed in compliance with strict energy consumption limits. This obligation is also extended to private buildings starting from 2021. In addition to the requirements of excellent thermal insulation, these buildings also require that the energy demand should be met by very efficient systems powered by energy produced for a mainly from renewable sources on site.

With the DLGS of 4.06.2013, Italy has fully implemented the European Directive extending the application also to the renovation of existing public and private buildings (Ministero Economia e Finanza, 2013).

As reported in previous Chapter , Ecobonus and New Thermal Account 2.0 will play a fundamental role in achieving energy saving objectives and in making this type of interventions more attractive.

In this regard, this Chapter shows first of all an elaboration of the public data available regarding the use of Ecobonus, New Thermal Account and White Certificates in the civil sector: the objective is to provide a view about how they are actually used and what kind of interventions they currently incentivize.

In particular it appears that these mechanisms struggle to stimulate the interventions of global renovation of buildings (understood as interventions on the entire building-plant system): in fact, only 7% of the more than 400,000 interventions carried out in Italy in 2018 involved the thermal coat. Significant is the fact that are no more than 1300 nZEB buildings out of 13 million (ENEA, 2018).

The main barrier is that these types of interventions, especially because of the high cost of thermal coat compared to its economical return, are not considered attractive due to the long PBTs. It is therefore necessary to study new mechanisms to spread this type of interventions.

4.2 Incentivized interventions in 2018

Figure 4-1 and Figure 4-2 show the number, the distribution and the delivered amount of incentives in 2018. The mechanisms have facilitated a considerable number of interventions (more than 400'000 in all): Ecobonus plays a predominant role, having sustained more than 3/4 of the interventions; New Thermal Account 2.0 appears to be less used although, compared to last year, a 122% increase of requests have been recorded; TEEs in the civil sector have instead played a marginal role.

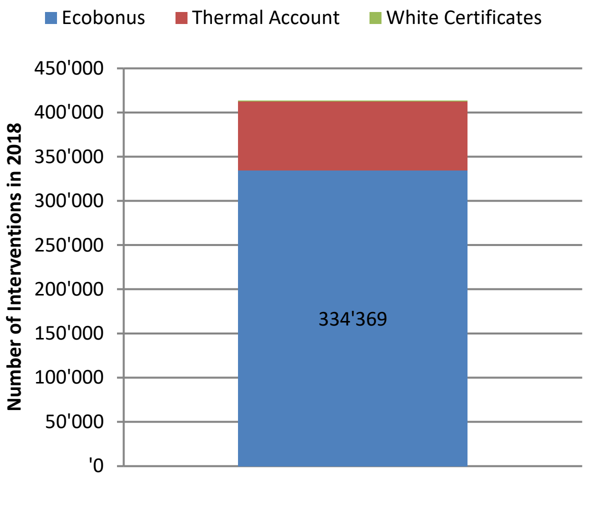
On the other hand, Figure 4-3 shows that these mechanisms have not been particularly effective with regard to interventions involving the envelope. In fact, just 7% has regarded the thermal coat only (as foreseen by Ecobonus or Conto Termico for PA), or the “global renovation of the building” i.e. intervention of the entire envelope-plant system (as foreseen by Ecobonus for private individuals), or the transformation of the building into nZEB (as foreseen by Thermal Account for PA). Instead, the vast majority of incentives has concerned single interventions on power generation plants or the mere replacement of windows and solar shading.

Figure 4-4 e Figure 4-5 reports the number and the distribution of the interventions for each mechanism from which it appears that all 3 mechanisms were mainly used to incentivize air-conditioning systems. The Ecobonus groups together all the window replacement work and the relative application of solar shading. In the Thermal Account, however, the solar panels for DHW take on particular importance. With regard to White Certificates, in addition to winter air conditioning, the interventions are almost all related to private lighting.

A more detailed analysis on the interventions incentivized by Ecobonus reveals that those involving the envelope mobilize 35% of investments (Figure 4-7), and generate 36% of annual energy savings, (Figure 4-11). Indeed, these are the interventions that have the highest average cost per intervention, but also they achieve the largest energy savings per intervention (Figure 4-9 and Figure 4-10. On the contrary, the other interventions (the majority) have an efficacy in terms of energy savings due to intervention at least 4 times lower than those involving thermal coat.

As already widely known in the technical literature (Energy & Strategy Group, 2018), interventions involving the thermal coat present return times and costs that make them decidedly unattractive.

Figure 4-1: Number of interventions in Italy in the civil sector in 2018 divided by type of incentive mechanism



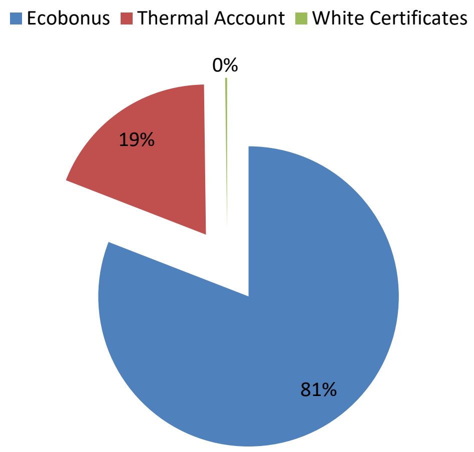
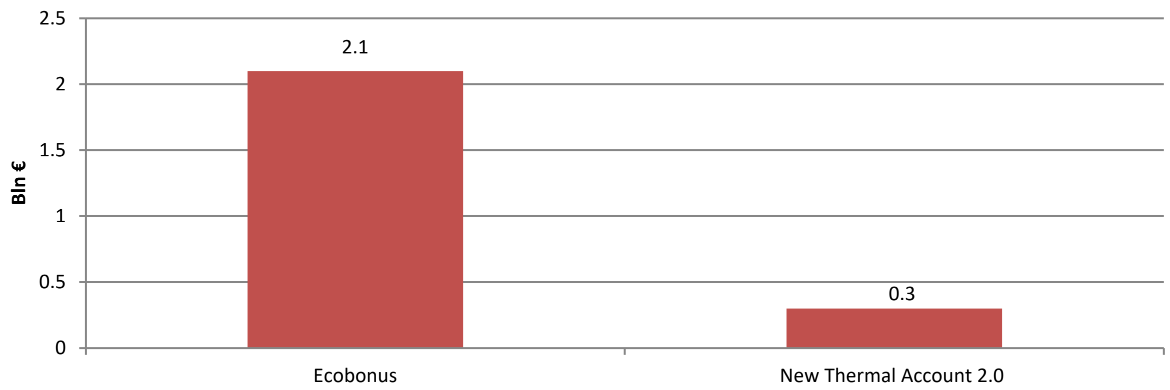
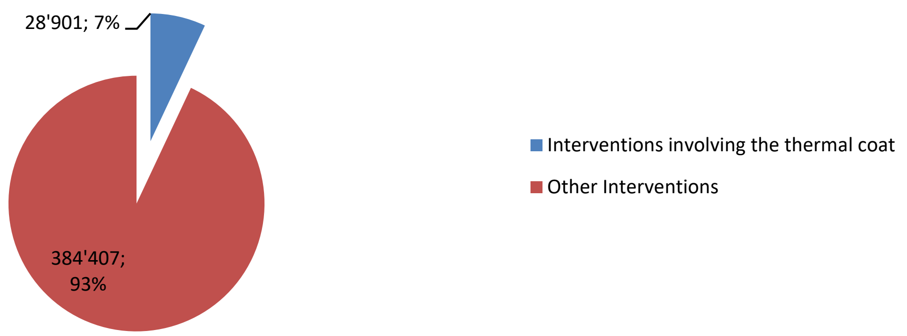


Figure 4-2: Number of interventions and incentives delivered in Italy in 2018 divided by type of incentive mechanism.



Processing data from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019), (GSE, Rapporto attività 2018, 2018). The TEEs do not present the data relating to the incentive paid as the mechanism "self-regulates", as described in Chapter 3.5.

Figure 4-3: incentive interventions involving the thermal coat promoted in 2018 by Ecobonus and Thermal Account



Data processing from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019) (GSE, Rapporto attività 2018, 2018) (GSE, Rapporto annuale Certificati Bianchi, 2018) (Ministero dello Sviluppo Economico, 2018)

Figure 4-4: Distribution of Ecobonus, Thermal Account and White Certificates in number in 2018

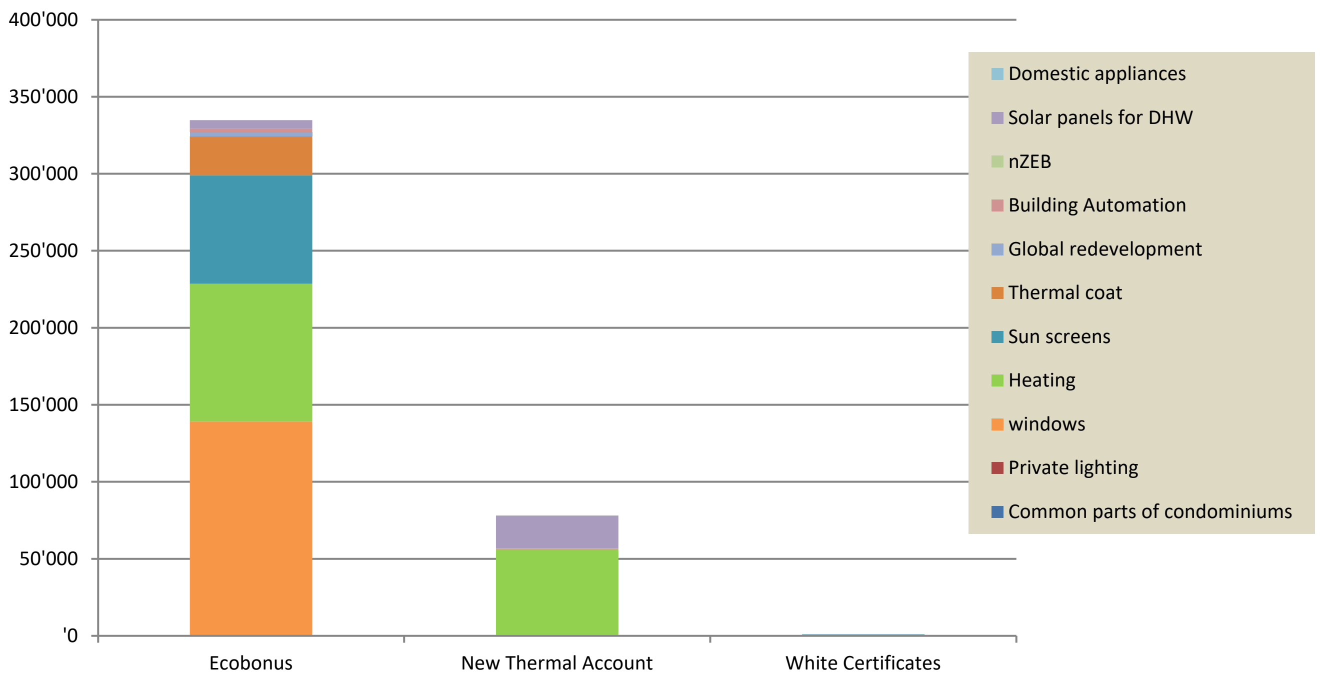
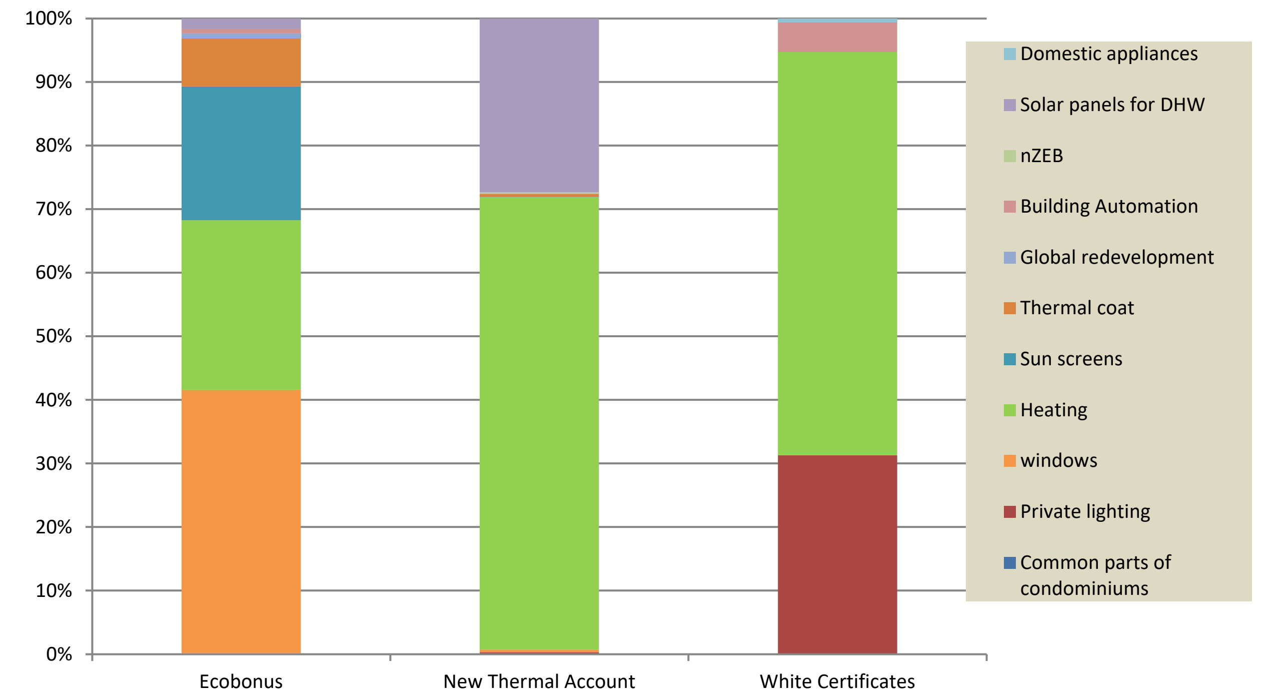


Figure 4-5: Distribution of Ecobonus, Thermal Account and White Certificates as a percentage in 2018



Data processing from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019) (GSE, Rapporto attività 2018, 2018) (GSE, Rapporto annuale Certificati Bianchi, 2018) (Ministero dello Sviluppo Economico, 2018)

Figure 4-6: Number of Interventions vs. Investments in 2018 - Ecobonus	Figure 4-7: Investments (Mil€) in 2018 - Ecobonus

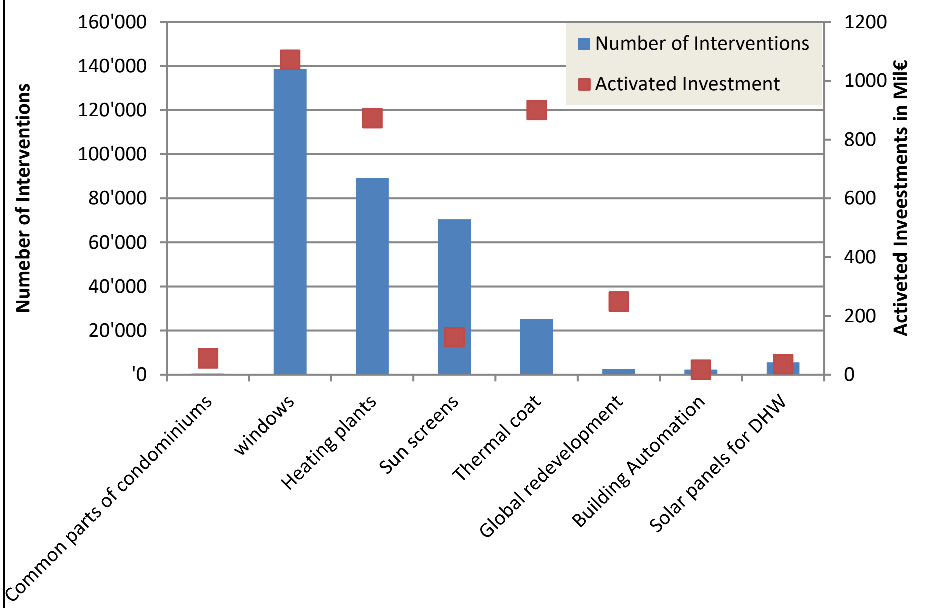
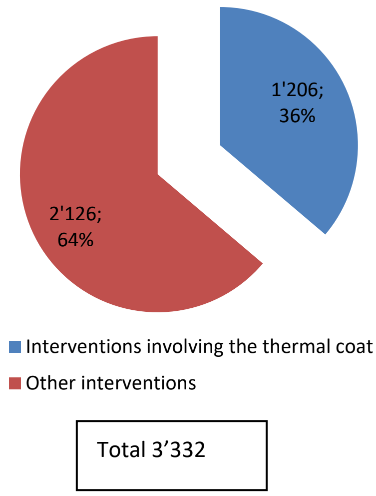

	

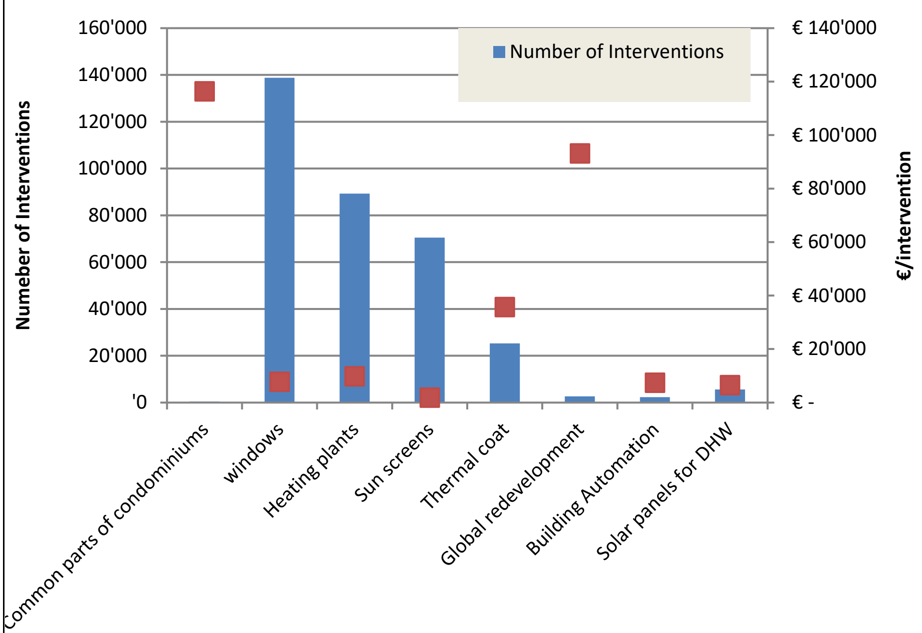
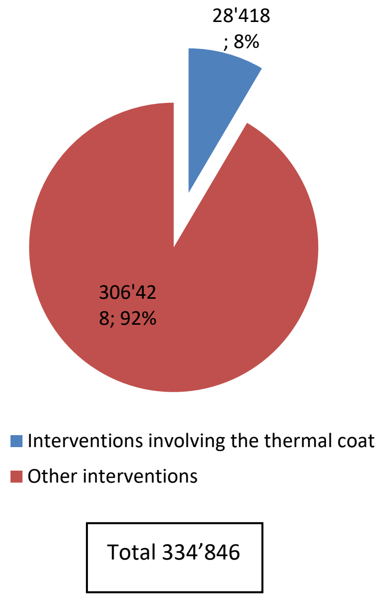
Figure 4-8: Number of Interventions Vs average investment in 2018- Ecobonus	**Figure 4-9: Number of interventions in 2018- Ecobonus**
	

Figure 4-10: Energy savings in 2018- Ecobonus

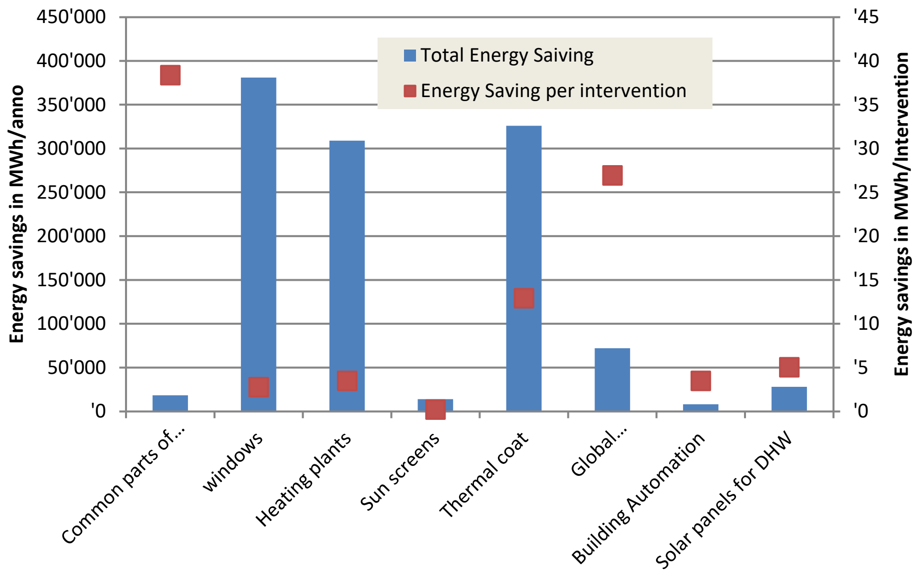
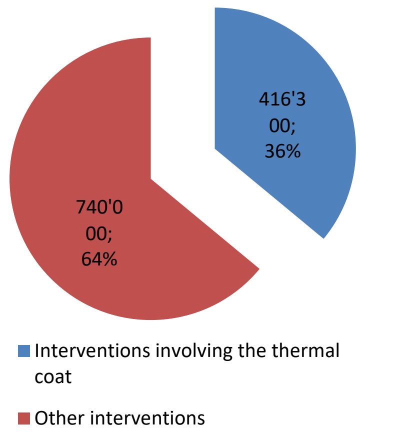


Figure 4-11: Energy savings (MWh) in 2018 - Ecobonus



Data processing from (ENEA, Rapporto Annuale Detrazioni Fiscali, 2019)

4.3 The building energy classification

In accordance with European directives, the Italian legislation requires that the heat requirement of a building, as well as its energy class, is calculated through the so-called "quasi-steady " method defined according to UNI 11300 , details of which are reported in the 3rd part of this thesis.

The new APE, as determined in DM 26/06/2015 (“*Minimum Requirements Decree*” of 26 June 2015), which came into force on 1 October 2015, defines 10 Energy Classes which are:

- based on the non-renewable global energy performance index;
- named based on alphabet letters - plus numbers - from class A4 - the best - to G - the worst.

According to DM 26/06/2015, (Annex 1, Chapter 3), the energy class of a building is established by relating its energy consumption to the so-called ***reference building*** defined as:

1) identical to the analysed building in terms of geometry, orientation, territorial location, use and boundary situation;
2) having predetermined thermal characteristics and energy parameters (e.g. thermal transmittances, dynamic parameters, plant efficiencies) whose values are established by this law (Appendice A, (Allegato 1, Capitolo 3)) as function of the specific climatic zone.
3) equipped with the standard technologies that are precisely identify by law.

By definition, the maximum non-renewable energy that the Reference Building can consume establishes the Class A1. Therefore, all the ***buildings belonging to the classes A1 - A4*** have, according to the current legislation, an insulation and an efficiency of the heating systems that respect the best building practice - in other words they ***do not waste energy unnecessarily***.

However, for nZEB buildings this is not yet sufficient: a series of additional requirements must be met and, in particular, that more than 50% of the energy consumed by the building be renewable. The precise technical definitions of Building Energy Class and nZEB building are reported in Chapter 14.

In June 2017 the new ISO 52016 was published which profoundly changes the method of calculating the energy performance of the building, introducing the so-called ***dynamic method***. Compared to the classic static evaluation, the main advantage of the dynamic method is to bring the theoretical calculation closer to reality and to obtain a prediction of the behaviour of the building-plant system that is increasingly faithful to the true behaviour of the building, please refer to next Section 7.2.2.

4.4 The new nZEB normative

Directive 2010/31/EU marked a turning point in European energy policies: it aims to achieve almost zero energy consumption for the building heritage, turning the buildings into "*nZEB* " (near Zero Energy Building). In particular, with this directive 2010/31/EU, the EU has requested all Member States to ensure that:

a) starting from 31 December 2018, new buildings owned and occupied by public bodies are almost zero-energy consumption;

b) by 31 December 2020 all new buildings are almost zero energy consumption.

With the DLGS of 4.06.2013, Italy has fully implemented the European Directive, extending the application also to the restructuring of existing public and private buildings (Ministero Economia e Finanza, 2013).

Subsequently the Ministerial Decree of 26 June 2015 specified that, from a technical point of view, every building is considered "near Zero Energy Building", ", whether new or existing, if it has not only a very low energy demand but also that a significant proportion of that energy is achieved from on-site, or closely sourced renewable energies (refer to Section 14.5 for a details).

The first estimates of the "nZEB Observatory" show that in Italy the nZEB buildings are around 1400 (ENEA, 2019) (Energy & Strategy Group, 2017): this is a small percentage compared to the real estate assets that, as seen in the Chapter 2.2, has 14 million buildings.

Moreover, 90% of nZEB s are newly built, mostly residential and concentrated in Lombardy region.

In most cases, the technologies used are heat pumps combined with photovoltaics; on the other hand, there is no single design solution to comply with the nZEB requirements, but it is necessary to integrate different technologies according to non-trivial economic and design constraints.

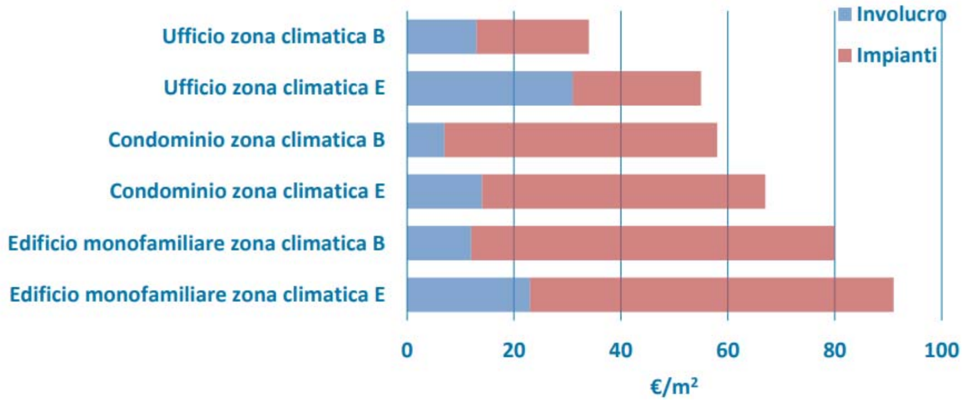
According with (ENEA, 2019), the aforementioned requirements increase construction costs for 15%-25% of the renovation costs (Figure 4-12), which, however, are not covered by energy savings over the building life (Energy & Strategy Group, 2017).

Thus, in order to make the nZEB buildings more attractive, the actions that can be taken:

- study more effective financing and incentive mechanisms;
- lowering construction costs through the use of innovative design methods, materials and systems;
- further optimize management costs (and ease);
- promote awareness so that the market recognizes a greater value in terms of both energy efficiency, comfort and safety.

Figure 4-12: Additional cost to rase the energy class level from A1 to nZEB

a) Additional cost as function of the climite zone



b) Average additional cost

Tipologia	Edificio monofamiliare	Edificio condominiale	Edificio adibito ad ufficio
Involucro	4,2%	4,6%	5,3%
Impianti	50,2%	27,4%	28,1%
Totale	22,0%	14,6%	14,0%

Source: (PA*NZEB* , 2018) - Original figures

4.5 The transition from natural gas to renewable energy in buildings

4.5.1 The role of heat pumps within PNIEC

The diffusion of the envelope insulation is not important only to reduce the energy needs but also to facilitate the transition to the much-desired diffusion of the so called "*electrification of buildings*", through progressively replacing natural gas for heating and DHW.

Indeed, the new PNIEC 2019 states that the energy savings objectives can only be achieved through the combined effect of several factors:

1. the reduction of energy needs, through measures to improve the efficiency of the building;
2. the gradual giving up of fossil fuels such as gas and oil thanks to the electrification of buildings and the diffusion of electric vehicles for transport, also powered by electricity produced on site.
3. greater use of renewable thermal and biofuel sources.

In this regard, PNIEC repeatedly insists on the fact that this transition can take place only thanks to the widespread distribution of the so-called "electric heat pumps" for the production of thermal energy, especially if combined with a photovoltaic system: if correctly sized, this type of systems is able to generate electricity to power the heat pump, or to transfer excess energy to the electricity grid.

Heat pumps combined with photovoltaic plants appears to be the most compatible configuration with the distributed generation paradigm, necessary for the future development of so-called "smart-cities".

4.5.2 The differences between condensing boiler and heat pump

Compared to traditional boilers, the main advantage of heat pumps, in addition to the possibility of cooling, lies in a considerable reduction in operating costs and emissions.

Currently the most widespread heat pumps are the aerothermal ones: these generators, through a Carnot cycle, are able in winter to transfer heat from a cold source (outdoor air) to a warmer temperature environment (inside the home); in summer, on the contrary, they can operate with a reverse cycle, transferring cooling energy from a warmer environment (outdoor air) to a colder one (inside home). This thermodynamic process involves the use of an electric compressor, thanks to which the heat pump is able to transform 1 kWh of electric energy into approximately 3-4 kWh of thermal energy. The ratio between generated thermal power and absorbed electrical power takes the name of COP (Coefficient Of Performance) with reference to the winter performances and EER (Energy Efficiency Ratio)with reference to the summer performance. Instead the main technological disadvantages with respect to boilers can be summarized as follows:

- Heat pumps take much more space than a boiler, as they require special accumulations of technical water or DHW. Furthermore, to obtain the desired economic and environmental benefits, it is necessary to install a photovoltaic system on the roof, which must therefore be available (this is not obvious for example in condominiums).
- The cost for a heat pump system is around 500-600 €/kW_t, and that for domestic photovoltaic system is around 1500-2000 €/kW_e. A boiler is instead around 130-150 € / kW_t (Direzione Generale Ambiente, 2014) (Energy & Strategy Group, 2012) (Energy & Strategy Group, 2019)
- In addition to this, also the costs for rebuilding the distribution system and the terminals should also be added:
  - The heat pumps are able to supply hot water at much lower temperatures (maximum 55°) compared to boilers (70-75°): this is very significant limit, as this implies that, in order to guarantee the same energy (and so comfort), much more hot water should be provided. On the other hand, the pipes (often not well isolated) and the emitters are sized for smaller flow rates and their replacement is often technically difficult and expensive. There are air heat pumps that are able to supply water at 65 °, but only with decidedly higher initial and operating costs.
  - Most of the existing terminals are radiators: it means that to enjoy the cooling it is necessary to replace them even if they are sufficiently sized for heat pump heating.
- Summer and winter performances decrease as the thermal energy demand of the building increases: in winter, COP decrease significantly as the outdoor air temperature decreases; similarly in summer, EER decrease as the outside temperature increases.

This last point implies that the designer must double check the heat pump system to guarantee comfort both in the coldest and in the hottest periods.

Since the design must also satisfy the peaks in demand, the drop in efficiency force us to forsee plants with much higher thermal power than that would be needed to cover the average needs. As a first consequence, the cost of the plant increases significantly and, as well as, the time of return of the investment.

Moreover, unlike what happens with boilers, a ”precautionary“ oversizing of a heat pump can cause serious technological and economic problems: in fact it can generate malfunctioning and anomalous consumption due to continuous switching on and off that takes place in the average conditions.

It follows that the adoption of heat pumps is advisable only when the building is thermally well insulated, in order to allow:

- the installation of heat pumps of relatively small size, so as not to excessively impact on costs and optimize returns;
- to operate at relatively low temperatures, thus ensuring the right comfort, high performance and, consequently, low operating costs.

These technological constraints prevent heat pumps from gaining a rapid foothold in the market: in 2018 heat pumps sold in Italy were 15% (Figure 4-14) of total generators. Compared to 2011, the heat pumps growth trend can be considered interesting (+ 33%), but, compared to the growth trend of condensing boilers, the existence of a certain gap is evident (Figure 4-13).

Figure 4-13: Heat generators sold in 2011-2018 in Italy

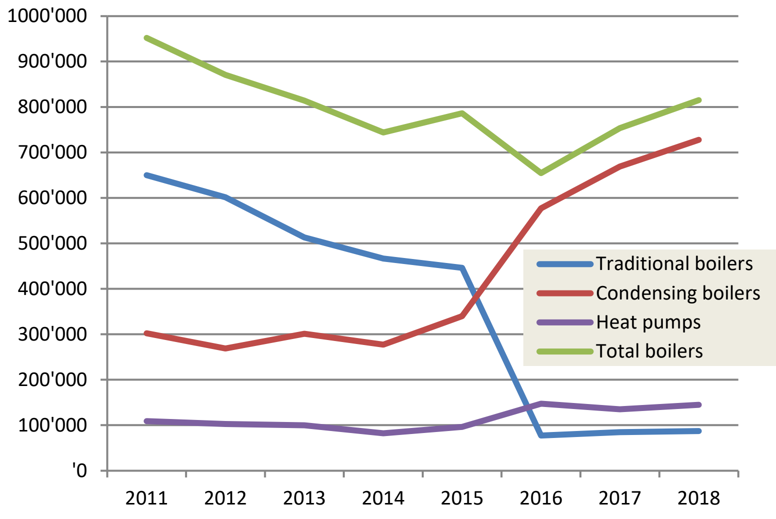
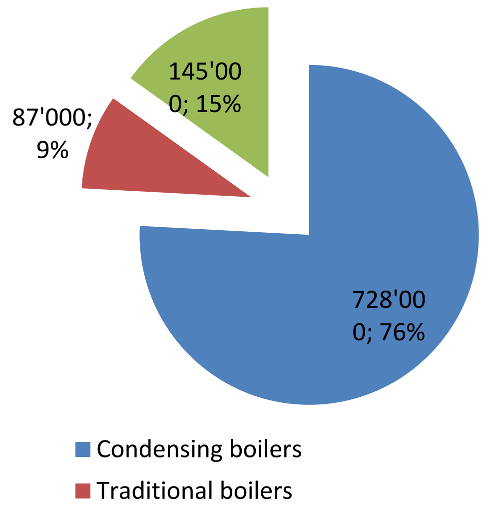


Figure 4-14: Heat generators sold in 2018 in Italy



Processing data from (Assoclima, 2019) and (Assotermica, 2018)

Figure 4-15: Distribution of fuels and plants in Italy

RISCALDAMENTO CASA					
	Impianto centralizzato	Impianto autonomo	Apparecchi singoli fissi	Apparecchi singoli portatili	Totale
	% famiglie	% famiglie	% famiglie	% famiglie	% famiglie
Metano	83,8	86,5	6,1	-	70,9
Energia elettrica	1,4	0,4	17,7	54,2	5,1
Biomasse	0,7	4,8	73,9	-	14,5
GPL	2,5	5,3	2,3	45,8	5,8
Gasolio	11,6	3	-	-	3,7

Tabella 1 Distribuzione degli impianti e dei combustibili in Italia (ISTAT 2014)

Source: (ISTAT 2014) - Original figure

The above leads to the conclusion that, to take a decisive step towards decarbonisation and distributed generation, it is necessary to act on the entire building-plant system: the nZEB regulation reported in the next Chapter goes exactly in this direction.

2nd PART

5 Renovation of the public buildings stock: the role of New Thermal Account 2.0 and EPCs

5.1 Introduction

As previously described in Section 4.4 and 4.5, the 2010/31/EU Directive has marked a turning point in European energy policies due to the introduction of the so-called nZEB limits (nearly Zero Energy Building), in order to achieve a near zero energy use for the building stock.

Unfortunately, the economic benefits are not so obvious; in fact, because of the significant upfront capital investment required, the profitability of nZEB s renovations, which should be one of the main drivers for a significant diffusion, is not guaranteed (Adhikari, Aste, Del Pero, & Manfren, 2012) (Energy & Strategy Group, 2017). Furthermore, an nZEB renovation project necessarily includes the combined use of different technologies (Thermal Coating, renewable energy, mechanic ventilation, etc.).

This implies that the design of an intervention, as well as the relative evaluations by final customer or financing institutions, is not easy and very often it does not comply with the optimum cost-benefit for the building (J.Kurnitski, et al., 2011). From many studies (Kurnitski, et al., 2011) there are indications that the cost of requalification is economically justified in savings on the bill only if the intervention is limited to reaching the old C Energy Classes or at most B (L.Cattani, Locatelli, & M.Marengo, 2008).

Despite it does not represent a significant share of the energy consumption or the number of real estate properties (Chapter 2), the Public Administration (PA) is still a strategically important sector, as it can act as an example and a driving force for the private sector. For these reasons, both the European Union and the individual countries are granting funds and making incentives available to local Public Administrations, in order to finance a significant number of nZEB renovation projects.

To support Public Administrations to carry out interventions to increase energy efficiency, the Italian Government provides the so-called "New Thermal Account 2" which is nothing else than the revival of the so-called "Thermal Account" (Ministerial Decree 28.12.2012), a measure previously been in force for a few years (01/2013-05/2016) which didn't achieve the expected results.

The "New Thermal Account 2.0" includes new provisions to simplify procedures, increase the amount of incentives and encourage the spread of nZEB requalification works in public buildings: in particular it grants up to 65% of capital investment for nZEB retrofitting, while for other cases the grant is lowered from 40% to 55%.

However, given the poor financial standing of the majority of public bodies, the retrieval of the remaining portion of the investments is not always feasible, even more in case of nZEB renovation.

Lawmakers are therefore seeking to strengthen funding mechanisms, allowing public bodies to cover the remainder of the total amount requested through third party funding and, specifically, through the so-called Energy Service Company (ESCO), the only ones that are entitled to operate through an Energy Performance Contract (EPC), Section 5.2.

In addition to the study of more effective financing and incentive mechanisms, the interest of the ESCOs can be stimulated through design methods capable of optimizing the returns taking into account all the technical, economic, financial and regulatory aspects.

In this regard, Section 5.3 proposes a new methodology for designing renovation projects: the novelty resides in the integration, in a single robust process, of existing models and techniques used to evaluate the feasibility of such projects, taking into account at the same time the technical aspects, legal constraints, incentives and financial feasibility.

Then, in Section 5.4, the methodology is applied to a real case of the renovation of a typical medium size public building, taking into account nZEB legislation and New Thermal Account mechanism: through this case study it was intended to demonstrate the effectiveness of the method itself and, furthermore, to highlight the main economic aspects that must be taken into consideration when entering into an EPC.

5.2 EPC contracts for the energy upgrading of public buildings

The EPC is defined by the Energy Service Directive (European Directive 32, 2006) as "*a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, where investments in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement*". An EPC model can be structured in different ways, depending on the different risk allocation between the Parties (N.Carbonara, 2018). The two most important structure are:

- the ***shared savings contract***, in which the ESCO funds the Energy Efficiency Intervention, receiving a periodic (typically monthly) payment by the customer proportionally to the obtained savings.
- the ***guaranteed savings contract***, in which the customer finances the intervention, but the ESCO guarantees to achieve the expected savings; if the savings are not achieved, the customer uses the guarantee to reimburse the difference between actual savings and expected savings.

In both cases the ESCo is responsible for the redevelopment project and the execution of the intervention. For the identification of the ESCo with which to enter into the EPC, the PA is obliged to perform a public tender.

At present, many public tenders have gone deserted since they did not find the interest of the ESCOs to be subject to the contractual conditions of the tendered EPC. It should, in fact, be remembered that in the previous Thermal Account only € 10M out of the € 200M available for the renovation of public buildings were used; of such € 10M, less than € 3M were conveyed through ESCOs, i.e. the 1.4% of the €200M available (GSE, 2015).

Shared saving contract is the most interesting form for the PA, since the ESCO covers for both technological and financial risks. Another specific advantage for the PA is the possibility of circumventing the problem of blocking investments due to the so-called Stability Pact or what remains of it. In fact, for the purposes of the financial statements, the EPC transforms an investment item into a current cost item, which, moreover, is already present in the balance of the previous year and, possibly, it is of a lower amount.

The ESCO will be interested in financing the project if this periodic payment allows to pay back the investment in a reasonable time which, for contracts with public administrations, is typically 8-10 years (ENERGY&STRATEGY, 2015).

Several authors have focused their efforts in studying the relationship between the implementation of an Energy Efficiency Intervention and the adoption of an EPC. In particular a wide literature exists based on interviews and surveys to Public Administrations (F., von Flotow, & Nolden, 2016), ESCOs (Marino, Bertoldi, Rezessy, & Boza-Kiss, 2011) (Bertoldi, Rezessy, & Vine, 2006) (Paolo Bertoldi, 2017) (Vine, 2005), Hotels (Xu, Chan, & Qian, 2011) and SMEs (F., von Flotow, & Nolden, 2016).

Also, the literature presents some EPC evaluation models, especially for shared savings contracts: the goal is typically to find the best tradeoff for the economic convenience between the various players involved (ESCO, Client and Financial Institution) (N.Carbonara, 2018) (Liu H., 2018) (A. Giretti, 2018) (Qian & Guo, 2014).

These models typically focus on the economic side and require as input the results of technical evaluations, such as energy savings and capital costs; then they carry out various scenario analyzes by varying economic-financial parameters such as the fluctuation rate of the energy price, the inflation, the percentage shares of the distribution of economic savings between the Parties. However, cases in which these models are tested are sparse.

Yet, this type of analysis is of extreme interest especially in the case of nZEB renewal where, instead, the technical literature usually tends to focus on the engineering aspects while neglecting the economic constraints in which a lender is forced.

Addressing the technical and financial issues separately likely cause to lose the global perspective of the problem, which is necessary in the preparation phase of a call for tenders. The PA must be able to manage and propose a technical project that not only meets the new nZEB requirements but, also, maximize the savings deriving from the government incentives and adequately repays the financing from third parties, otherwise the tender will fail and the building will not be renovated.

In this perspective, the phase between the audit and the definitive project become even more important: an increasingly multidisciplinary expertise is required to the design team, as well as more managerial skills are required to the Public Administration to better address the work of the designer. Lastly, the role of the Legislator remains very delicate, as he has to support these interventions, especially through EPCs, without excessively favoring private companies. The task is even more complicated, considering that EPCs in the civil sector are struggling to take off regardless of regulatory complications and nZEB obligations.

5.3 The Project Feasibility Assessment Methodology - PFAM

5.3.1 Objective

The objective of this Section is to develop an integrated and robust methodology that allows the designer to take into account all technical, financial, normative and contractual aspects, optimizing the work flow and the information exchange between all the actors involved in the process. At the same time the work intends to provide the end user with a tool to support the supervision of the process in order to increase the probability to successfully manage the project. To do this, the methodology is structured as follows:

1) A technical part, intended to develop a procedure able to rigorously and systematically evaluate:

a) the cost items to achieve the required level of energy consumption in order to classify the renovated building as *nZEB* , taking into account any type of incentives and investment;

b) the baseline consumptions of the existing building;

c) the savings realized through the requalification of the building into an *nZEB* ;

2) An economic-financial part aimed at investigating and defining the feasibility of such requalification works, evaluating:
   a) *Ex-ante* situation: the level of comfort provided by the existing systems and the relative O&M (Operation and Maintenance)cost;
   b) *Ex-post* situation:
      i) The investment cost required for realizing the Energy Efficiency Interventions;
      ii) The (lower) O&M costs to provide the *ex-ante* level of comfort after the realization of Energy Efficiency Interventions or, alternatively;
      iii) The O&M costs to provide a higher level of comfort compared to the *ex-ante* one, if agreed in the EPC;
      iv) The risk allocation of the project.

The result of this analysis should allow the PA to identify its best requalification option considering either the alternative of self-financed requalification works, or requalification works executed by an ESCO through an EPC under the provision of the Public Incentive.

The methodology has been tested in a real case study of the requalification of a typical medium size public building, the town hall of a small city in the province of Bergamo (Lombardy) and the potential impact of the Italian “New Thermal Account 2.0”.

5.3.2 Determining the feasibility of an investment

The profitability indices of an investment most used in the buildings energy requalification sector are:

1. PBT - Pay Back Time
2. NPV - Net Present Value
3. IP - Profit Index
4. IRR - Internal Rate of Return

Firstly, It should be specified that these parameters depend on the so-called *Operating Life* which indicates the number of years that the work resulting from the investment presumably continues to produce economic value. Normally the value of the *Operating Life* is established conventionally and varies according to the type of investment. For example, in the energy redevelopment, it is normally assumed:

- for the redevelopment of the outer envelope *Operating Life* = 30 years
- for a new heating system the life expectancy is reduced *Operating Life* = 15 years

Throughout its life, the work requires investment costs for its construction and operating costs for its operation. In return, the investment produces revenues with which, in the case of a good investment, it first pays the operating costs and then, with the difference, gradually repays the investment cost over the years. This monetary movement of income (income) and of expense (cost) is called cash flow.

In the specific case of an energy requalification project, the Cash Flow is given by the *Operating savings* obtained in energy consumption net of the *Mortgage Payment* and the *Tax Deductions*, namely

Cash Flow = Operating savings - Mortgage Payment + Tax Deductions

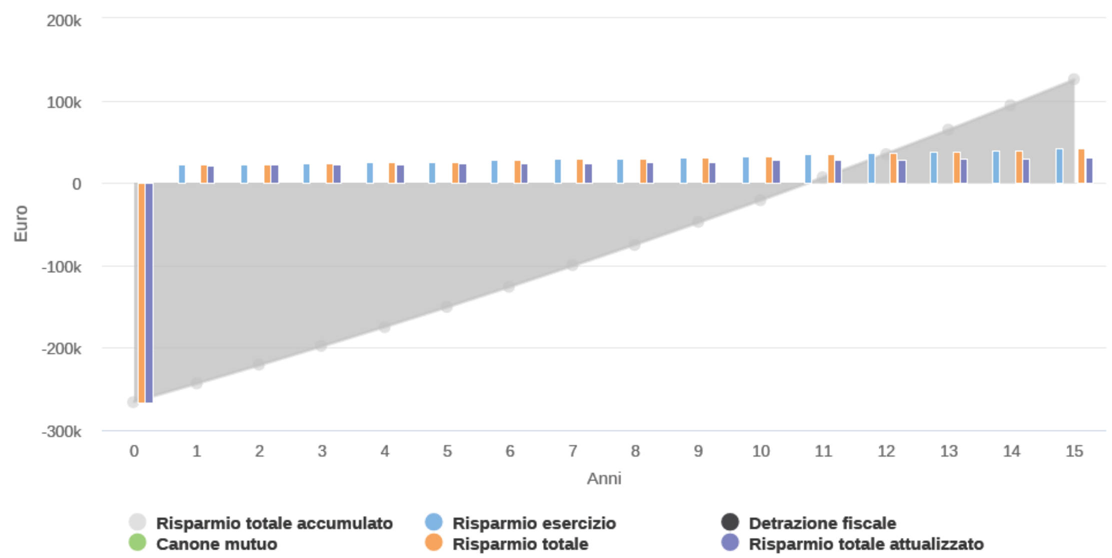
where

Operating savings = Energy bill ex-ante – Energy bill ex-post

It is known that, due to the so-called monetary inflation, the value of money decreases over the years. To take this phenomenon into account, the cash flows must be "*corrected*" by multiplying each of them by a *Discount rate* which allows to evaluate the value to date of the cash flows that will be generated. As said, the discount rate is usually set equal to the current inflation value.

Figure 5-1, taken from the DSS-RRE simulator described in the 3rd part of this thesis, reports the total savings (annual cash flow) calculated for each year of the *Operating life*, the total discounted savings (*discounted cash flow*), and the total accumulated savings (*accumulated discounted cash flow*) whose annual value is obtained by adding the discounted annual cash flow of all previous years.

Figure 5-1: Cumulative cash flow



In case the investment is totally covered by equity capital, as in Figure 5-1, the trend of the discounted accumulated cash flow shows:

- a first period in which its value is negative, a sign that the costs incurred are still lower than the savings obtained and, therefore, the investment is still at a loss;
- a second period in which its value becomes positive, a sign that the savings have paid off the costs incurred and that the investment finally produces profits.

In particular, for what has been said:

A) The point where the value of the cash flow is canceled, passing from the negative sign to the positive sign, indicates the *Pay Back Time*, namely the time it took for savings to pay back the investment.

B) The cash flow value at the end of the *Operating Life* is called the *Net Present Value* (NPV)

Therefore, having set the discount rate and the operating life, a positive NPV indicates that the investment has produced value; alternatively, a negative NPV indicates that the investment has produced losses.

The measure of the profitability of an investment is given by the IRR - Internal Rate of Return. Simplifying as much as possible, the IRR can be seen as the annual interest rate that is recognized on the investment. Mathematically, the IRR is defined as the specific discounting rate for which the NPV of a project is equal to zero and expresses the real rate of return of the project. However, it presents some technical criticalities that limit its applicability to a set of cases that have specific characteristics that are not always found in real projects.

Where it is not possible to use the IRR to determine the performance of the project, its suitability can always be assessed using the NPV criterion which, unlike the IRR, is applicable in all circumstances.

Another index used to measure the profitability of an investment is the IP - Project Index defined as

IP = NPV / Investment

which does not have the limits of applicability of the IRR.

5.3.3 The simplified Pay Back Time (PBT)

In this case study, the chosen metric to evaluate the feasibility of an intervention is the Pay-Back Time. In this methodology, the Pay-Back Time (PBT) of an energy efficiency investment is a measure of the time that is required to reach the point at which the sum of the savings (discounted or not discounted) generated by the intervention is equal to the investment cost.

$$\sum_{t=1}^{PBT} S\,(1+k)^t = I_0$$

where:

- I_0 = Initial investment that includes all the required for realizing the requalification net of ncentive funds.

- $S =$ the annual savings, defined as the difference between:
  a. the baseline, that establishes the costs related to energy and O&M sustained by the PA for the climatic comfort of the existing building *ex-ante* the intervention. The definition of the baseline is the pillar to properly evaluate the optimal Energy Efficiency Intervention to be implemented, the expected energy savings and related economic benefits (Marino, Bertoldi, Rezessy, & Boza-Kiss, 2011) (Lam & Lee, 2014).
  b. The new energy cost, constituted by the sum of all the annual outflows related to the intervention, such as energy savings, new maintenance cost, but also recursive incentives (i.e. annual tax deduction), and the eventual instalment of the bank loan
- $k =$ discount rate

A first approximation of the PBT formula above reported is obtained by neglecting the discount rate which simplifies the expression into

$$PBT = I_0/S$$

Differently from other metrics such as Net Present Value and Internal Rate of Return, the PBT is more subjective in its application, as the decision maker has to define a maximum acceptable time (generally called cut-off time) to define the economic feasibility of an investment (Chiaroni D. , Chiesa, Chiesa, Franzò, & Toletti, 2016).

On the other hand, the PBT analysis is the most commonly used financial instrument for evaluating EPC, since it is an effective tool for the ESCO to limit performance risks by selecting a proper project with a short PBT (Jackson, 2010). In the Italian building sector, when the counterpart is the PA and the requalification works are related to public buildings, a typical acceptable PBT is set in 8-10 years (ENERGY&STRATEGY, 2015).

5.3.4 Defining the baseline and savings

The baseline is the sum of the normalized historical cost associated with energy consumption and maintenance costs: it should be (Krarti, 2011) calculated on measured data, such as the ones collectable from electricity bills and/or through monitoring campaign (if available). These data must be related at least to the last three years and the Degrees Day detected by the nearest weather station.

These type of data, on the other hand, have to be considered in relation to the level of services (i.e. comfort) obtained - or that you should obtain (for example a low consumption can derive from a low comfort condition). The consumption difference between “as is” and “as should be” can be estimated only through energy simulation.

At the same time, in order to define the savings obtained through the retrofit works on the building, it is necessary to determine the new energy consumption and costs, in the same climatic comfort and Degrees Day conditions of the baseline. This assessment requires appropriate engineering calculations.

The access to public funds, as the “New thermal account 2.0”, requires the evaluation of the building energy performance class, following the quasi-steady method as defined by the UNI/TS 11300. It is necessary to underline that, as it will extensively discussed in the 3° part of this thesis, this quasi-steady method was developed (only) to provide a standardized way for classifying the energy performance classification of buildings; for this reason, standard usage hypotheses are imposed in terms of occupation, operating hours, climate data. Thus, the calculated value may differ significantly from the real ones as a matter of fact, several research works (Corrado, Ballarini, Paduos, & Primo, 2016) indicates that this method fails to provide a realistic evaluation of energy consumption.

Nevertheless, any contractual agreement with an ESCO requires a realistic evaluation of the energy consumption that can be achieved with the renovation of the building, as the lack of a proper assessment method on performance risks in EPC projects is one of the reasons hindering the further development of ESCOs markets (Lee, Lam, Yik, & Chan, 2013).

More reliable results can be obtained through the use of advanced numerical simulation tools based on the so-called “*dynamic method*”. Thus, in this research, a series of numerical comparative analyses between the two methods (quasi-steady and dynamic) have been performed, using various software, including EDILCLIMA and TERMUS for the quasi-steady method, and Energy Plus, Energy Evaluation, Eco Designer Star for the dynamic method.

5.3.5 Determining capital investment and incentives

Since the payment foreseen within an EPC is typically established based on the savings, ESCOs are interested in limiting their requalification works only to such Energy Efficiency Interventions that ensure the highest energy saving and, thus, economic return. ESCOs, therefore, tend to restrict their requalification works solely to the thermal plants (with shorter PBT) and to avoid typically larger investments in the building envelope (e.g. application of thermal coat and windows replacement)) or the renovation of the energy distribution systems, whose pay-back times are often longer than the duration of the EPC.

On the other hand, nZEB renovations requires interventions that reduce the need of thermal energy by the building, highlighting the problem of determining the initial investment to be sustained by both Party. Thus, the determination of the investment cost necessary for the realization of the work becomes essential, and in this context identifying contributions obtainable from the available incentives plays a key role, reducing the costs sustained by the parties and the risk on technologies with higher PBT (Fusco & Brioschi, 2015).

The amount of public fund granted by regional and national incentives is usually governed by a series of readily identifiable factors: this is true also for the specific case taken into account below, where the "New Thermal Account 2.0", is considered as the incentivizing mechanism. Additional details on the specific fund are reported in Section 3.4 and a resume is listed in Table 5-1.

Table 5-1: Typical factors governing the funding available through the regional and natonal incentives

Factors	Examples
Type of applicant	public or private
Type of interventions	windows, thermal coat, boiler, heat pump, LED revamping, etc.
In which combination they are realized	single intervention or combined intervention
The climate zone where the building is located	A, B, C, D, E, F
The type and size of heat plant	heat pump, boiler, solar thermal, renewables
The energy performance class ex-post (after the requalification)	nZEB , or not

Correctly identifying and taking into account those factors is fundamental, as the higher is the amount of funding received through the incentives, the lower is the investment required from the parties (ESCO and/or PA) in the EPC.

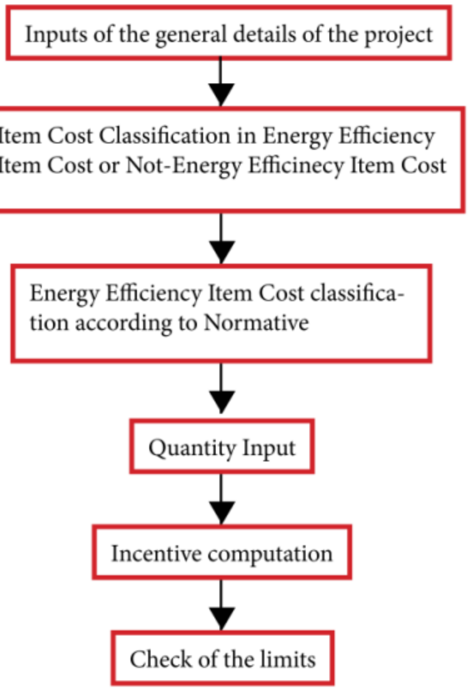
Following this, each individual intervention usually need to comply with either one of the following constraints, or both, as in the case study detailed later in the Chapter :

1. Maximum unit cost, expressed in unit cost (€/U.M.): this constraint is used to align the incentives with the market prices. Especially in the case of building works, the government fixes a maximum price considered appropriate to achieve determined energy efficiency performances, avoiding to incentivise extra cost not directly related to the Energy Efficiency Intervention;
2. Maximum total incentive: each incentivable item must be lower than the expenditure ceiling. This constraint is present to contain the overall size and price of the requalification works, limiting them to medium size buildings.

To overcome the complexity of the above mentioned rules, an IT tool have been herein developed, based on a metric computation, able to classify the type of requalification work divided per single item, and to calculate the amount of the incentive receivable. The IT tool has then been tailored for use with the "New Thermal Account 2.0" scheme.

The IT tool is made by 6 steps, as illustrated in Figure 5-2. First of all, the user inputs the general details of the project (i.e. type of applicant, climatic zone); then, based on the bill of quantities of the project, the user is called to classify each item cost in either EEIC (*Energy Efficiency Item Cost*) or non-EEIC. Subsequently each EEIC has to be classified according to the clusters (type of intervention) indicated in the regulation (e.g. Window replacement includes labor, material and disposal that are generally listed separated cost items in a bill of quantities). Then the IT tool organizes the item cost as reported in first column of 5.8 Annex 1. Finally, the user inputs the quantity according to the Unit of Measure (U.M.) indicated for each cluster and the IT tool is able to compute the incentive, showing if the above mentioned limits have been exceeded.

Figure 5-2: IT tool working phases



As an example of this process, referring to the case study subsequently discussed, the implemented procedure through the use of the following relationship:

- Project unit cost = Computed cost/Quantity [€/u.m.]
- C Max = Maximum unit cost recognized by the "Conto Termico" [€/u.m.]
- Eligible unit cost: min(Project unit Cost; C Max), that is the constraints described at the point 7 of the previous bullet list [€/u.m.]
- Eligible Cost = Eligible unit Cost x Quantity [€]
- % Incentive = Max. percentage of incentive for each cluster allowed, computed automatically by the IT tool according to the data inserted in point 1 [€]
- Incent_1 = % Incentive x Eligible cost [€]
- I max = Max. Incentive allowed for each cluster. Regarding the envelope, it is noted that the Max. Incentive is referred to the sum of the interventions on all the surfaces. [€]
- Incentive = Min (Incent_1; I max), that is the constraints described at the point 8 of the previous bullet list. It is the real incentive recognized by the "Conto Termico". [€]
- % Incentives = Incentive/Computed cost.[%]

In the New Thermal account 2.0 case, the underlying logic is to reward more the interventions on the envelope (e.g. insulation coats, windows, etc. with a higher cost/ benefit ratio), especially in combination with interventions on the thermal plant, such as to make the whole building-plant system more efficient. In addition, the interventions carried out in the coldest climates are better rewarded, where, at equal cost, the environmental benefits become more substantial.

It should be emphasized that, while for buildings that do not reach nZEB levels, each cost element must comply with specific constraints, in the event of nZEB adaptation, the entire renovation work can be considered globally and the verification of the compliance of the expenditure it simplifies enormously. First of all, the loan is set at 65% of the total cost of the intervention and the constraints to be respected are: 1) a maximum unit cost of 500-575 € / m2 depending on the climatic zone; 2) maximum total incentive of 1.5-1.75 M € depending on the climatic zone.

5.3.6 The flow chart of the PFAM

As stated so far, the definition of a redevelopment project necessarily follows an iterative process where the technical solutions progressively refine to possibly meet both the various regulatory requirements and achieve financial sustainability. Within this process it is necessary to alternate engineering and economic-financial calculations, more specifically: perform numerical simulations to estimate the energy consumption achieved by the current project solution, evaluate the cost of the intervention, determine the portion covered by the government incentive and the remaining part to be financed, assess the economic convenience indices, translate the results obtained into contractual terms and conditions in the EPC.

The whole process is rather complex and involves the use of different specialized software from which the need to develop communication interfaces among the various SWs. These activities are rarely carried out by single professionals, but require the collaboration of several subjects..

A robust methodology needs, therefore, to be defined in order to ensure that every step is properly addressed and the results from the different steps are correctly gathered and passed to the following ones. This methodology, also named " PFAM" (Project Feasibility Assessment Methodology), is represented by the flow chart reported in Figure 5-3.

This is intended to be a general framework applicable to the execution of requalification works according to the EPC scheme, and each phase can be addressed using the preferred tools and techniques:

Phase 1. Define the basic model for the project: develop the ex-ante building model through a building energy simulation program, based on the dynamic energy theory (Section 7.2.2), so that the numerical a coherent framework between energy bills, monitored data and interviews with users (A. Giretti, 2018). This is a very critical phase since various parameters are difficult to define, such as comfort and human behavior, the evaluation and measurement of real temperatures in each room and other aspects related to the real use of the building.

Phase 2. Perform a building energy simulation program, based on the quasi-steady energy theory (3rd part of the Thesis), with the operative conditions prescribed by law, in order to determine the ex-ante Energy Class;

Phase 3. Design the requalification intervention according to nZEB requirements: this phase (i.e. the core of our process) has to be repeated in an iterative process until the technical design is optimized with the financial factors.

Phase 4. Determine the financial feasibility, refer to 5.3.2, as function of:

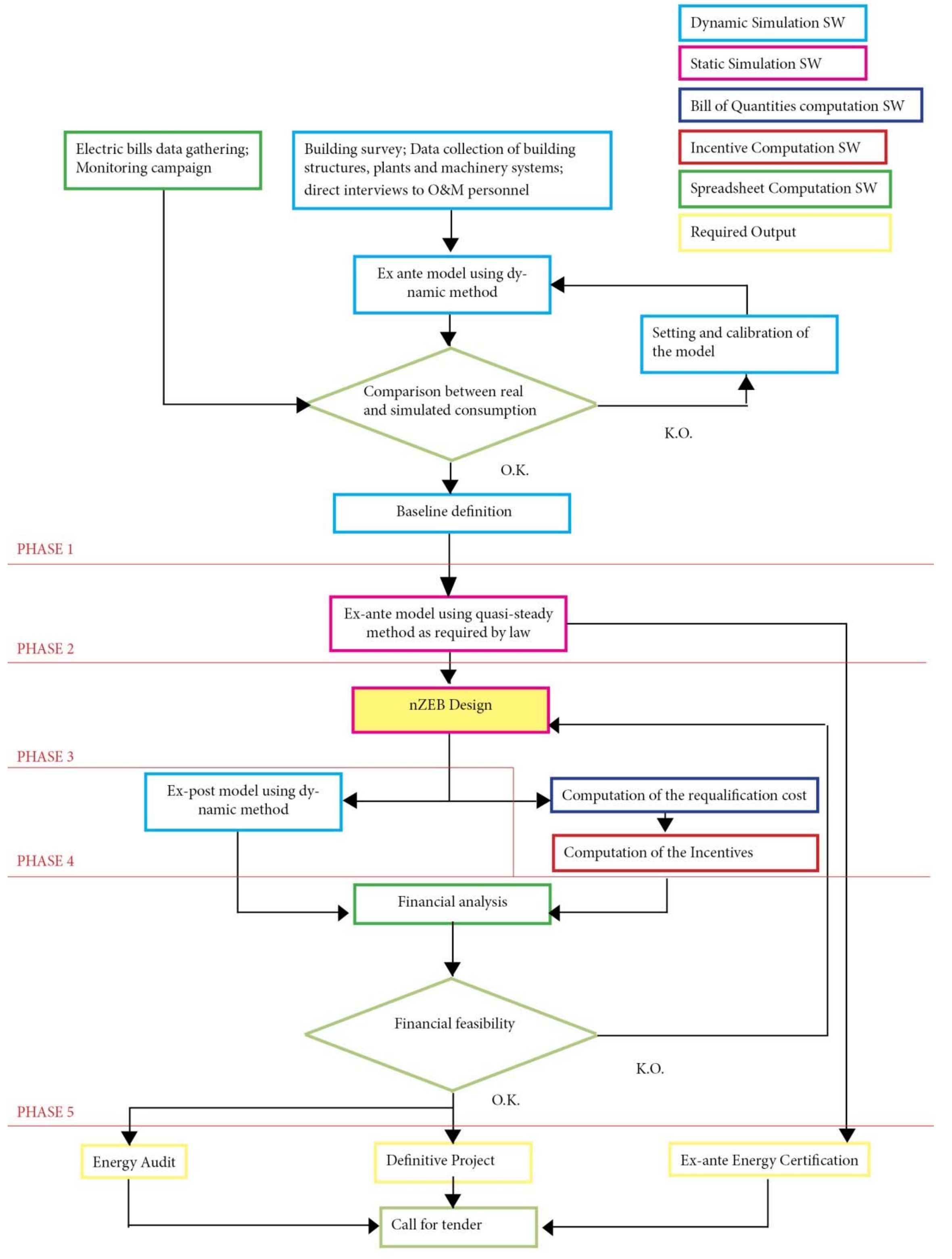
a. the Baseline Model defined in Phase 1;
b. the energy consumption of the new nZEB design, computed through the dynamic energy theory;
c. the total investment cost of the new nZEB design;
d. the obtainable financial incentives.

If the financial parameters are not considered satisfactory, modify the nZEB design and perform a new iteration starting from phase 3. Otherwise continue to the next phase.

Phase 5. Output of the documents required for the call of tender and the incentive bid:

a. the energy audit;
b. the ex-post Energy Classification;
c. the complete nZEB design with the economic and financial analysis.

Figure 5-3: PFAM Flow Chart



5.4 The case study

5.4.1 The Italian background and incentives

With DGR 3868/2015, the Lombardy region decided to implement nZEB regulations ahead of time, starting from January 2016.

This decision was taken following the regulation for financing the restructuring of public buildings contained in the DL 141/2016 (Interministerial Decree 16.02.2016): the so-called "New Thermal Account 2.0", described in Section 3.4.

The following Table 5-2 summarizes the main features of this regulation regarding the public sector:

Table 5-2: Main feature of the "New Thermal Account 2.0"

Ceiling	200 M€
Type of incentive	Grant up to 65% of the capital investment
Access for the PA (either)	Direct
	Through an EPC contracted with an ESCO
Delivery mode	40% Advanced payment, 60% at the end of the works
Interventions allowed	On the building envelope (walls and windows)
	Replacement of HVAC and lighting systems
	Systems for the production of renewable thermal energy

It is important to report that the aforementioned DL 141/2016 actually contains the supplementary and corrective provisions of Legislative Decree 102/2014 (Legislative Decree 04.07.2014, n. 102) implementing the directive 2012/27 / EU on energy efficiency. This document must therefore still be considered the reference text where to find the overall picture and operational details.

In particular, as regards relations with the ESCo and EPC contracts, Annex 8 provides the "Minimum elements that must appear in the energy performance contracts signed with the public sector or in the relative tender specifications". In this short document, less than one page long, the Government lists the items that must characterize a contract so that it is classified as an EPC.

5.4.2 General overview of the building

The case-study concerns the retrofit works of the town-hall, shown in Figure 5-4, of a medium-size town (10,000 inhabitants) in the province of Bergamo (Lombardy, Italy; Degree-Days 2,533). The building consists of three floors with a total floor area of 1,176 mq, a volume of about 5,942 m3 and a surface area to volume ratio (S/V) equal to 0.38. The building is characterized by a traditional masonry structure with outer walls thicknesses varying from 0.625 m to 0.750 m.

The case-study is significant since the building belongs to the PA and can therefore have access to the incentives as provided for by the "New Thermal Account 2.0"; the building dates back to the XVIII century and shows several features typically found in many public buildings, such as: the medium size, the intended use as an office building and a certain historical value from which various constraints imposed by the public authorities ensue.

Due to its epoch, the building is also very energy-inefficient, falling in Energy Class G (the lowest one). This is mainly due to the poor insulating property of the walls and presence of the large windows made of solid iron frame, single-glazed, high infiltration values.

In December 2015, the municipal authorities approved an executive project for the retrofit of the entire building, and the entire project documentation has been made available by the municipal authorities for the purposes of this research.

It must be pointed out that the main driver of the municipal authorities was the redefinition of the office spaces and there was no specific initial focus on the energy efficiency intervention. In fact, the existing documentation shows that, from an energy efficiency point of view, the project redeveloped the building into Class B, as it respected the regulatory limits in force at the time of approval (December 2015) and not the more rigorous one that would have gone in force in Lombardy a few days later (1 January 2016) where the obligation to PA to restructure in nZEB is imposed.

Figure 5-4: Front of the building used for the case-study

Figure 5-5: Comparison between quasi-steady vs dynamic method

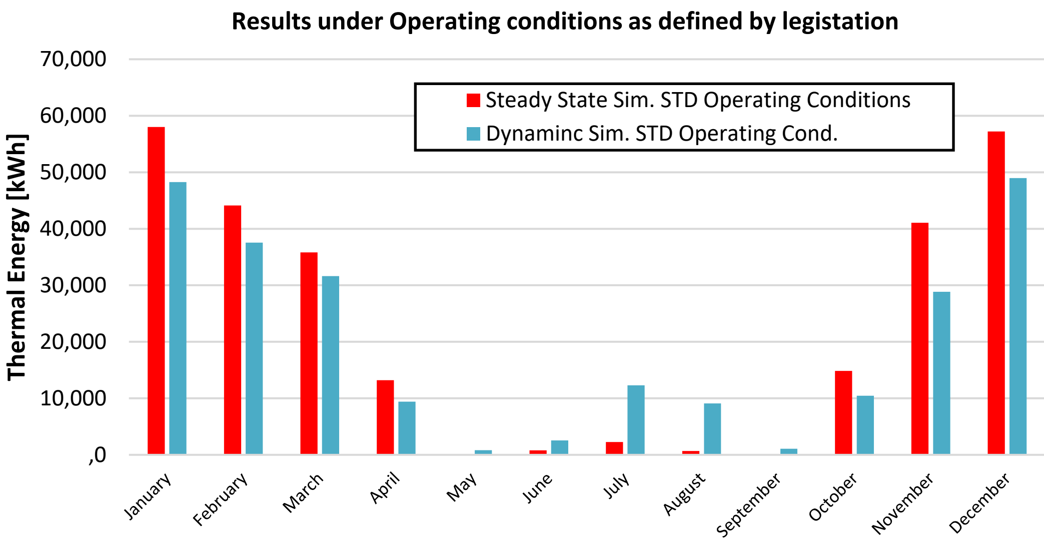
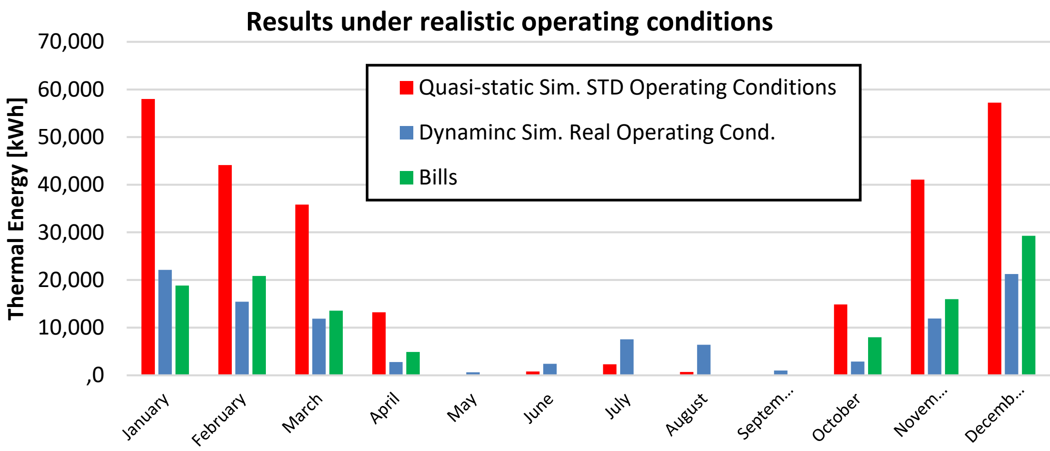


Figure 5-6: Comparison between quasi-steady vs dynamic method considering realistic operating conditions.



In term of energy efficiency, the requalification works as planned by the design include:

- the replacement of the n. 54 windows, with new ones of greater energy efficiency: (U = 1.2 W/mqK);
- the application of 8 cm inner coat of expanded polystyrene (U = 0.034 W/mK) along the external walls;
- the replacement of the roof, including the installation of 80 mm of cork insulation (U = 0,435 W/mqK);
- the replacement of the existing traditional gas boiler, with a 127.5 kW condensing boiler.

5.4.3 Evaluation of the energy consumptions

Referring to the flow chart proposed in Figure 5-3, this Section reports the analysis relating to Phases 1 and 2.

In order to correctly evaluate the energy savings obtainable through the nZEB renovation, detailed simulations on the building energy need has to be performed. We recall that this is not required by the current legislation, only asking for a quasi-steady analysis, but it becomes mandatory when there is the intention to stipulate an EPC with an ESCo as it is necessary to correctly estimate the Base Line and the energy savings generated by the intervention.

Figure 5-5 and Figure 5-6 show the comparison between the Building Energy Demand related to the e*x-ante* situation, obtained using the two different approaches previously mentioned: A) The *quasi-steady* method in accordance with the UNITS11300 through the use of the TERMUS BIM software BIM (Picco, Marengo, & Beltrami, 2015) (Magrini, Alfano, Magnani, & Pernetti, 2010); B) The *dynamic method* using Energy Plus. The results are also compared to the average monthly natural gas consumption of the last 3 years obtained through the available bills.

The results reported in Figure 5-5 were obtained by imposing in the two cases identical operating conditions, as prescribed by the regulations currently in force. Figure 5-6 shows the same TERMUS results as in Figure 5-5, but it compares them with:

- The results achieved by the dynamic simulation when tailoring the operating hours according to the real office time-schedule (8 working hours/day from Monday to Friday, 5 working hours on Saturday; off on Sundays and festivity calendar days) – blue bars
- The average energy consumption of the last three years calculated from the actual energy bills.

Table 5-3 shows a synthetic overview of the obtained numerical results.

Table 5-3: Summary of obtained results in term of energy consumption

		Realistic operating Conditions (ROC)		Normative Operating Conditions (NOC)	
		Adapted Bills	EnergyPlus	EnergyPlus	Termus
Heating	[kWh]	111,311	88,143	214,963	264,270
Cooling	[kWh]	-	17,857	25,888	3,739
Total	[kWh]	111,311	106,000	240,851	268,008
Difference from Bills (Heating)	[%]	0%	-20%	+93%	+138%

The analysis highlights that the overall results of the dynamic method, calculated under the Realistic Operating Conditions (ROC), are consistent with the energy consumption reported in the bills, being only 21% lower, with the difference largely attributable to poor management and un-optimal regulation of the plant which could not been taken into account in the simulation.

The quasi-steady method at Normative Operating Conditions (NOC), when compared to the dynamic simulation, drastically overestimates the heat requirement for winter heating, with a +138% difference, and underestimates the summer cooling, thus confirming the findings already discussed in literature (Corrado, Ballarini, Paduos, & Primo, 2016).

Even imposing the same operating conditions (NOC), the two methods continue to show a relevant difference. As widely discussed in part 3 of this thesis, this difference derives above all from the inability of the quasi-steady method to take due account of the inertial phenomena, originating from the mass of the external walls, which are opposed to the hourly variation of the external temperature.

Furthermore, there is the underlying problem of the climatic conditions that can be practically imposed on the softwares that are used in the calculations. In fact, all the softwares certified by the institutional bodies to carry out quasi-steady analysis use the monthly average values provided by UNI 10349-1, lastly updated in 2016. In Italy, the basic data available are limited to 110 provinces.

On the other hand, Energy Plus, as well as all the most well-known softwares that perform dynamic analysis, uses the hourly climate files provided by the TMY (Typical Meteorological Year) library arranged by World Meteorological Organization region and Country. In particular, the dataset available for Italy is made up of 66 meteorological files and are the result of statistical analyzes carried out over a historical period from 1951-1970.

Hence, two completely different worlds that certainly contribute to the differentiation of results. For the analysis in question, the climatic data used for the steady analysis refer to the Province of Bergamo. While the time series referred to the Orio-Bergamo station was used for the dynamic analysis.

5.4.4 The nZEB re-design

Referring to the flow chart proposed in Figure 5-3, this Section reports the analysis relating to Phases 3.

In order to reach the nZEB level, the following redefinition of the interventions relating to the energy consumption of the building contained in the project approved by the municipal authorities was carried out:

- Expected insulating materials on walls (EPS) replaced with better performance products, while maintaining the same thicknesses (U = 0.028 W/mK);
- Additional 90 mm of stone-wool insulation on the roof (W/mK = 0.036);
- 0.25m layer of clay (U = 0.09 W/mK) insulation between the first floor and the ground;
- Installation of a 38 kW photovoltaic array on the rooftop, sized to satisfy the annual electricity energy demand from the heat pump.

From the calculation performed in accordance with current legislation, it appears that with these limited modifications the building can be classified as nZEB and Energy Class A3.

5.4.5 Cost analysis of the different scenarios

Table 5-4 shows the costs (including VAT) for the renovation of the building as per the project approved by the municipality and those necessary to achieve the nZEB qualification, according to the specifications listed in Section 5.4.4 above. The table is completed by reporting the value of the incentives obtainable with the "New Thermal Account 2.0" and, therefore, the net cost of the intervention.

Table 5-4: : Investment alternative scenarios exploiting the “New Thermal Account 2.0”

Requalification works	Contracted Project	“New Thermal Account 2.0”	
		Class B	nZEB
Cost of the works	€ 1,337,360	€ 1,337,360	€ 1,439,516
- Energy retrofit works		€ 753,800	€ 870,808
- Architectural Requalification		€ 568,709	€ 568,709
Obtainable incentives	€ 0	€ 200,956	€ 439,530
Net Cost	€ 1,337,360	€ 1,136,404	€ 999,986
Savings over the contracted project	-	€ 200,956	€ 337,374
	-	15%	25%

Table 5-5 highlights that in order to reach the nZEB level, the costs relating to energy improvement alone increase by 16% (from € 753,880 to € 870,808). On the other hand, the incentives to reach the nZEB level increase so that the resulting net cost even decreases from, going from around € 1.1 million to 1 million.

Table 5-5: Incentives obtainable through the “New Thermal Account 2.0” (VAT included) for the Case Study

Energy Cost Recognized	Costs	Incentives	% Incentives	Net costs
Requalification works to Class B	€ 753,880	€ 200,956	27%	€ 552,924
Requalification works to nZEB	€ 870,808	€ 439,530	50%	€ 431,278

The reasons for this great difference in the value of the incentives can be understood by referring to the Table 5-6 and Table5-7 which report the detail of the calculations obtained through the algorithms described in Section 5.6 and 5.7.

For non nZEB requalification, the Table 5-6 shows that the greatest obstacle is the low value of the maximum unit cost. In fact, only the energy efficiency measures relating to the opaque surface do not reach the maximum unit costs. With regard to windows, on the other hand, the regulatory limits refer to conventional devices while, for the case in question, special solutions are needed to overcome the constraints imposed by the Superintendence for Architectural Heritage.

As far as the lighting system is concerned, the incentives apparently concern only the lighting fixtures and not the relative electrical system. Looking at the heating system, the regulatory limit takes into account only the cost of replacing the generator while, in reality, replacing a traditional generator (boiler) with a heat pump often also requires the replacement of the distribution system and heating terminals.

For nZEB interventions, the calculation of the incentives appears much simpler and, although the overall cost still exceeds the maximum eligible cost, the consequences are much more limited and the final incentive is equal to 50% of the costs, compared to the theoretical maximum of 55%. .

5.5 Conclusion

The case study shows that the "New Thermal Account 2.0" significantly rewards nZEB requalification so that the net cost of the intervention can be even lower than that relating to a lower quality intervention.

As for the remaining part of the cost not covered by the incentive, it is essential to observe that, by applying the simplified form of the PBT reported in Section 5.3.3, we obtain

$$\mathrm{PBT} = \frac{I_0}{S} = \frac{€\,431'278}{\frac{€}{\mathrm{year}}6'688} = 64\ \mathrm{years} \gg 10\ \mathrm{years}$$

being

- I_0 the net cost in case of nZEB requalification;
- S the energy total annual cost that , as average, the PA has payed for the building in the last 3 years.

Therefore, even in the extremely favorable (absurd) hypotheses that the renewal could completely eliminate the cost of energy, the repayment time of the loan is still totally incompatible with that which an ESCO can reasonably grant. On the other hand, assuming that it is possible to save S, the maximum possible investment would be

$$I_0 = \mathrm{PBT} \times S = 10 \times \frac{€}{\mathrm{year}}6'688 = €\,66'880$$

which could roughly allocate the replacement of the thermal power plant, very little to reach the nZEB level.

These simple considerations lead to the conclusion that the participation of an ESCO in an nZEB redevelopment project can possibly take place through an EPC "guaranteed saving" formula, where the ESCO does not participate in the investment but is responsible for the effectiveness of the intervention through forms of penalty on the annual fees due for the supply of the energy service.

5.6 Annex 1

Ref. Laws: Art.4	Type of Intervention	Computed Cost	UM	Quantity	Project unit cost	C max	Eligible Unit Cost	Eligible Cost	Max %Inc.	Incent_1	I max	Incentive	% Incentives
§1, let. a)	Horizontal opaque structures: external insulation	89'005	mq	572	156	200	156	89'005	55%	48'953	400'000	109'253	55%
§ 1, let. a)	Horizontal opaque structures: internal insulation	-	mq		-	100	-	-	55%	-			
§ 1, let. a)	Horizontal opaque structures: ventilated structure insulation	-	mq		-	250	-	-	55%	-			
§ 1, let. a)	Horizontal opaque structures: external floor insulation	6'058	mq	81	75	120	75	6'058	55%	3'332			
§ 1, let. a)	Horizontal opaque structures: internal floor insulation	45'784	mq	1'176	39	100	39	45'784	55%	25'181			
§ 1, let. a)	Vertical opaque structures: external walls insulation	-	mq		-	100	-	-	55%	-			
§ 1, let. a)	Vertical opaque structures: external walls insulation	57'796	mq	947	61	80	61	57'796	55%	31'788			
§ 1, let. a)	Vertical opaque structures: insulation ventilated walls	-	mq		-	150	-	-	55%	-			
§ 1, let. b)	Replacement of transparent closures including frames, if installed in conjunction with the thermoregulatory systems …. Climatic Zones A, B, C	-	mq		-	350	-	-	55%	-	75'000	-	0%
§ 1, let. b)	Replacement of transparent closures including frames, if installed in conjunction with the thermoregulatory systems …. Climatic Zones D,E,F	209'789	mq	146	1'437	450	450	65'700	55%	36'135	100'000	36'135	17%
§ 1, let. c)	Installation of condensing heat generator with Pn <= 35 kWt	-	kW		-	160	-	-	55%	-	3'000	-	0%
§ 1, let. c)	Installation of condensing heat generator with Pn > 35 kWt	-	kW		-	130	-	-	55%	-	40'000	-	0%
§ 1, let. d)	Installation of screening systems and/or fixed shading, also integrated, or mobile	-	mq		-	150	-	-	40%	-	30'000	-	0%
§ 1, let. d)	Installation of screening systems and/or fixed shading, also integrated, or mobile	-	mq		-	30	-	-	40%	-	5'000	-	0%
§ 1, let. e)	Transformation of existing buildings into "nearly zero energy buildings NZEB" - climatic zone A, B, C	-	mq		-	500	-	-	65%	-	1'500'000	-	0%
§ 1, let. e)	Transformation of existing buildings into "nearly zero energy buildings NZEB" - climatic zone D,E,F	-	mq		-	575	-	-	65%	-	1'750'000	-	0%
§ 1, let. f)	Replacement of lighting fixtures including lamps for indoor lighting and outdoor appliances - Installation of high-efficiency lamps	-	mq		-	15	-	-	40%	-	30'000	-	0%
§ 1, let. f)	Replacement of lighting fixtures including lamps for indoor lighting and outdoor appliances - Installation of LED lamps	156'808	mq	1'176	133	35	35	41'160	40%	22'470	70'000	16'464	10%
§ 1, let. g)	Installation of building automation technologies	-	mq		-	25	-	-	40%	-	50'000	-	0%
§ 2, let. a)	Electric Heat Pump	188'641						188'641	65%	122'617	39'104	39'104	21%
	TOTAL	**753'880**						**494'143**				**200'956**	**27%**

Table 5-6: New Thermal Account 2.0" Incentives for Climatic Zone E and requalification in Energy Class B

5.7 Annex 2

Ref. Laws: Art.4	Type of Intervention	Com-puted Cost	UM	Quantity	Project unit cost	C max	Eligible Unit Cost	Eligible Cost	Max %Inc.	Incent_1	I max	Incentive	% Incen-tives
§1, let. a)	Horizontal opaque structures: external insulation		mq			200			55%		400'000		
§ 1, let. a)	Horizontal opaque structures: internal insulation		mq			100			55%				
§ 1, let. a)	Horizontal opaque structures: ventilated structure insulation		mq			250			55%				
§ 1, let. a)	Horizontal opaque structures: external floor insulation		mq			120			55%				
§ 1, let. a)	Horizontal opaque structures: internal floor insulation		mq			100			55%				
§ 1, let. a)	Vertical opaque structures: external walls insulation		mq			100			55%				
§ 1, let. a)	Vertical opaque structures: external walls insulation		mq			80			55%				
§ 1, let. a)	Vertical opaque structures: insulation ventilated walls		mq			150			55%				
§ 1, let. b)	Replacement of transparent closures including frames, if installed in conjunction with the thermoregulatory systems …. Climatic Zones A, B, C		mq			350			55%		75'000		
§ 1, let. b)	Replacement of transparent closures including frames, if installed in conjunction with the thermoregulatory systems …. Climatic Zones D,E,F		mq			450			55%		100'000		
§ 1, let. c)	Installation of condensing heat generator with Pn <= 35 kWt		kW			160			55%		3'000		
§ 1, let. c)	Installation of condensing heat generator with Pn > 35 kWt		kW			130			55%		40'000		
§ 1, let. d)	Installation of screening systems and/or fixed shading, also integrated, or mobile		mq			150			40%		30'000		
§ 1, let. d)	Installation of screening systems and/or fixed shading, also integrated, or mobile		mq			30			40%		5'000		
§ 1, let. e)	Transformation of existing buildings into "nearly zero energy buildings NZEB" - climatic zone A, B, C		mq			500			65%		1'500'000		
§ 1, let. e)	Transformation of existing buildings into "nearly zero energy buildings NZEB" - climatic zone D,E,F	870'808	mq	1'176	740	575	575	676'200	65%	439'530	1'750'000	439'530	50%
§ 1, let. f)	Replacement of lighting fixtures including lamps for indoor lighting and outdoor appliances - Installation of high-efficiency lamps		mq			15			40%		30'000		
§ 1, let. f)	Replacement of lighting fixtures including lamps for indoor lighting and outdoor appliances - Installation of LED lamps		mq			35			40%		70'000		
§ 1, let. g)	Installation of building automation technologies		mq			25			40%		50'000		
§ 2, let. a)	Electric Heat Pump								65%		39'104		
	TOTAL	870'808										439'530	50%

Table5-7: "New Thermal Account 2.0" Incentives for Climatic Zone E and requalification in *nZEB*

6 Renovation of private buildings: the effectiveness of Ecobonus

6.1 Introduction

In the previous Chapter , it was shown how the New Thermal Account 2.0 can actually facilitate the redevelopment of public real estate stock, that is a relatively small sector in terms of the number of buildings (Chapter 2.2), but strategic as a driving force for the sector.

On the other hand, the first part of the thesis highlighted how a significant part of energy savings for the next decade are expected from the condominium sector and, equally, the Ecobonus will be by far the incentive with the highest expectations in absolute terms.

As described in section 3.4, Italian Government recently introduced the so called "Transfer of Credit", i.e. the possibility of transferring the tax deduction linked to the Ecobonus to suppliers who have carried out the renovation. It is a mechanism that effectively removes most of the problems that applying this incentive has encountered in past years.

In light of the above, this Chapter proposes a case study with the aim of analyzing the effects of the Ecobonus on the renovation of a typical Italian condominium of 24 housing units in the City of Milan.

In particular, the profitability of different types of intervention is examined:

- Boiler only: replacement of the boiler only, as the majority of interventions in 2018 (see previous Section 4.2)
- Standard renovation: replacement of the boiler + thermal coat, in order to reach the A1 class (as *reference building* according to current normative)
- complete nZEB renovation, as will be obligatory for all buildings (see Section 4.4):
    - Installation of an electric heat pump instead of the condensing boiler,
    - Substitution of the distribution and emission system (fan coil)
    - Installation of a 30 kW photovoltaic system combined with the heat pump.

This study shows that it is actually possible to redevelop a typical Italian condominium up to the nZEB level with a low cost, estimated at around 1000 €/ year per condominium.

The analysis is conducted adopting the PFAM approach described in the previous Section 5.3.

6.2 The case study

The residential complex consists of 2 separate buildings with the following main features, Figure 6-1:

Figure 6-1: Building views

- Sharing of the same thermal plant for heating systems.
- Four floors above ground, a non-habitable attic, an unheated cellar floor, an unheated stairwell.
- A total of 24 housing units of about 100 square meters each.

The case study is certainly interesting as

- It is a typical building built during the construction market boom in 1980;
- According with Section 2.2:
  — It belongs to the Energy Class G (the worst one), like more than half of buildings in Lombardy;
  — The condominiums are fundamental in the national energy strategy, as they include 49% of the total residential real estate units

The geometrical data of the building are shown below

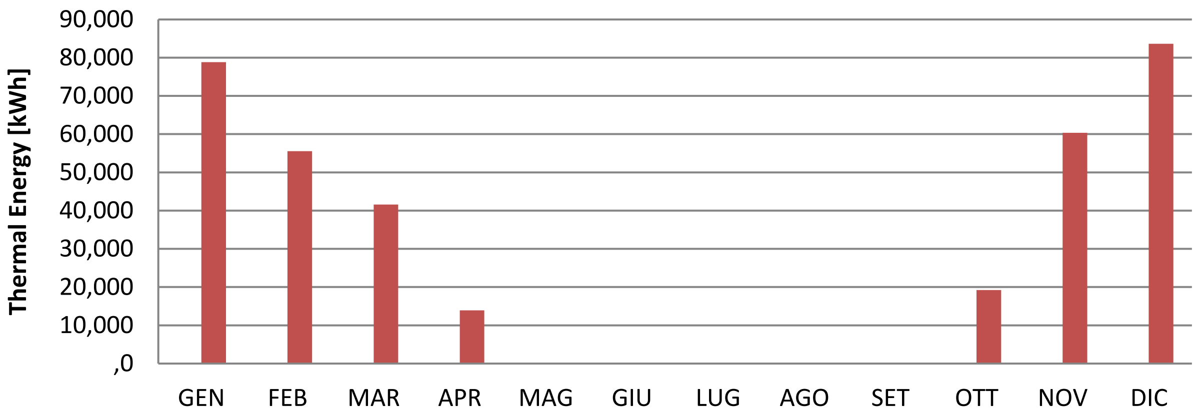
Net area	mq	2´072.48
Net volume	m3	5´962.77
Average net height	m	2.88
Net area (with height less than 1.5 m)	mq	0.00
S / V ratio	mq/m3	0.51
Gross dispersant surface	mq	3´915.24
Gross dispersant surface of the frames	mq	345.98
Gross volume	m3	7´727.08
Total heat capacity	kJ/K	408´131.88
Periodic thermal transmittance -YIE	W/mq K	0.3428

As in the previous case of the City-Hall, also in this project the PFAM methodology reported in Section 5.3 was followed. Thus a 3D virtual model of the condominium was therefore created in which the structural elements have a parametric representation of all their geometric and physical characteristics, Figure 6-2.

Figure 6-2: The developed BIM Energy Model

Then the 3D model was imported into a specialist SW and, after a calibration process having the feedback of the energy bills paid by the condominium in the last 3 years, the base line was finally put in place. The following Figure 6-3 reports the calculated primary energy for the building as is.

Figure 6-3: Montlhy primary energy demand



6.3 The typology of interventions in the renovation of buildings

Typically, an energy renovation of a building, and in particular when this is a condominium, may include one or more of the following interventions:

1. Replacing the heat generator to produce the air conditioning and/or domestic hot water .
2. In the case of centralized heating system for condominiums (and if still absent), installation of heat regulation and metering systems for the correct distribution of the costs incurred between the dwellings, as required by the LG. 102/2014.
3. Application of a thermal coat on the masonry between the heated and non-heated areas: typically the external infill walls and the internal ones towards the stairwell.
4. Application of a thermal insulation on the roof or on the attic floor to protect the living areas below.
5. Application of a thermal insulation on the ceiling of the garage and/or basement to protect the living spaces above.
6. Replacement of windowed surfaces either in their entirety or limited either to the window frame or to the glass only.

Less frequently, interventions are also performed for

7. The insulation of the floors between the housing units.
8. The rebuilding of electricity grids and water networks for the distribution of hot water in order to eliminate dissipative phenomena due to the age of the plants.

To determine the extent of the intervention, the Italian legislation compares the energy performance of the building in question with the so called "*reference building*", i.e. a building identical to the one in the project or a real building in terms of geometry, orientation, territorial location, intended use and boundary situation but having thermal characteristics and energy parameters equal to those considered by the regulations as minimum acceptable. The comparison takes place on the basis of engineering calculations referred to a standard methodology based on the UNI/TS 11300 standards, which in turn refer to the European standards UN UNI EN ISO 13790: 2008. Details are extensively reported in the 3rd Part of this thesis.

6.4 The renovation hypotheses

Table 6-2 shows all the interventions that were necessary to get the building to have the same thermal characteristics as the *reference building* (Energy Class A1). In order to carry out a standardized economic evaluation, the unit costs of the interventions were assumed here to be equal to the reference costs provided by the GSE, within the New Thermal Account 2.0. Although close to the market, the costs are still to be considered just indicative since they strongly depend on the features of the material chosen: that features are not related only to energy efficiency, but they can vary depending on the useful life, design, thicknesses, acoustic characteristics, structure, etc. Of particular interest is the fact that, for each single intervention, this Table shows alongside the construction cost:

- the energy savings;
- the profitability of the intervention summarized by the simple PBT calculated as the ratio between the construction cost and the annual savings achieved.

Table 6-1 considers the most common case of replacing only just the heat generator (refer to Chapter 4.2), that it must inevitably be done at the end of its life. Thanks to the technological evolution of the last 20 years, the latest boilers generation (the condensing ones) are far more efficient, fostering management economies that repay the investment in a short time.

On the other hand, the replacement of a traditional boiler with a condensing one may also entails considerable adaptation works on the system. In fact, for example, since 26 September 2015, implementing the Directive European2005/32 / EC, called “Eco-Design”, the Italian legislation requires that all new boilers must be condensing boilers. This entails the need to extend the work of merely replacing the machine body to the non-trivial adaptation of the flame emission system. Furthermore a series of mandatory interventions must be carried out to comply with the numerous safety regulations in force since 1980 to present.

This is the case of this condominium, as evidenced by the important cost item (Additional work) shown in the Table 6-1

Table 6-2 considers the complete case in which the renovation also includes the reduction in energy requirements obtained by improving the insulation of the envelope that separates the heated areas from those that are not heated. The reported values shown indicate that:

A. The realization of the coat on the perimeter walls reduces energy consumption by about 35%;

B. the insulation of the two floors separating the heated volume from the unheated one produces almost as much;

C. The substitution of windows presents a lower cost but also a less impact on the reduction of consumption. The reduction in is mainly due to the replacement of the frame: this is because the current technology, with the introduction of the so-called “thermal break” and better closing systems, allows to reduce heat dispersion up to 70% compared to traditional windows.

D. Thanks to the drastic reduction in heat requirements, the design power required by the boiler are considerably reduced, as well as its cost, making its replacement even more profitable.

Point B is explained by the fact that, traditionally, the floors of the condominium buildings used to be made all in the same way, granting above all structural safety. On the other hand they often completely neglect the problem of heat dispersion, with the result that these elements are far less thermal efficient than the external walls.

In the inter-floor slabs, since normally the neighboring rooms are normally kept at the same temperature, the heat dispersion is practically negligible. On the contrary in the floors at the borders of the heated zones, the temperature difference induces a thermal flow towards the outside and, due to the worst thermal properties of the floor, the intensity of the heat dispersion is much greater than that which triggers through the external perimeters walls.

It is also necessary to consider that the current provisions require heat metering for each unit. Consequently, the residents living on the top floor not only have a much lower level of comfort than all the other residents but they are also forced to pay a much higher energy cost.

In conclusion, the example of renovation herein described shows that just replacing the boiler produces a good economic return (about 5 years PBT), but a limited energy saving (12%). On the contrary, the complete renovation has a much lower economic profitability (more than 20 years PBT), but also it allows a 70% reduction in energy consumption, with a great environmental benefit.

Table 6-1: Replacement of the heat generator only

Interventions	U.M.	Quantity	Unit Cost	Cost	Cost Incidence	Heating Requirement	Energy Savings	Consumption Incidence	Bill Saving	Effectiveness	Simple Pay Back time
		a	b	c = a x b	di = ci / S ci	e	fi = eo - ei	gi = fi / eo	hi = fi x cugas	m = ci / hi	m = hi / ci
			(€ / U.M.)	(€)	(%)	(kWh_t)	(kWh_t)	(%)	(€)	(%)	years
As is		-	-	0	0%	355'840	-	-	-	-	-
Thermal power plant renovation	n°	-	-	43'950	7.8%	311'936	43'904	12.3%	3'777	8.6%	11.6
- Boiler replacement	kW	146	130	18'980	3.4%	311'936	43'904	12.3%	3'777	19.9%	5.0
- Additional works		1	24'970	24'970	4.4%	-	-	0.0%	-	0.0%	-

Table 6-2: Case of application of the external thermal coat and replacement of the windows

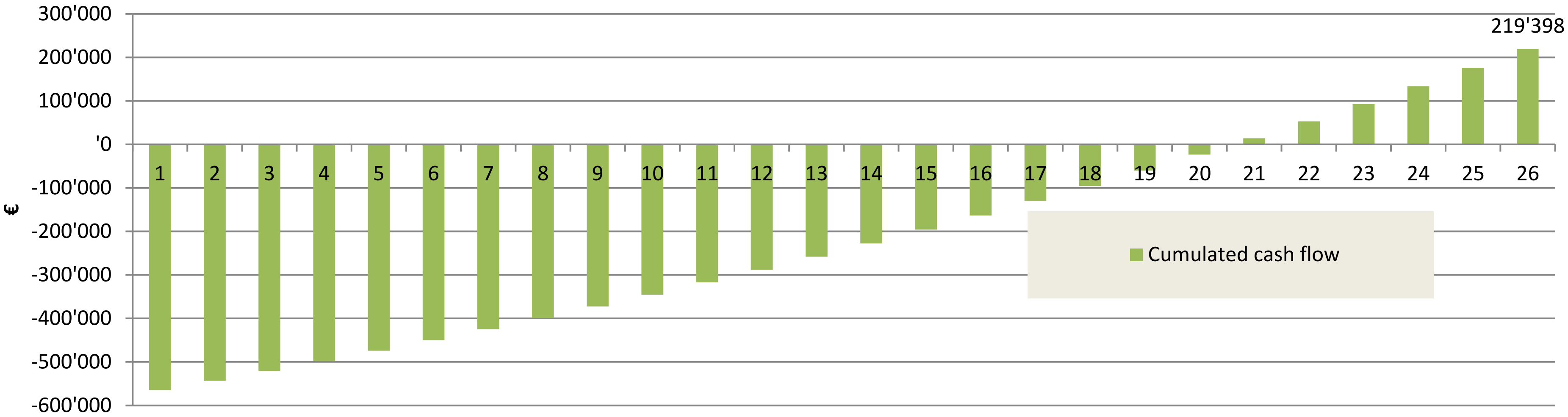
Interventions	U.M.	Quantity	Unit Cost	Cost	Cost Incidence	Heating Requirement	Energy Savings	Consumptio n Incidence	Bill Saving	Effectiveness	Simple Pay Back time
		a	b	c = a x b	di = ci / S ci	e	fi = eo - ei	gi = fi / eo	hi = fi x cugas	m = ci / hi	m = hi / ci
			(€ / U.M.)	(€)	(%)	(kWh_t)	(kWh_t)	(%)	(€)	(%)	years
As is		-	-		0%	355'840	-	-	-	-	-
Thermal power plant renovation	n°	-	-	35'370	6.3%	311'936	43'904	12.3%	3'777	10.7%	9.4
- Boiler replacement	*kW*	*80*	*130.00*	*10'400*	*1.8%*	*311'936*	*43'904*	*12.3%*	*3'777*	*36.3%*	*2.8*
- Additional works	*0*	*1*	24'970	*24'970*	*4.4%*	*-*	*-*	*0.0%*	*-*	*0.0%*	*-*
Vertical exterior thermal coat	mq	2'715	100.00	271'469	48.0%	230'625	125'215	35.2%	10'772	*4.0%*	25.2
Ceiling thermal coat towards attic	mq	432	100.00	43'196	7.6%	289'380	66'460	18.7%	5'718	*13.2%*	7.6
Ceiling thermal coat towards cellar floor	mq	423	100.00	42'261	7.5%	308'611	47'229	13.3%	4'063	*9.6%*	10.4
Frame replacement	mq	384	450.00	172'701	30.6%	283'142	72'698	20.4%	6'254	*3.6%*	27.6
- Glass replacement	*mq*	*384*	*100.00*	*38'378*	*6.8%*	*318'825*	*37'015*	*10.4%*	*3'184*	*8.3%*	*12.1*
- Windows replacement	*mq*	*384*	*350.00*	*134'323*	*23.8%*	*300'491*	*55'349*	*15.6%*	*4'762*	*3.5%*	*28.2*
All interventions	-	-	-	564'997	100%	98'789	257'051	72.2%	22'115	*3.9%*	25.5
Methane cost	€/Smc	0.81									
Methane cost = cugas	€/kWht	0.09									

Table 6-3: Cash flow calculation and profitability

Annual methane cost increase	%	5.0%
Discount rate	%	2.0%

Year	€	0	1	2	3	4	5	6	7	8	9	10	19	20	21	22	23	24	25
Own capital		564'997																	
Mortgage		-	-	-	-	-	-	-	-	-	-	-							
Savings (+) fuel consumption	€	22'115	22'115	23'220	24'381	25'600	26'880	28'224	29'636	31'117	32'673	34'307	53'221	55'882	58'677	61'610	64'691	67'925	71'322
Tax Deductions (+)		-	-	-	-	-	-	-	-	-	-	-							
Cash flow		564'997	22'115	23'220	24'381	25'600	26'880	28'224	29'636	31'117	32'673	34'307	53'221	55'882	58'677	61'610	64'691	67'925	71'322
Discounted cash flow	€	- 564'997	21'681	22'319	22'975	23'651	24'346	25'062	25'800	26'558	27'340	28'144	36'533	37'607	38'713	39'852	41'024	42'231	43'473
Cumulated cash flow	€	-564'997	-543'316	-520'997	-498'022	-474'372	-450'025	-424'963	-399'163	-372'605	-345'265	-317'121	-23'502	14'105	52'819	92'671	133'695	175'925	219'398

Pay back period	y	19.88
NPV	€	219'398
IRR	%	2.2
IP		0.39



6.4.1 The evaluation of the incentive

As pointed out in the previous Section 3.4, Ecobonus is undoubtedly the most appropriate incentive for a condominium, as it is the only that facilitates the expensive interventions on the coat for private subjects. So, after the (non-trivial) technical verifications prescribed by the regulations, it results that tax incentive percentages applicable to the case are:

- 65% (and not 50%) for the renovation of the thermal power plant, as the selected plant meets the advanced technical characteristics required by the legislation to be able to access this incentive level.
- 70% (and not 75%) for all other interventions.

Operationally, in order to determine the value of these parameters with reasonable certainty, considerable technical work is required. In this case, the mere calculation and drafting of the technical report took 7 workdays, plus the time necessary to perform the inspections, recover the documentation, participate in technical and condominium meetings.

This is because, in order to get the incentives it is necessary to verify compliance with the numerous rules and “interpretations”. Mandatory references are:

A. Law 11 December 2016, n. 232, "State Budget for the 2017 financial year and multi-year budget for the 2017-2019 three-year period, Art. 1 - Section 2 - point a.3.

B. Budget law 2019 (law n.145 dated 30 December 2018).

C. Revenue Agency, tax breaks for energy savings, updated March 2019.

D. National Energy Efficiency Agency - Enea, Vademecum deductions for energy renovation of common parts of buildings condominiums, updated 29.05.2019.

E. National Energy Efficiency Agency - Enea, Vademecum deductions for condensing boilers for condensing air generators, updated 05.29.2019.

to which, the following must be added

F. DM 06.26.2015 "Adaptation of the decree of the Minister of Economic Development, 26 June 2009 - National guidelines for the energy certification of buildings",

G. Ministerial Decree of 26 January 2010 "Update of the decree of 11 March 2008 on the energy requalification of buildings"

H. DGR Lombardy Region 2456/2017, text on energy efficiency of buildings

In particular, from the indications provided by Enea in its “vademecum”, it is concluded that the documentation necessary to get the incentives consists of:

1. Description of the complete intervention signed by a qualified technician.
2. Asseveration prepared by a qualified technician who must certify compliance with all national and local laws and regulations on energy efficiency;
3. Energy Performance Certificate (APE) of each individual property unit for which deductions are requested;
4. Technical data sheets of materials and components

In article 4, Section 4 of Ministerial26 June 15, we read: “*Decree of Each APE (Energy Performance Certificate) is drawn up by a qualified person pursuant to the Presidential Decree of 16 April 2013, n. 75 and it obligatorily reports, for the building or for the real estate unit, under* ***penalty of invalidity****:… .. the recommendations for improving energy efficiency with the proposals of the most significant and economically convenient interventions, distinguishing important restructuring interventions from those of energy requalification*”.

From this set of regulations it is concluded that, prudently, it is necessary to draw up before the execution of the interventions an Energy Audit (in any case mandatory in the event of replacement of a generator of power grater than 100 kW), in which the current efficiency energy is evaluated, presented the possible improvements, identified among these the optimal intervention also taking into account the needs of the client.

For the case study examined here, Table 6-4 summarizes the analytical results of the 5 distinct interventions examined, for each of them the following analysis were carried out: energy analysis, economic and environmental benefits, cautions and interactions with other interventions, cost factors, check of regulatory and legislative technical references.

The complexity of the calculations necessary by law requires the use of specialized software with the consequent high risk of using it with detachment, as a black-box, losing the engineering control on calculation. The analysis is further complicated by the high number of rules that have accumulated over the years, by the continuous changes the standards already issued, by the lack of a single text that collects them systematically, and by the interpretative difficulties of these rules.

For example, for the renovation interventions of the external facades of a building, the 70% rate is obtainable with the simple verification that the intervention involves at least the 25% of the gross dispersing surface. On the contrary, to obtain the rate of 75% it is first of all necessary to perform two complete energy analyses; then, from the results obtained, it is necessary to calculate some indicators that, according to the legislator, allow to evaluate the quality of the envelope. But apparently the requirements imposed are so restrictive that it is impossible to satisfy them.

All this seems to be confirmed by the case reported in the Table 6-4 where the required rate is 70% even if the engineering common sense would lead to the conclusion that the intervention has all the ideal conditions to obtain 75%: very bad insulation in the current state (Energy Class G), excellent insulation in the state of project (Class A1), both in summer and winter.

For this reason, an in-depth analysis was performed to determine the origins of these impediments. Apparently the problem lies merely in a clarification contained in the handbook distributed by Enea for which the requirement set by the law, that literally reads

"same interventions as in point a) aimed at improving the winter and summer energy performance and at least achieving" average quality media "as in tables 3 and 4 of Annex 1 to Ministerial Decree 26/06/2015"

a further (arbitrary) clarification was added

*"the building envelope of the entire building must have, before the intervention, **low quality** and, after the intervention, at least **average quality**,"*

In this case study, the analytical expressions given by the norm estimated the quality before the intervention as "***average***" and the one after the intervention as "***high***". So the fact that in the present state the quality resulted to be "average" instead of "low" prevents the access to 75%.

Certainly it is puzzling that the calculation procedure apparently is not consistent with the judgments on quality of the external facades. It is even more puzzling that interpretative notes that make substantial changes to the law, approved by the whole government, are released while their author remains unknown.

Complicated procedures, over-regulation, interpretative uncertainty motivate the request of many professionals to consolidate what has been legislated so far through a systematic and certain framework law.

6.4.2 The net cost of intervention

Table 6-4, compared with Table 6-3, exemplifies the economic-financial benefits that the Ecobonus brings in the interventions for energy requalification. It is important to note that due to the tax refund:

- The net cost of renovation is reduced of about 70%.
- The investment payback time is halved of about 10 years.
- The profitability of the investment, expressed by the IRR, is almost quadrupled, reaching the interesting value of 8.4%

Obviously these advantages considerably increase the number of condominiums that can face the expense. In fact Table 6-2 shows the cost that each owner must face according to the type of intervention implemented. In particular:

Case 1 represents the reference case in which the condominium pays the full price (without deductions) by using only their own funds. The amount each apartment have to pay is approximately € 23,500 (230 €/mq) which, due to the saving in energy consumption, it can be recovered in about 20 years;

Case 2 assesses that, thanks to the annual repayment due to the Ecobonus, the return time is halved.

Case 3 hows that the Ecobonus and the use of a bank loan allow the condominium to carry out the renovation at a net cost of just € 560 (= energy savings + tax deductions – loan mortgage) per year for 12.4 years.

Table 6-4: calculation of cash flows and profitability in the case of Ecobonus

Interventions	U.M.	Quantity	Unit Cost	Cost	Incentives	Tax deduction	Net Cost	Bills savings	Simple Pay Back time
		a	b	c = a x b	d	e = c x d	f = d - e	g	mi = fi / gi
			(€ / U.M.)	(€)	(%)	(€)	(€)	(€)	anni
Thermal power plant renovation	n°	1	35.370	35.370	65,0%	22.991	12.380	3.777	3,3
Vertical exterior thermal coat	mq	2.715	100	271.469	70,0%	190.028	81.441	10.772	7,6
Ceiling thermal coat towards attic	mq	432	100	43.196	70,0%	30.237	12.959	5.718	2,3
Ceiling thermal coat towards cellar floor	mq	423	100	42.261	70,0%	29.583	12.678	4.063	3,1
Windows replacement	mq	384	450	172.701	70,0%	120.891	51.810	6.254	8,3
Total	-	-	-	564.997	69,7%	393.729	171.268	22.115	7,7

Intervention		Boiler	Thermal Coat
Max amount for each housing unit	€	30.000	40.000
n. real estate unit	N	24	24
Maximum total amount	€	720.000	960.000
Total amount	€	22.991	249.848

Annual methane cost increase	%	5,0%
Discount rate	%	2,0%
Useful life of the project	Year	20,00
NPV (net present Value)	€	367.776
PBT (Pay Back Time)	N	9,4
IRR (Internal Rate of Return)	%	8,4
IP (Van / Investment)		2,15

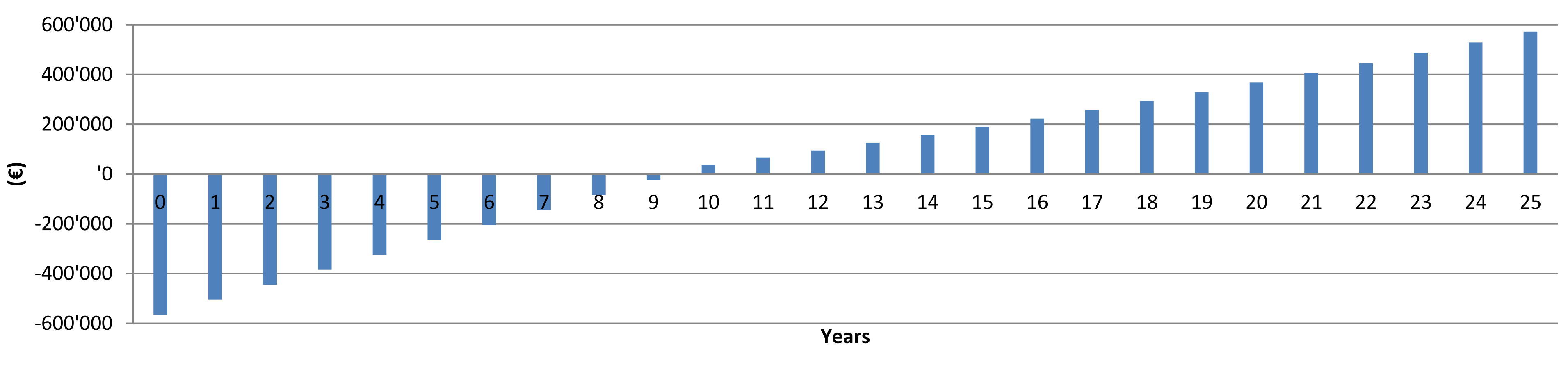


Table 6-5: comparison of costs and economic-financial results for the case study

		Case	-	1	2	3	4	5
		Ecobonus		No	Yes	Yes	Yes	Yes
		Mortgage Payment		No	No	Yes	Yes	Yes
		Transfer of tax credit		No	No	No	Yes	Yes
A		Total cost of the work	€	564'997	564'997	564'997	564'997	564'997
B		Total tax credit	€	-	393'729	393'729	393'729	393'729
C		Commission on Ecobonus value	%	-	-	-	25.0%	45.0%
D	= B x (100% - C)	Income from the tax credit transfer	€	-	-	-	295'297	216'551
E	= A - D	Net total cost of the work		564'997	564'997	564'997	269'700	348'446
F		Own capital		564'997	564'997	-	-	-
G	= E - F	Funded capital	€	-	-	564'997	269'700	348'446
H		Interest Rate	%	-	-	5.5%	5.5%	5.5%
I		Mortgage Duration	Year	-	-	10	10	10
L	= f(G,H,I)	Mortgage payment	€	-	-	74'957	35'780	46'228
M		Bills saving	€	22'115	22'115	22'115	22'115	22'115
N	= B / 10	Annual tax deduction	€	-	39'373	39'373	-	-
O	= L - M - N	Annual cost	€	- 22'115	- 61'488	13'469	13'666	24'113
P		n. real estate unit	N	24	24	24	24	24
Q	= A / P	Net total cost per condominium	€	23'542	23'542	-	-	-
R		Amount financed by the loan	€	0	0	23'542	11'237	14'519
S	**= M / P**	**Annual cost per condominium**	**€**	**- 921**	**- 2'562**	**561**	**569**	**1'005**
		Annual methane cost increase	%	5.0%	5.0%	5.0%	5.0%	5.0%
		Discount rate	%	2.0%	2.0%	2.0%	2.0%	2.0%
		Useful life of the project	Anni	20.0	20.0	20	20	20
		NPV - Net present Value	€	14'105	367'776	259'466	462'994	163'859
		Payback time	Anni	19.9	9.4	12.4	12.5	15.41
		IRR (Internal rate of return)	%	2.2	8.4	16.4	16.2	8.5
		IP (NPV / Investment)		0.4	1.0			
		IRR (credit buyer)	%				5.6	12.7

6.5 Transfer of Tax Credits from Ecobonus

We remind from Section 3.5 that the major obstacles that have limited the use of the Ecobonus is the so-called “fiscal capacity” (*capienza fiscale*), that is the ability of the taxpayer to reduce the income tax using the Irpef deductions of that year. This mechanism unfavorably affects the less well-off classes and in particular the pensioners, or those who would need it most. In the case of condominiums, however, the consequences extend to all condominiums as the less well-off subjects, being unable to bear the costs, block the approval of the redevelopment works.

The Transfer of tax credits introduced by Law 205/2017 consists in the possibility to ”sell“ its own Ecobonus to the contractor. In this way, all taxpayers, even those who do not have sufficient "fiscal capacity", can benefit from the immediately (against the 10 installments of the same amount recognized as a reduction in the personal income tax or IRES tax due). The benefit achieved is therefore twofold: 1) all taxpayers can access the Ecobonus. 2) immediate reduction of the amount due to the contractor and, consequently, a reduction of the amount to be requested as a bank loan and of the financial costs connected to it..

Clearly the price payed by the contractor cannot be equal to the entire amount of the deduction as the contractor must take into account the monetary cost due to the anticipation of a capital that will be returned over a period of 10 years.

Case 4 and Case 5 reported in Table 6-4 shows the results in case of the Transfer of Credits described in Section 3.5.1: The only difference between these 2 cases is the value of the Commission on Ecobonus value required by the contractor to purchase the Ecobonus. In fact, it should be noted that the purchase value of the Tax Credits, like any other asset for sale, is assigned by the market following the law of supply and demand. Therefore:

Case 4 the buyer recognizes 75% of the value of Credit to the seller. Even if the seller receives a value reduced by 25% due to the lower financial cost linked to his bank financing, he does not suffer any real economic loss. In fact, as in case 3, the condominium has the same annual economic burden of about € 560. For the buyer this investment represents an IRR= 5.6%.

Case 5 the buyer recognizes 50% of the value of Credit to the seller. Consequently, the buyer is able to raise the profitability of his investment to 12.7% to the detriment of the condominium, which increases its annual economic annual cost to around € 1,000.

Apparently Case 5 is the one that best represents the current market offer which however is constantly evolving due to the changes that are made to the existing normative: for example the very recent law 34/08/2019 has made numerous changes including that for which, apparently, there are particular circumstances where the buyer could discount the Transfer of Credits in just 5 years bringing the profitability of Case 5 to 24%.

With the Transfer of Credit, a typical family living in a condominium could receive the following benefits:

- Almost halve the size of the initial capital from € 23,500 to about € 14,500 per person;
- Be able to guarantee to the bank that with a 10-year mortgage the additional family economic commitment is just € 1,000 a year.

6.5.1 Tax Credit Transfer for nZEB renovation

As stated in Section 6.4 the requalification analyzed so far is designed to reach level A1, namely of the so-called reference building. In the 3° Part of this Thesis it will be specified that this energy class is that obtainable by respecting all the minimum values of transmittance of the external envelope of the building and of efficiency and efficiency of the heating system established by law in that specific climatic zone (DM 26/6/2015, so-called "Minimum Requirements Decree").

The nZEB level, in addition, requires that more than 50% of the energy consumed by the building be renewable. To this end, the national energy plan adopted by Italy, PNIEC 2019 – Section 4.5.1, is hoping for an increasing diffusion of thermal plants composed of heat pump powered by a photovoltaic system built on site.

Specifically, applied to the condominium analyzed here, to reach the nZEB level it is necessary to integrate the works envisaged in the Section 6.4 with:

a) The installation of an electric heat pump instead of the condensing boiler, included the installation of technical water tanks;
b) Substitution of the distribution and emission system (fan coil), according to Chapter 4.5.2;
c) Installation of a 30 kW photovoltaic system in combination with the heat pump.

The following Table 6-6 reports the comparison between:

- The Standard intervention, i.e. the redevelopment work shown in the Section 6.4 which allows you to reach level A1, that is, the one corresponding to the so-called *reference building*. In particular this is the case reported in Table 6-5 case 5
- NZEB intervention, i.e. the same redevelopment work integrated as reported above that allows you to bring the building to the nZEB level.

The cost difference between the two cases is € 114,630, about the 20% of the total amount, in line with the ministerial estimates shown in Figure 4-12. Applying the "transfer of the credit", the difference in costs decreases to about € 61,275. Moreover, the greater efficiency of the heat pump compared to the boiler and, above all, the energy produced by the photovoltaic system, guarantee a further annual saving in the bill of about € 4'249. Hence the final difference of the total annual cost is € 3'880, about the 16%, that is just 162 €/year for each individual condominium.

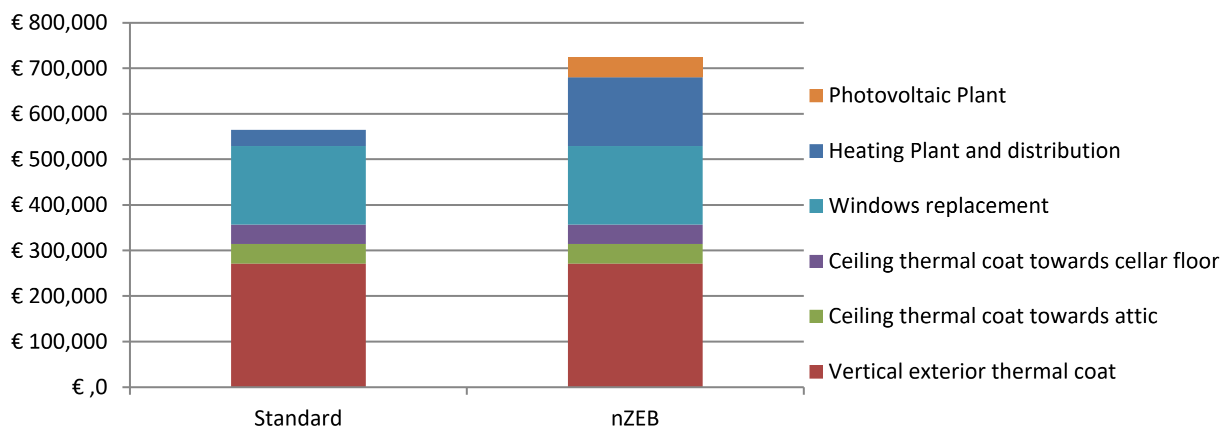
6.6 Conclusion

As observed in the year 2019, the combination of increasing the incentives and the possibility of monetizing them immediately, transferring the tax credit to the contractor, seems to have finally cracked the resistance in undertaking energy redevelopment works. This is particularly true in the condominium sector where, above all, the possibility of transferring the tax credit has significantly reduced the number of people who, being "*incapienti*", have up to now blocked the required approval of the condominium assembly.

The example shown in this chapter of a redevelopment work of a condominium in a non-central area of Milan, has allowed to quantify that the real average cost that the owner of an apartment of about 90 square meters has to bear can be contained among the 600 ÷ 1'000 € / year for 10 years. It is referred in particular to the 4 case in Table 6-5 of a renovation in class A1, with tax credit transfer and bank loan taken out for the excess cost. We remind you that in addition to the coat, this work included the replacement of the centralized boiler which had now reached the end of its life having more than 20 years of use.

Table 6-6: Comparison between traditional and nZEB intervention

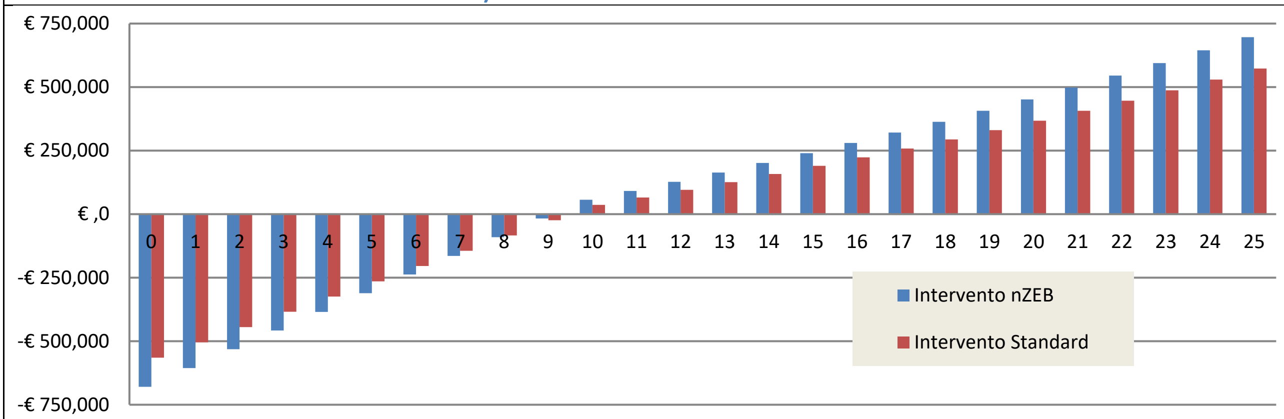
a) Cost allocation



b) Economic and financial result

		Case		A) Standard	B) nZEB	B) – A)	
		Ecobonus		Yes	Yes		
		Mortgage Payment		Yes	Yes		
		Transfer of tax credit		Yes	Yes		
A		Total cost of the work	€	564'997	679'627	114'630	20%
B		Total tax credit	€	393'729	490'739	97'010	25%
C		Commission on Ecobonus value	%	55.0%	55.0%	-	
D	= B x C	Income from the tax credit transfer	€	216'551	269'906	53'355	25%
E	= A - D	Net total cost of the work	€	348'446	409'721	61'275	18%
F		Own capital	€	-	-	-	
G	= E - F	Funded capital	€	348'446	409'721	61'275	18%
H		Interest Rate	%	5.5%	5.5%	-	0%
I		Mortgage Duration	Year	10	10	-	0%
L	= f(G,H,I)	Mortgage payment	€/ Year	46'228	54'357	8'129	18%
M		Bills saving	€/ Year	22'115	26'364	4'249	19%
N	= B / 10	Annual tax deduction	€/ Year	-	-	-	
O	= L - M - N	Annual cost	€/ Year	24'113	27'993	3'880	16%
P		n. real estate unit	N	24	24	-	0%
Q	= A / P	Net total cost per condominium	€	-	-	-	
R		Amount financed by the loan	€	14'519	17'072	2'553	18%
S	**= M / P**	**Annual cost per condominium**	**€**	**1'005**	**1'166**	**162**	**16%**

C) Cumulated cash flows for traditional



It should also be noted that following these works, it has been estimated that the building's real estate value has increased from around € 1,800 / m2 to € 2,400 / m2, therefore an apartment of approximately 90 m2 has increased in value by approximately € 54,000. All summarized as follows

Note		Building		Flat	
A	N. real estate unit			N	24
B	Net habitable surface (flats)	mq	2'072	mq	86
C	Net total cost of the work	€	348'446	€	14'519
D = C / B	Net cost of the work per unit area	€/mq	168		
E	Mortgage payment	€/year	46'228		1'926
F	Bills saving	€/year	22'115		921
G = E - F	Annual cost	€/year	24'113		1'005
H	Building value as is	€/mq	1'800	€	155'400
I	Building value after renovation	€/mq	2'400	€	207'200
L = H - I	Increased value	€/mq	600	€	51'800
M = L / H		%	33%	%	33%

which objectively represents for the condominiums a low-cost and very profitable economic operation.

However, the market still has strong resistances, many of which chargeable to the following widespread uncertainties:

- Unclear legislation, subject to too many continuous variations and with too many (believed by many specious and useless for the purpose) technical requirements.
- Fear that this lack of clarity may lead to disputes with the Revenue Agency with the consequent failure (or simply late) recognition of the Ecobonus.
- Little transparency in the offer to buy Ecobonus

In fact, the record shows many cases of disputes brought by the Tax Agency for divergent interpretations of the legislation. The dangerous lies in the fact that these disputes arise after the works have been carried out and that, therefore, the condominiums have made solvent economic commitments only with the recognition of the Ecobonus. In addition the objection by the Agency has an immediate economic effect, with the activation of a compensation procedure, where instead it would be right to wait for the third judgment by a court.

In this regard, it should be noted that by law, even in the case of Tax Credit Transfer, the condominium remains always the responsible to the right to the Ecobonus. This responsibility concerns all aspects of the redevelopment work: from checking the compliance of the project with the many technical requirements imposed by the legislation to checking the actual execution of the related redevelopment works. A dispute with the tax authorities entitles the buyer to compensation for the sum paid.

Clearly, the presence of this multitude of requirements makes the condominium incapable to carry out on its own a precise check and, thus, it has necessarily to rely on the professionalism of its technical interlocutors. On the other hand, with the introduction of the Tax Credit Transfer, all-inclusive turnkey packages immediately appeared on the market where the contractors offer the design, the execution of the work, the construction supervision and the purchase of Ecobonus Tax Credits.

Apparently these packages allow the condominium to carry out the work at a consistent discount compared to the current full prices and, at the same time, relieve it from all the complicated fulfilments for obtaining the Ecobonus. Instead, they are extremely dangerous, because they completely exclude the condominium from control, by exposing it to the risks of dishonest entrepreneurs that to win the contract elude the full compliance to the legal requirements that allow the recognition of the Ecobonus.

In conclusion, although the Ecobonus seems to have found a potentially effective direction, to apply it extensively it is necessary to operate a series of targeted actions, such as, for example:

1. Simplify and stabilize the regulations for a long period so that, through the testimonies of those who have actually successfully used the Ecobonus, existing mistrust can be removed
2. Carry out an information campaign to make the terms and benefits of the Ecobonus well known, clearly highlighting roles and responsibilities. Consequently, the condominium will feel the need to protect itself by differentiating the role of the designer, to whom it will directly entrust the task of the design, from that of the company that will carry out the requalification work in compliance with design.

7 New nZEB buildings: the impact of BIM design and Building Automation

7.1 Introduction

Directive 31/2010 / EC provides that starting from January 2019 all new public buildings or buildings subject to major renovations must be nZEB . In 2021 this obligation will also be extended to private buildings. In some Italian regions, such as Lombardy and Emilia Romagna, this obligation was brought forward to 2016.

As reported in the previous two Chapters, the Italian government offers different types of economic incentives for existing buildings that significantly reduce renovation costs. For new buildings, however, there are no incentives to cover the additional costs that the construction of an nZEB building involves compared to the "*traditional*" ones. In this regard, a research study was conducted in this thesis to demonstrate that by using modern design tools and technologies currently available, it is possible to fill this gap.

This Chapter reports the result of this study which consists in the project of a new nZEB condominium to be built in Southern Italy: in summary, thanks to the use of innovative systems, the building has a construction cost comparable to that of a traditional building (1’100 € / mq); on the other hand, energy costs are substantially zeroed for both common and private uses.

It should be noted that this project, considered innovative by ENEA, was included in the 2018 Annual Energy Efficiency Report (page 95) presented to the Italian government in June 2018, as a success story for the application of the BIM project for nZEB (ENEA, 2018). At this link a video-presentation of the project is available: https://www.youtube.com/watch?v=2HzKjDxu9ZY.

In particular, the building was entirely designed in BIM, both as regards the architectural, structural and technological systems aspects, Section 7.2. Furthermore, the latest generation of BIM software, suitably integrated and calibrated for the purposes of this research, has also allowed to calculate the energy thermal needs by means of the so-called “dynamic method”, using the same geometric model developed for architectural and structural modeling .

The heat requirement is met through a system consisting of two multi-purpose 40 kW air-water electric heat pumps; in the summer, this system is able to generate domestic hot water from the waste heat deriving from the production of cold water used for cooling.

The annual electricity demand is entirely met by a photovoltaic system installed on the roof of the building, Section 7.3. The energy consumed and the energy produced are balanced on a daily level, but not always on an hourly level, requiring an exchange of electricity with the grid. A research, still in progress, is studying a system of electrical and thermal storage which, combined with a control system designed *ad hoc* by Building Automation (BA), is able to satisfy also the evening needs.

In this regard, it was deemed necessary to carry out a detailed study of the current BA legislation in Italy in advance: in particular, this has concerned mainly the study of the new version of the UNI EN 15232 standard which, came into force in 2016, intends to set a minimum level of BA functions that must be present in new and renovated buildings.

In fact, this standard is still to be considered in the verification phase and in this study it was intended to deepen the following aspects, Section 7.4: in which class of BA can a new nZEB building fall according to UNI EN 15232? How does the UNI EN 15232 standard take into account the peculiarities of nZEB buildings? What is the cost-benefit impact of moving from the minimum class that an nZEB building must have to the next one? What is the role of BIM in the design of this type of plant and what are the possible future scenarios in this regard?

7.2 The case study

7.2.1 Description of the building and design choices

Figure 7-1 shows a rendering of the nZEB building designed in this research study. It is a residential building located in Crotone of 5 floors (ground floor for garages, 3 residential floors and a last floor used as a technical room).

It consists of 12 apartments of 3 different sizes (90, 100 and 110 mq), plus 3 large attics (two from 143 and one from 123 mq). The total commercial area of the building is 2’650 mq. Figure 7-2 shows two significant tables of the project with an indication of the main geometric characteristics of the condominium and the related guidelines. The building is classified into class A4 – nZEB according to national energy legislation.

The structure of the building consists of a load-bearing masonry in polystyrene disposable formwork (Figure 7-3). This is an innovative construction system to create reinforced concrete walls based on formwork consisting of two EPS panels facing each other and connected by spacers, in which the iron is housed in the cavity and cement is cast.

Figure 7-1: Building front view

Among the many advantages of this solution we mention: the double layer of EPS which guarantees thermal and acoustic insulation; the reinforced part gives the structure anti-seismicity, allowing the use of fewer pillars, thus making the management of the building spaces more free; the assembly of blocks (in the LEGO Way) is simple to install as it does not require specialized labor and large equipment.

Hence this construction solution allows to obtain an excellent thermal and seismic performances with a significant reduction in the cost of construction compared to the traditional beam and pillar system.

On the roof is installed a 42 kW photovoltaic plant that feeds the heat pumps and the other condominium facilities, plus another 15 plants of 3 kW, one for each housing unit, to power the private electricity needs, Figure 7-4.

In the attic, under the roof, there is the technical room divided into 2 symmetrical areas in each of which the technological central systems are installed to service the apartments located on the vertical below, Figure 7-5. The technological networks that connect the central systems to the apartments are located in the two cavedio located next to the stairs.

Regarding the HVAC system, given the preponderant demand for cooling compared to heating, a fan coil system was chosen. The fan coil system is powered by two 40 kW air-water polyvalent heat pumps placed outside the technical room on the top floor: thanks to this technology, the plant is able to generate the ACS from the heat wasted during the production of the climatic cold water..

The generation and distribution plants are separated through the use of DHW storage tanks and technical water, Figure 7-6. Because of the need to install a VMC plant, it was decided to allocate all the distribution systems (air conditioning, ACS, electrical system) inside the false ceiling, in order to reduce installation costs and to break the walls as little as possible, Figure 7-8.

Table 7-1 shows the cost of the building that is absolutely in line with the traditional buildings while respecting all the nZEB requirements

Table 7-1: Summary of the building costs

Cost of construction	€	1'919'067
Total area of the apartments	mq	1'646
Construction Cost = total cost / area of apartments	€/ mq	1'166
Total cost (including fees, charges and land)	€	3'253'557
Commercial Area	mq	2'590
Commercial Cost = Total Cost / Commercial Area	€/ mq	1'256

Figure 7-2: Geometric data and significant tables - Original figure

Dati di Progetto	U.M.	Valore
N.Piani	n.	5,00
N. Appartamenti	n.	15
Superficie Appartamenti	mq	1'646
Supercie Accessi	mq	391
Supercie Locali tecnici	mq	635
Supercie Garage	mq	574
Supercie Lorda Pavimentata	mq	3'244
Superificie Commerciale	mq	2'650
Altezza Interpiano	m	3,5
Volume urbanistico	mc	5'759
Superficie Lorda Disperdente	mq	1710
Superficie Lorda Disperdente Vetrate	mq	259
Rapporto di Forma S/V	1/m	0,30

Dati Geometrici Edificio

Primo e Secondo Piano 1:300

Attico 1:300

Figure 7-3: Construction system with disposable formworks - Original figure

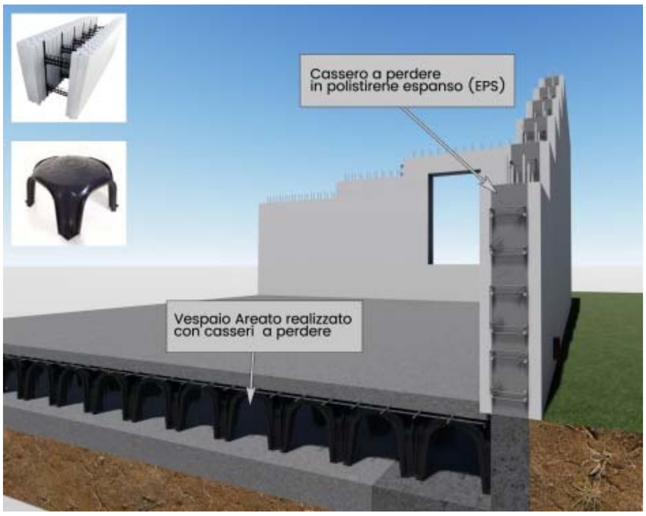


Figure 7-4: Photovoltaic plant of 42 kW + 15 x 3 kW installed on the roof.

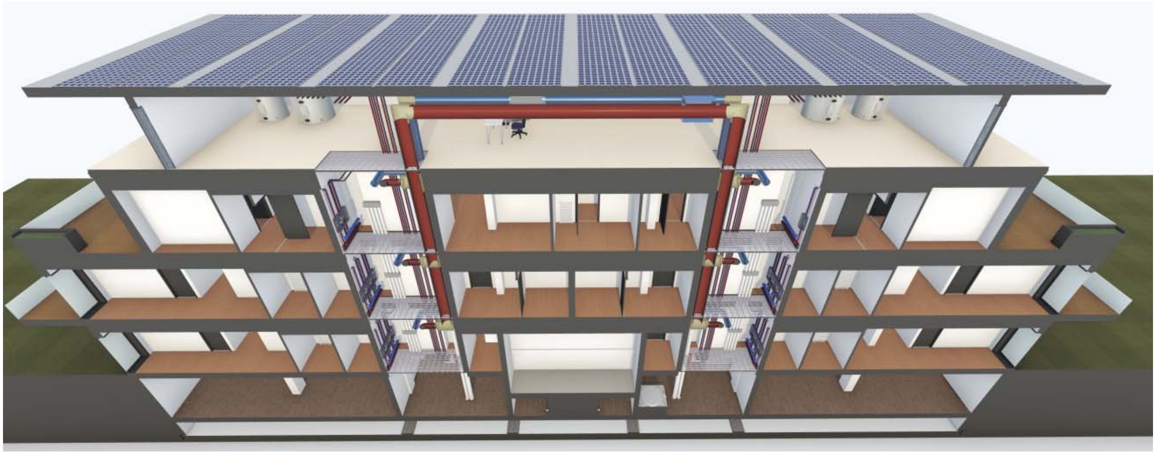


Figure 7-5: Section across the cavedium for the placement of technological networks

Figure 7-6: Left side ot the thermal power plant (the right side is symmetrical) - Original figure

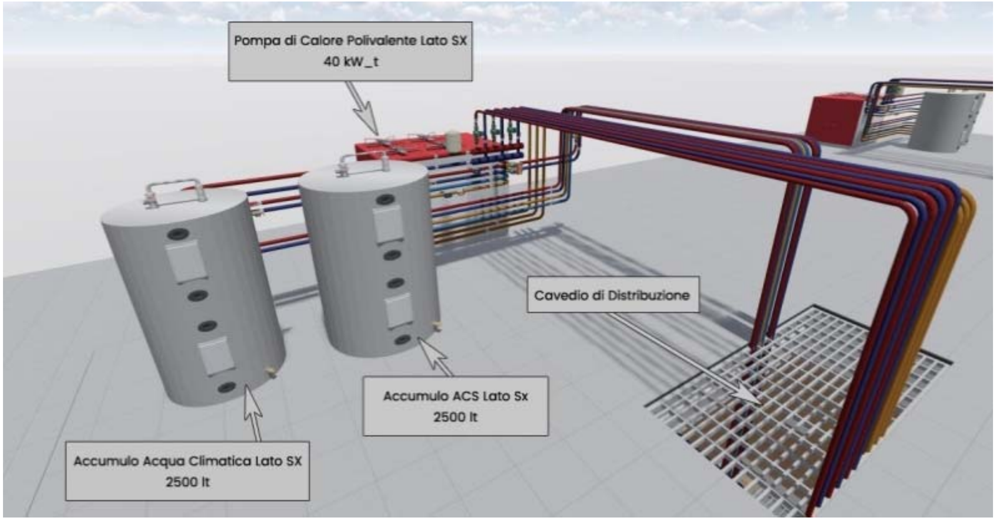


Figure 7-7: Technological network inside the cavedio

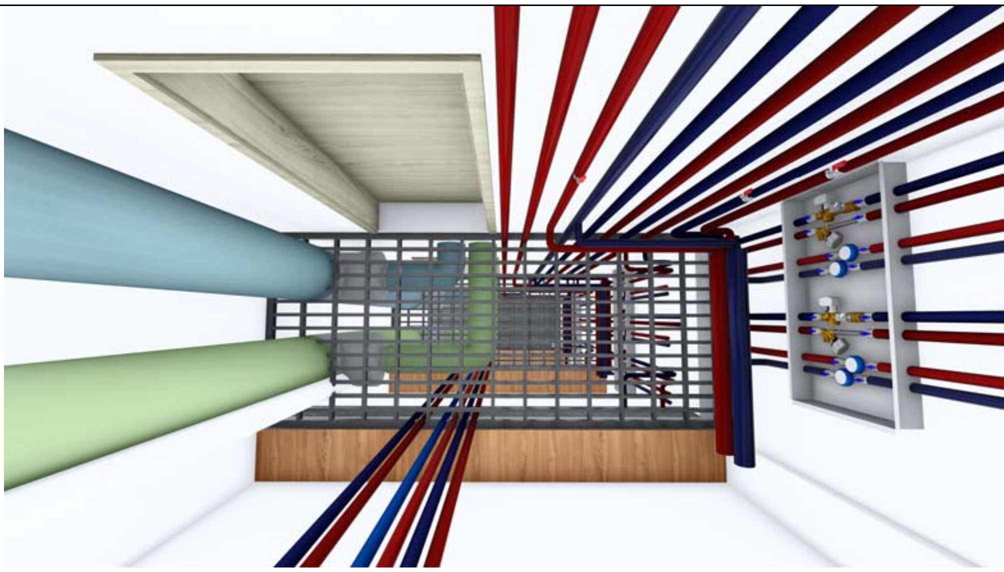
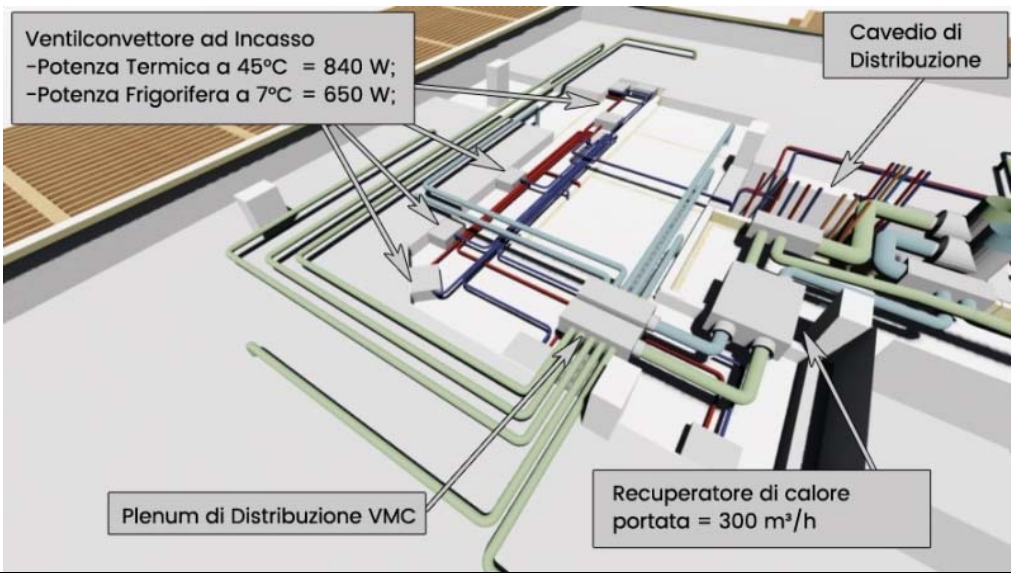


Figure 7-8: Left side ot the technological network allocated through the false ceiling - Original figure



The presence of load-bearing walls in reinforced concrete, which are extremely difficult to modify once they are made, and the dense technological network that must be installed, makes it absolutely necessary to develop the project in an integrated manner taking into account, from the outset, all the installation and structural requirements.

For this reason, the project was developed entirely in BIM (Building Information Modeling), with particular regard to architectural modelling, structural and thermal design, metric calculation, MEP modeling of thermal and hydraulic plants, video-rendering and photo-rendering

It should be noted that BIM is currently only a methodological indication in which the project development is envisaged through the integration of the various calculation procedures present in the project through specialized SWs which, although completely distinct, are capable of sharing the same database: geometric characteristics of the building, physical properties of the materials, technical results calculated by the other SW. As a rule, the main user interface is a 3D CAD which also allows the graphic representation of the results produced by the various SWs.

With Directive 2014/24 / EU, the European Union has introduced some guidelines to member countries on the use of the BIM system in the design and construction of public works. The BIM system is therefore strongly encouraged as a means of increasing the effectiveness and transparency of procurement procedures. It is important to underline that in the text of the directive there is no explicit reference to the use of particular software, but rather to the creation of methodologies for managing and verifying the data constituting the whole building process. Europe also sets a period of thirty months for Member States to transpose these directives.

As regards the dissemination of the BIM procedure to European operators (designers and companies), from the data released in 2013 by the European consultancy firm Arch-Vision (Q4 2013 European Architectural Barometer), strong differences emerge according to the countries. The state of the art appears to be the Netherlands followed by the United Kingdom while Italy ranks in the bottom position.

So to develop this project it was necessary to carry out a long work for the creation of the BIM platform in which the SW adaptable to the purpose were identified, the accuracy of their results verified, the compliance with Italian regulations checked and the necessary exchange data procedures were built.

7.2.2 Calculation of energy requirements through dynamic simulation

In accordance with European directives, the Italian legislation requires that the heat requirement of a building, as well as its energy class, is calculated through the so-called "quasi-steady " method defined according to UNI 11300.

Referring to the next Chapter 12 for an in-depth examination, here we limit ourselves to anticipating that this method can calculate the thermal demand of the building on an average monthly basis while, for the purposes of this project, it is necessary to calculate them on an hourly scale, so as to be able to superimpose the request for electricity by the thermal generator with the availability of solar energy.

For this purpose it was necessary to resort to the more refined methodology called "*dynamic analysis*" which allows a much more precise and realistic assessment of the behavior of a building, as it not only performs an analysis on a daily hourly scale but, also, adequately considers all the variable factors that affect the behavior of a building and the resulting energy balance. In dynamic analysis, factors such as the thermal inertia of the envelope, internal contributions and changes in the conditions of use of the environments, solar contributions and the change in external climatic conditions are taken into account how they happen in reality during the day.

Unfortunately, up to three years ago when this research study started, the only SW accredited by the academic world to carry out this type of analysis was only EnergyPlus which, however, was devoid of a graphical interface and, also for this reason, extremely complicated and time consuming to use it. A couple of other SWs have recently been released which, having a graphical interface, are much simpler to use but, on the other hand, there is no certain evidence of having already passed a complete validation by the scientific world.

This project was therefore preliminarily developed by making sure that the building was in compliance with UNI TS 11300 and in the nZEB class from the quasi-steady analysis. Then the thermal study was refined through the dynamic analysis first carried out with EnergyPlus and then with EcoDesigner, a much more recent SWs equipped with a satisfactory graphical interface.

Figure 7-9 ÷ Figure 7-11 show the main results of this analysis. In particular, Figure 7-9 shows the monthly thermal energy requirement of the building and, as expected given the geographical location of the site, the cooling requirement in summer (60,993 kWh) is significantly higher than the heating requirement in winter (1,346 kWh). .

Figure 7-9: Monthly thermal energy needs of the building from dynamic analysis

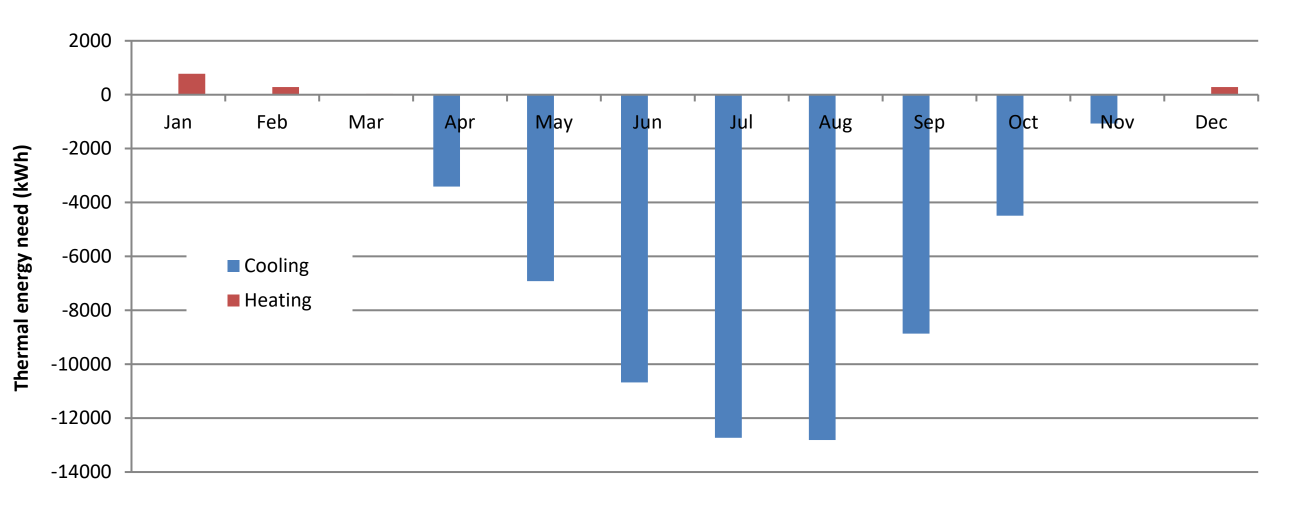


Figure 7-10: Electricity consumption for condominium services [kWh]

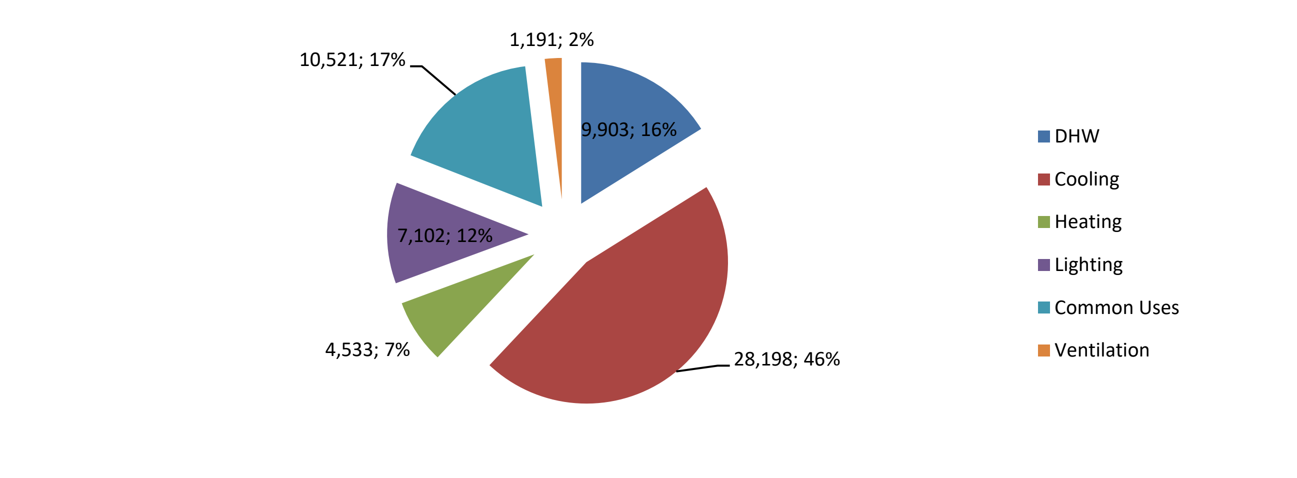


Figure 7-11: Electricity required from the building and produced by the photovoltaic plant

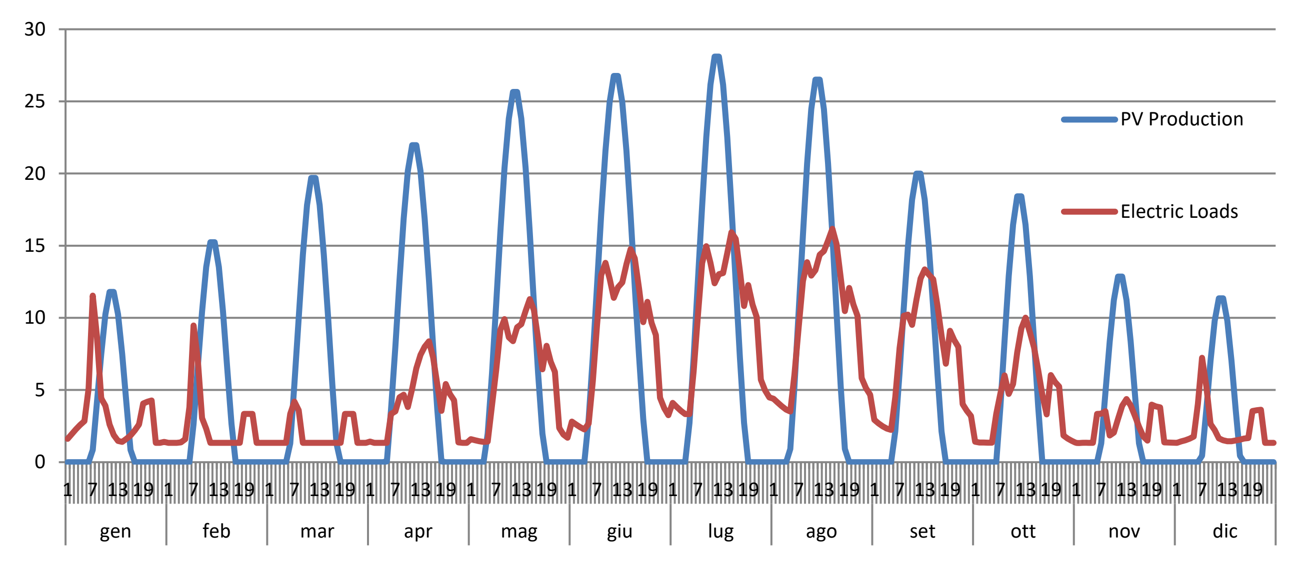


Table 7-2: Electricity consumption for private use and condominium services

Electric consumption for condominium services			
A	the whole building	kWh	61'448
B = A / 15	per apartment	kWh	4'097
Electricity consumption for private use			
C	per apartment	kWh	4'500
D = C x 15	the whole building	kWh	67'500
Total electric consumption			
E = A + D	the whole building	kWh	128'948
F = B + C	per apartment	kWh	8'597
G = F x 0.25	annual cost	€	2'149

Figure 7-10 shows the total electricity consumption for the condominium facilities, namely:

- Heating and cooling: consumption related to the heat pump and water distribution;
- DHW: consumption related to the heat pump and water distribution;
- Common areas lighting: lighting related to the building's condominium parts (stairs, technical room, external appurtenances)
- Common uses: uncontrollable electrical consumption such as video intercom, video surveillance and elevators;
- Ventilation: consumption of the 2 ventilators placed on the roof to service the VMC of the whole building (which move 0.3 vol / h 24/7)

Table 7-2 summarizes the electricity consumption for condominium services and for private use, the latter calculated considering also the induction plate for cooking.

7.3 Photovoltaic and energy storage

To meet the energy needs of the building, the project involves the installation on the roof of a photovoltaic plant of 87 kW_p of total power divided as follows:

Table 7-3: photovoltaic plant installed horizontally on the roof of the building

		per apartment	total
PV plant for condominium services			
Power	kW_p		42
Annual energy production	kWh		61'740
PV plant for private use			
Power	kW_p	3	45
Annual energy production	kWh	4'410	66'150

Figure 7-11 shows the monthly electricity demand for condominium uses and the monthly production of the 42 kW_p photovoltaic plant. The trend of the graphs shows that during the day the electricity demand is directly covered by the production of the photovoltaic plant. Indeed the production is for large periods of time well above the demand. In the afternoon, however, after the sunset, the photovoltaic plants no longer able to meet the demand. It was verified that unused daily production in the morning could cover the evening request.

In order to store this unused energy, two alternative systems have been evaluated:

A. the construction of an electrical energy storage system using solar batteries;
B. the construction of an underground water tank, located under the garage, for the accumulation of thermal energy.

Nowadays batteries for the storage of electricity still have a decidedly high price. They also have a limited life (not exceeding 10 years) and their disposal represents a non-trivial problem. The solution of the storage tank cannot in itself solve the problem as it would require a considerable volume of water.

The solution under investigation foresees to use a water reservoir as a thermal source for a geothermal pump: the high (or low) temperature that can be reached in the reservoir using the thermal energy unused in the morning, combined with the high efficiency of this type of generator, allow to significantly reduce the consumption of electricity to be used in the evening hours. The functioning scheme studied can be summarized as follows:

- During the day, an aerothermal heat pump is used to first meet the current demand and then, with the energy in excess, for heating (or cooling) the water in the tank.
- In the evening, a geothermal pump is used having the water in the tank as a thermal source.

Obviously the executive scheme is much more complex and requires a Building Automation (BA) system for the control and regulation of the system. At present it is believed that the operating scheme shown in Annex 2, Section 0, may be suitable for the purpose and includes the following BA functions:

A) Management of the thermal and the electric central production plants by:
  - monitoring the production of the photovoltaic plant;
  - monitoring of electricity exchange with the grid,
  - monitoring of the consumption of the heat pump;
  - monitoring of heat production (DHW + HVAC) of heat pumps and consequently calculating the COP;
  - optimizing of the operation of the heat pump according to photovoltaic production;
  - monitor the operating parameters of the distribution;
  - monitor the consumption of DHW, heat and cold water of individual condominiums controlled through a single interface.

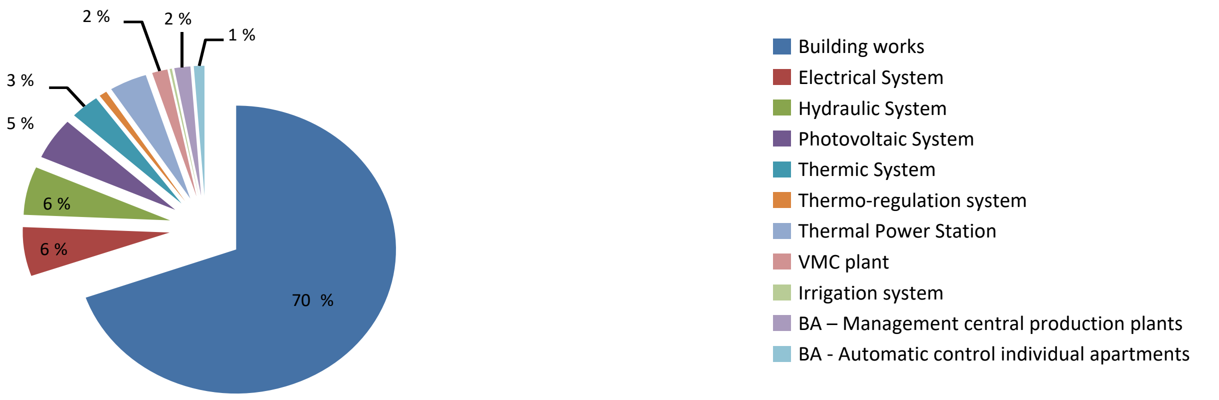
  Estimated cost of the BA system only = € 35'631, or 21.65 €/mq.

B) Automatic control and monitoring of the systems installed in the individual apartments:
  - scheduling loads according to solar production (washing machine, dryer);
  - scheduling the thermoregulation according the standard use of the apartment;
  - monitoring of the consumption of ACS, heat, cold water and electricity of individual condominiums, through a domotic control unit equipped with APP for each user.

  Estimated cost of the BA system only = € 22'620, or 13.76 €/mq.

Figure 7-12 shows that the weight of the BA system described above within the total costs of the building is just about 3% of the total cost reported in Table 7-1.

Figure 7-12: Subdivision of costs



7.4 Building automation: framework

7.4.1 General Overview

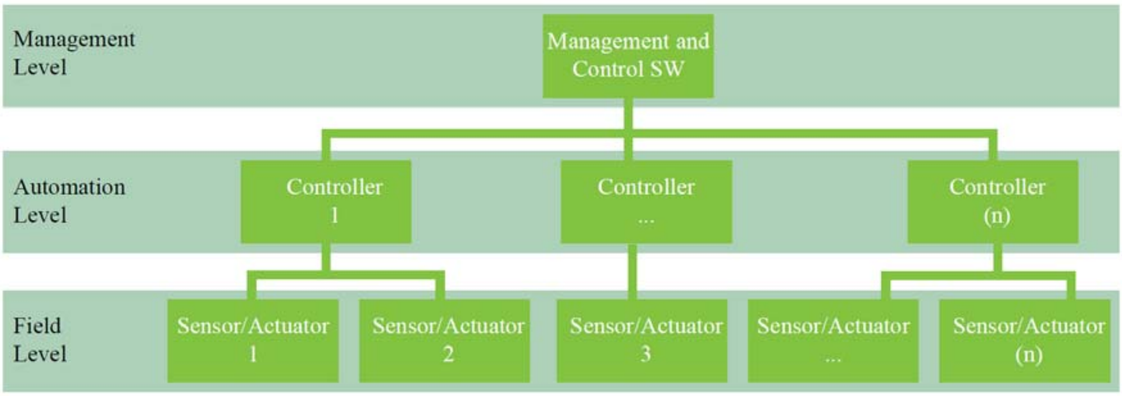
Building Automation can be understood as the automated management of the technological systems of a building, through the adoption of a supervision and control infrastructure, in order to maximize energy savings, comfort and safety of the occupants . (Energy & Strategy Group, 2015). BA plants can be classified into 3 macro-categories:

- Energy: plants for the production, management and consumption of energy;
- Safety & Security: systems for the prevention and management of «risks» that can compromise the safety and security of the occupants
- Entertainment: systems for the management and control of audio-video multimedia equipment;

Resuming the scheme proposed in the Intelligent Building Report (Energy & Strategy Group, 2015), the typical architecture of a BA infrastructure can be represented as in Figure 7-13:

1. A first "Field" level made up of the whole sensors/actuators of each individual device (for example, the temperature sensor actuating valve for the regulation of a fan coil).
2. A second "Automation" level that regulates these devices in a automatic and coordinated manner (for example, the Chrono thermostat that regulates the operation of several fan coils according to a given rule).
3. A highest "Management" level which supervises and checks the operation of all the plants (such as heating, ventilation, cooling, etc.).

Figure 7-13: Architecture of a BA plant



Source: (Energy & Strategy Group, 2015)

BA is an absolutely strategic topic in the diffusion of the Energy Performance Contracts (and therefore of the ESCO market in the building sector) both to measure the obtained energy savings and to control the correct use of the building. Furthermore, BA is a strategic topic also for the legislator since it gives a means to verify the actual energy savings obtained from the redevelopment works to which economic incentives have been granted.

For these reasons the BA has recently been included as beneficiary of various incentives, from Tax Deduction, to the Thermal Account, to White Certificates.

From a technological point of view, BA's solutions are more and more varied and advanced, with increasing levels of sophistication and integration which allow ever greater advantages both in terms of energy efficiency and comfort and safety.

At the same time, however, the cost of these systems tends to increase considerably and often nonlinearly. Therefore, the study presented in the following intends to analyze the cost / benefit impact of BA for a newly constructed residential nZEB building such as the one proposed in the previous Section.

7.4.2 Normative overview

The main normative reference at European level for the BA is certainly the UNI EN 15232: a technical standard born in 2012 and recently updated (2017). The main purpose of this standard is to establish conventions and methods for the estimation of impact of building control and automation systems (Building Automation and Control Systems, BACS) and technical building management (Technical Building Management, TBM) on energy performance and energy use in buildings. In particular, it focuses on three fundamental aspects:

1. To provide a classification of "systems" and "building automation functions" that can be implemented within buildings.
2. Identify 4 classes of building automation systems (from «D» to «A», in increasing order with A the best), based on the automation functions implemented.
3. To estimate the impact that "building automation systems" have on the energy performance of buildings through two different calculation methods based on the availability of energy data.

The classification method contained in the UNI EN 15232 is currently used as a reference for the provision of incentives for improvement interventions of the BA systems (Thermal Account and TEE) and, above all, the imposition of minimum levels of automation in buildings. In fact, with the entry into force of the D.M. 26/06/2015 – *"General criteria and requirements for the energy performance of buildings"*:

- New non-residential buildings or those subject to major renovation are obliged to equip themselves with BA systems to fall at least in class B..
- As for residential buildings, it is the same UNI EN 15232 that establishes that, unless otherwise imposed by the various national regulations, the minimum level of automation is the C.

Table 7-4: Incentives and duties related to BA in Italy

	Scope of application	
	RESIDENTIAL	NON RESIDENTIAL
DUTIES	*	Minimum requirements on building Automation class (DM 26 Jun 2015 + Uni EN 15232 Technical standards)
	NZEB Buildings Obligation (DL 4 June 2013 N. 63 and SMI + units 11300)	
	Requirement for Heat accounting (Legislative Decree 102/2014 + units 10200)	
INCENTIVES	White certificates (UNI EN 15 232)	
	Tax Deductions	
	Thermal account - for PA (UNI EN 15 232)	
	There are regional decrees that have adopted the technical standard to prescribe minimum classes also for residential buildings	

Table 7-5: BA regulations based on the scope of application

Functions from uni EN 15232 Technical Standard	**Regulatory obligations**		
	DM 26 June 2015 **(rif. Uni EN 15232)**	**DLgs 102/2014**	**DL 4.06** **.2013** **Duty *nZEB***
Heating			
Cooling			
ACS			
Ventilation			
Illumination			
Sun Shields			
Integrated management of different functions			

At the same time, these requirements intersect with other regulatory provisions: Table 7-4 summarizes current obligations and incentives, based on the scope of application (residential or non-residential). Entering specifically, with reference to the classification proposed by EN 15232; Table 7-5 illustrates where the various regulations overlap each other.

In fact, in addition to the aforementioned Ministerial Decree of 26.06.2015, the following laws are in force:

1. Decree Law 04.06.2013, which establishes the minimum requirements for nZEB buildings. Since this DL 2013 is based on the standard UNI TS 11300, it indirectly includes the BA as a parameter to determine the efficiency of distribution and emission systems for heating, cooling and DHW.
2. Legislative Decree 102/2014, which introduces, through the UNI TS 10200 technical standard, the obligation to account for consumption for multi-family dwellings and multi-purpose buildings.

It is therefore evident that for heating, cooling and ACS there are cases (as nZEB condominium or multi-purpose buildings) in which two or three standards must be met at the same time. For this reason, it was considered useful to analyze the problem by applying the current legislation to the practical case of the newly constructed nZEB building presented in the previous paragraphs.

7.4.3 Determination of the BA system class

As a practical example, Annex 1 (Section 7.6) reports the assessment according to UNI EN 15232. In particular, for our convenience, the table in the annex is divided into two vertical blocks:

- The first block "Choice of the project" reports the planned BA system.
- The second block contains the "UNI 15232 evaluation form" compiled according to the design choices.

As indicated by law, the analysis is conducted considering only the functionality foreseen by the project. It should be noted that the color in the first column of the 2nd block indicates, with reference to Figure 7-13:

- In yellow, the functionality that can be classified as Field level and that are normally already present in the equipment.
- In green, the functionality reported in the Section 7.3 along with their relative cost that can be classified as Level Automatic Level and Management level.

From this it is possible to draw the conclusions summarized in Table7-6: overall the functions foresees are 23 of which 12 belong to class A, 3 to class B, 6 to class C and 2 to class D.

Table7-6: Analysis of the building's functions

	Heating	Cooling	DHW	Ventilation	Lighting	Shielding	Monitoring and control	SUM
Class A	3	3	3	1	1	0	1	12
Class B	1	1	0	0	1	0	0	3
Class C	1	1	1	0	0	1	2	6
Class D	0	0		2	0	0	0	2
TOTAL	5	5	4	3	2	1	3	23

UNI EN 15232 states that the function with the lowest score determines the class of the entire BA system. The evaluation does not include functions that consume less than 5% of the total reading consumption.

Therefore, in this project, the BA class is equal to C, since the functions associated with ventilation, due to its low energy consumption, are excluded from the evaluation. Thus it respects the minimum requirement for residential building.

7.5 Conclusion

The project developed in this research has made it possible to verify that constructing nZEB buildings is not necessarily more expensive than building them in a "traditional" way, provided that the right design and construction technologies are chosen. In fact, the main obstacle to the construction of nZEB buildings at low cost seem to be above all a cultural problem that does not allow designers to identify the right technological solutions that the market is already able to offer today.

In fact, for the construction of nZEB buildings at low cost it is essential that the design is carried out with the BIM methodology as it is the only one that allows the concurrent, coordinated, but also independent participation of all the professional figures involved from the early stages of the project. First of all, it allows to identify the optimal technological solution that has the best relationship between construction cost and operating cost, in compliance with the requirements of the law on the containment of energy consumption. Moreover, BIM allows to obtain a detailed planning of all the phases of the realization, with the spaces for the technological systems perfectly allocated, eliminating the expensive modifications / corrections on site of the works already carried out, as typically takes place with traditional design where architects , structural engineers and installers must forcefully operate "almost" independently of each other.

However, designing with BIM requires a profound cultural evolution of the designers and, before that, of the contents of the university teachings. In fact, it should be noted that BIM is a methodology totally based on computer science and as such requires knowledge of cataloging and organization of information in the Databases, of Computer graphics, of Numerical Calculation, of Continuous Mechanics and so on.

To begin with, the design drawing is no longer a graphic exercise of lines that are composed into 2D representations, performed on independent sheets of paper. In BIM the design artifact is a discreet set of objects having their own 3D shape and their own physical nature characterized by mechanical, thermal, chemical properties, etc. Composing these individual objects to create the design artifact follows rules completely unknown to the traditional "designer" as well as classic graphic skills such as the cleanliness of the stroke and / or the ability of 3D axionometric development are no longer required. BIM requires the knowledge of CAD (Computer Aided Design), of data transmission protocols in the network to feed , among other things, the calculation programs that carry out the engineering analyzes, as well as knowledge of animation techniques that allows the client to have a realistic view of the work in all its details, perhaps traveling even within the work itself.

As far as design calculation is concerned, the traditional engineering school is based on the ability ot the engineer to reduce a complex problem into a much simpler one, which can be solved analytically in the so-called "closed form". These analytical solutions are normally available only for elementary geometric shapes and derive from a considerable simplification of the rigorous field equations provided by continuum mechanics which typically have the form of a system of nonlinear differential equations. For example, in the structural calculation, the closed form solution is available only for beams and pillars under the so-called "De Saint Venat" hypotheses in which, among other things, these structural elements are assumed to be mono-dimensional, elastic and subject to small deformations.

On the contrary, in the BIM the technical calculation are done only by specialized SW through numerical procedures able to analyze the design artifact in its real form through the geometric data created through CAD. Normally these SW are based on calculation procedures obtained by directly solving the original field equations, where the system of differential equations is not integrated analytically but instead transformed into a system of linear equations that are solvable numerically. Among the mathematical techniques of transformations of the system of differential equations, the best known are: Finite Elements, Finite Volumes and Finite Differences. The solution of the resulting system of linear equations requires the use of numerous numerical techniques that normally present problems of checking accuracy and convergence.

Evidently ignoring the theory on which these SW are based means not having any tool for judging the quality of the solution with all the possible serious consequences that may derive from it. The engineer who uses these SWs as a "black box" in fact declines responsibility for his project to the SW manufacturing company which, as a rule, declares in turn not to assume any responsibility.

7.6 Annex 1:

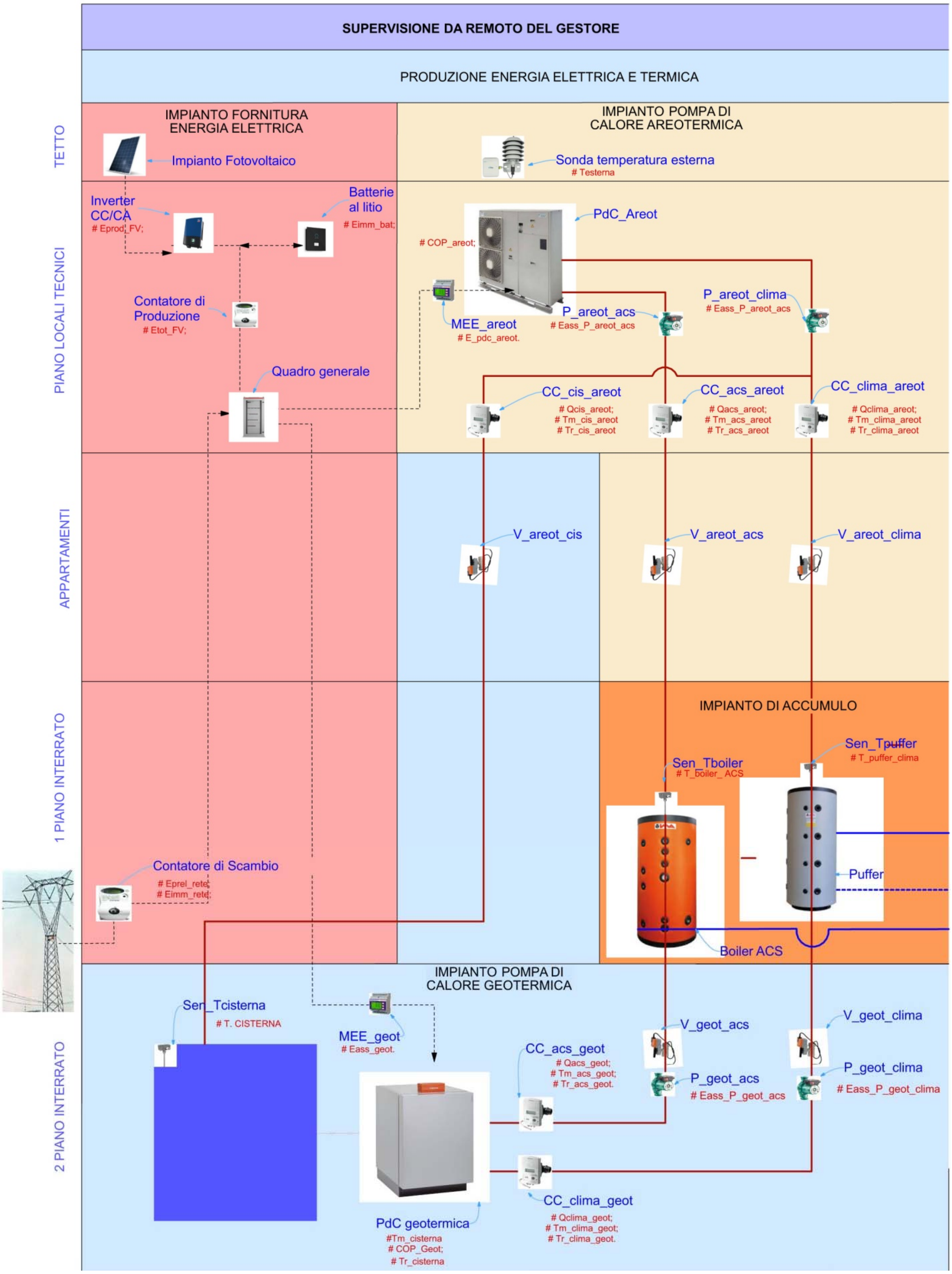
Table 7-7_A: Function analysis uni en 15232 - Original figure

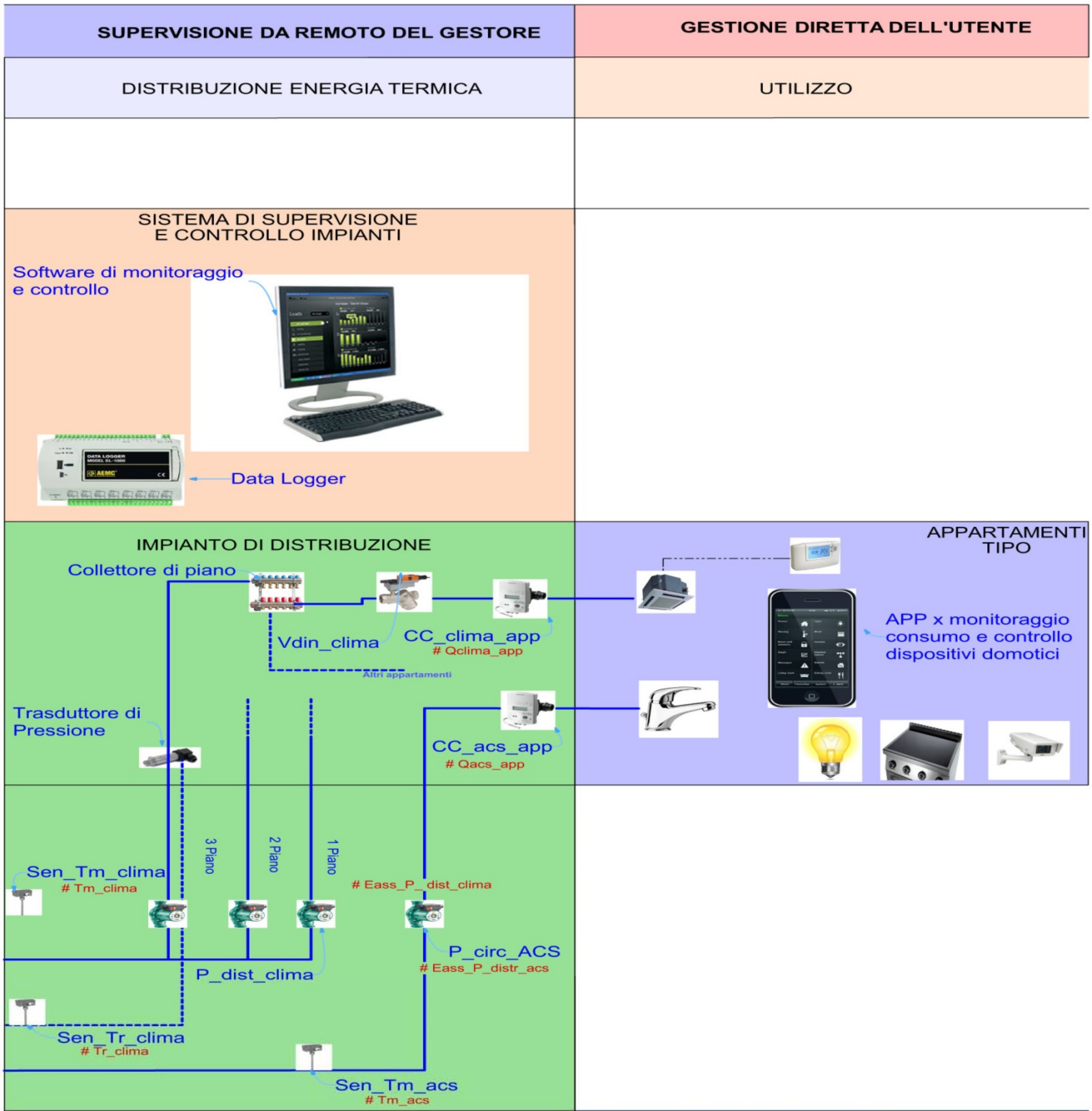
Scelta Progettuale			Modulo di valutazione della UNI 15232	Residenziale			
				D	C	B	A
			CONTROLLO RISCALDAMENTO E RAFFRESCAMENTO				
			Controllo di emissione				
Fan coil collegati in BUS a cronotermostato		0	Nessun controllo automatico				
		1	Controllo automatico centralizzato				
		2	Controllo automatico di ogni ambiente				
		3	Controllo automatico di ogni ambiente con comunicazione				
		4	Controllo integrato di ogni locale con comunicazione e controllo di presenza				
			Controllo temperatura acqua nella rete distribuzione (mandata e ritorno)				
Una sonda di temperatura nella mandata regola la richiesta della PDC		0	Nessun controllo automatico				
		1	Compensazione con temperatura esterna				
		2	Controllo basato sulla richiesta termica				
			Controllo delle pompe di distribuzione				
Pompe a velocità variabile regolate per mantenere un DP costante - in abbinamento a valvole di bilanciamento dinamiche		0	Nessun controllo automatico				
		1	Controllo On-Off				
		2	Controllo pompa multi-stadio				
		3	Controllo pompa a velocità variabile				
			Controllo intermittente della emissione e/o distribuzione				
Possibilità attraverso cronotermostato di programmarele accensioni dei terminali - una valolva di zona regola la distribuzione		0	Nessun controllo automatico				
		1	Controllo automatico con programma orario fisso				
		2	Controllo automatico con partenza/arresto ottimizzato				
		3	Controllo automatico con calcolo della richiesta termica				
			Controllo del Generatore per pompe di calore				
La pompa di calore è in grado di regolare la propria potenza in dipendenza del carico richiesto		0	Temperatura costante				
		1	Temperatura variabile in dipendenza da quella esterna				
		2	Temperatura variabile in dipendenza dal carico o dalla richiesta				
			CONTROLLO ACQUA CALDA SANITARIA				
			Controllo della temperatura nel serbatoio con integrazione di riscaldamento elettrico o con pompa di calore				
L'ACS è programmata per mantenere la T del serbatoio di accumulo a T costante, a prescindere dall'orario		0	Controllo automatico on/off				
		1	Controllo automatico on/off e controllo temporale				
		2	Controllo automatico on/off, controllo temporale e gestione con sensori multipli di temperatura				
			Controllo della pompa di circolazione dell'acqua calda sanitaria				
Pompe a portata variabile a seconda della richiesta			Nessun controllo temporale				
			Controllo temporale				
			Controllo in funzione della richiesta				
			Interblocco tra riscaldamento e raffrescamento a livello di generazione e/o distribuzione				
Essendo un impianto a 2 tubi, è impossibile che ci sia raffrescamento e riscaldamento contemporaneamente		0	Nessun interblocco				
		1	Parziale interblocco (dipende dal sistema di condizionamento HVAC)				
		2	Interblocco totale				
			Controllo del Generatore				
La potenza del generatore è modulare e varia in dipendenza della richiesta		0	Temperatura costante				
		1	Temperatura variabile in dipendenza da quella esterna				
		2	Temperatura variabile in dipendenza dal carico				

Table 7-8_B: Function analysis uni en 15232 - Original figure

Scelta Progettuale		Modulo di valutazione della UNI 15232	Residenziale D	C	B	A
		CONTROLLO DELLA VENITLAZIONE E DEL CONDIZIONAMENTO				
		Controllo mandata aria in ambiente				
Non previsto alcun controllo, in quanto si presuppone la VMC debba funzionare sempre.	0	Nessun controllo				
	1	Controllo a tempo				
	2	Controllo a presenza				
	3	Controllo a richiesta				
		Raffrescamento meccanico gratuito				
Presente una valvola di Bypass collegata a sonda di temperatura in caso di free cooling	0	Nessun controllo				
	1	Raffrescamento notturno				
	2	Raffrescamento gratuito				
	3	Controllo entalpico				
		Controllo Umidità				
Non previsto	0	Nessun controllo automatico				
	1	Controllo del punto di rugiada				
	2	Controllo dell'umidità				
		CONTROLLO ILLUMINAZIONE PARTI COMUNI				
		Controllo Presenza				
Nelle parti comuni è previsto sensore di movimento per accendere luci in caso di passaggio + sensore crepuscolare nelle pertinenze esterne	0	Interruttore manuale				
	1	Interruttore manuale + segnale estinzione graduale automatica				
	2	Rilevamento automatico				
		Controllo luce diurna				
	0	Manuale				
	1	Automatico				
		CONTROLLO ILLUMINAZIONE SINGOLI APPARTAMENTI				
		Controllo Presenza				
Nei singoli appartamenti non sono previsti controlli di presenza e crepuscolari. Tuttavia, in caso di domotica, le luci possono essere comandate attraverso scenari	0	Interruttore manuale				
	1	Interruttore manuale + segnale estinzione graduale automatica				
	2	Rilevamento automatico				
		Controllo luce diurna				
	0	Manuale				
	1	Automatico				
		CONTROLLO SCHERMATURE SOLARI				
Previste tapparelle motorizzate	0	Completamente manuale				
	1	Motorizzato con azionamento manuale				
	2	Motorizzato con azionamento automatico				
	3	Controllo combinato luce/tapparelle/HVAC				
		GESTIONE CENTRALIZZATA degli Impianti tecnici dell'EDIFICIO (TBM)				
		Rilevamento guasti, diagnostica e supporto alla diagnosi dei guasti				
Oggetto di valutazione sia per gestione parti comuni che singoli appartamenti	0	No				
	1	Sì				
		Rapporto riguardante consumi energetici, condizioni interne e possibilità di miglioramento				
Oggetto di valutazione sia per gestione parti comuni che singoli appartamenti	0	No				
	1	Sì				

7.7 Annex 2: Functional diagram of the thermal generation plant with storage - Original figure





LEGENDA ABBREVIAZIONI:
T = Temperatura
Eass = Energia elettrica assorbita
P = Pompa
V = valvola
Vdin = Valvola a bilanciamento dinamico
Sen_T = Sensore Temperatura
CC = Contacaloria
PDC = Pompa di calore
Areot = Pompa di calore areotermica
Geot = Pompa di calore geotermica
MME = Misuratore energia elettrica
Clima = climatizzazione estiva o invernale
ACS = acqua calda sanitaria
Q = energia termica
r = ritorno
m = mandata

8 The barriers of the energy renovation market

8.1 Introduction

The three case studies illustrated in the previous Chapters have shown that the combined use of the incentives currently available (although sometimes difficult to apply) and the adoption of innovative design methods are able to considerably reduce costs and make the profitability of the interventions at least acceptable.

At the same time, despite the considerable efforts made by EU member countries to support the energy efficiency market, the results achieved so far are far below expectations. Then, an in-depth analysis on all the barriers that still exist is needed.

In particular, the barriers of the energy efficiency market can be of different nature (cultural, technical, market structure, etc.), which take on different nuances and relevance, depending, among other things, on whether the potential customer is an industry, a private individual or a public administration (Energy Efficiency Report, 2012) (Energy Efficiency Report, 2013).

From the analysis reported in the three previous Chapters, it is clear that this differentiation must necessarily exist in that the forms of incentives, and therefore the "technical" problems connected with the possibility of taking advantage from them, differ considerably.

However, what does not emerge with as much evidence (if not just for the case of the condominium) is the problem connected to the decision-making process that leads these potential customers to carry out the energy requalification interventions or new buildings in nZEB . A positive decision always rests on the personal conviction of the convenience of the intervention that is achieved when the available information eliminates doubts and highlights the advantages. It is well known that the type of information requested, as well as the communicative process and language, varies according to the interlocutor.

Due to the importance of the topic, it was deemed necessary to analyze the most recent studies on the existing barriers that slow down the expansion of the energy efficiency market and, consequently, what actions can be used to overcome them.

Firstly, this Chapter reports a brief literature review regarding the identification and classification of barriers in the civil building sector. Moreover it reports a more in depth literature review regarding the relationship between barriers and decision making process, which shows that the models proposed so far in the literature do not immediately fit into the specific market for the renovation of civil buildings. This is because, as already noted above, the decision-making process can change significantly depending on the type of building owner, its internal organization and its size.

For this reason, a new decision-making model was developed in order to describe the decision-making process, based on 3 different type of end user.

From this discussion, it appears that: 1) the total weight of the barriers is greater in the early stages of the decision-making process and decreases along the way, 2) although the economic barriers are the most relevant of all, their effect is almost exclusively limited to one of the last steps decision-making process (economic-financial analysis); 3) On the contrary, there is a strong knowledge gap that already emerges in the very early stages of investment assessment; 4) this gap does not concern a specific barrier, but includes all the aspects concerning the intervention as a whole; 5) during these early stages, potential users prefer to deal with the issues independently, before entrusting an external consultant with an in-depth assignment, thus relying solely on their own (scarce) skills; 6) the decision-making process is not linear but cyclic/recursive; 7) there is a problem of skills even among technicians, often experts in their own specific field, but who lack a complete vision of intervention as a whole.

8.2 Classification of barriers

In 1990 Eric Hirst and Marilyn Brown published a study entitled " *Bridging the efficiency gap: obstacles to the efficient use of energy* ". In this study the term *“was coined Energy Efficiency Gap” with which was indicated “the difference between the potential energy efficiency level which minimizes costs (or theoretically implementable energy efficiency) and the energy efficiency level actually achieved”.*

With this study, an important line of research attempting to explain the reasons for this gap takes shape on an international scale. To date, these studies have mainly focused on:

- identifying and classifying barriers in various market sectors;
- identifying which barriers have a greater weight.

In particular, most of the research analyzes the barriers by dividing the energy efficiency sector into three macro-categories, which in turn contain several sub-categories::

1. Residential: (Azizi, Nair, & Olofsson, 2019) (Stieß & Dunkelberg, 2013) (Achtnicht & Madlener, 2014) (Wilson, Pettifor, & Chryssochoidis, 2018)
   a. Single-family homes or individual apartments (Buser & Carlsson, 2017) (Azizi, Nair, & Olofsson, 2019)
   b. Condominiums (Palm & Reindl, Understanding barriers to energy-efficiency renovations of multifamily dwellings, 2018)
2. Industrial, (Cagno, E.Worrell, A.Trianni, & G.Pugliese, 2013) (Sorrell, Mallett, & Nye, 2011) (Wohlfarth, Eichhammer, Schlomann, & Worrell, 2018)
   a. Small, medium (Cagno & Trianni, 2013) e grandi aziende (Chiaroni D. , Chiesa, Franzò, Frattini, & Latilla, 2017)
   b. Energy-intensive companies or non-energy-intensive companies (Trianni, Cagno, & Farné, 2016)
   c. Sector (Henriques & Catarino, 2016)
   d. Nation (Solnørdal & Foss, 2018)
3. Public Administrations (RajeevRuparathna, KasunHewage, & Sadiq, 2016) (Energy & Strategy Group, 2012)
   a. Small municipalities
   b. Central administrations

This classification reflects the fact that each of these three categories has different decision-makers and technical / economic needs.

As far as the real estate sector is concerned, however, it is worth noting that this classification does not concern the type of a building, but rather its ownership and use: it is indeed easy to verify that the same building can fall into several categories.

In this regards, Table8-1 shows a framework first proposed by (Cagno, E.Worrell, A.Trianni, & G.Pugliese, 2013) and subsequently taken up by (Chiaroni D. , Chiesa, Franzò, Frattini, & Latilla, 2017): although it has been developed with particular reference to the industrial sector, this framework is considered by the literature to be particularly complete and detailed to also describe the barriers of other sectors. For the sake of completeness, some more specific barriers to the building market and the residential sector have been included in this present study.

Applied to the civil sector, the barriers reported here may take on different nuances and relative weights depending on the specific case. For the purposes of this study, it is important to note that, from the list of barriers shown in Table8-1, it may appear that there are three main reasons for the *Energy Efficiency Gap*:

1. Difficulty finding the capital needed for the investment due to high initial costs and the perception of low profitability.
2. Lack of qualified information on:
   a. The availability of economic incentives and financial tools that reduce, even drastically, the commitment of equity capital.
   b. The available technologies able to reduce energy consumption and the consequent both social and economic advanteges.
3. Lack of adequate decision support tools (the so-called DSS) which, with limited, preferably non-specialist, data are able to process (almost) in real time the technical-economic-financial scenario that follows different strategic choices.

As reported in the previous Section 3.2, investments for energy renovation in the building market are not profitable in themselves. In recent years, however, thanks to public incentive tools, this is no longer true. Therefore it is to be considered that as regards the financial aspect, the obstacle is no longer the profitability of the investment but rather:

- the complexity of the rules governing the mechanisms for assigning and controlling incentives and their constant modification;
- the fear that at the end of the work, after having fully sustained the costs of restructuring, due to a defect in form or a material error caused by the complexity (and variability) of the rules, the incentives will not be effectively paid out.
- insufficient knowledge of the incentive tools that make the investment profitable.

Leaving the legislator with the burden of overcoming the complexity of the legislation and the uncertainty about the effective recognition of economic incentives, here we limit ourselves to investigating the aspect of "*information*".

To be effective, an information campaign requires first of all the identification of the subjects (target) to whom one wants to communicate: this makes it possible to select the means of communication and the language to be used. For this reason the next Chapter analyzes the decision-making processes that lead to making an investment in the market sector of energy efficiency in buildings identifying the the real targets of the information campaign. In the next two Chapters we will then analyze the most appropriate means and ways of communication for the identified targets.

On the other hand, an information campaign is effective if eventually allows to generate an investment. To this end, it is very useful to structure the information campaign with tools (DSS) that identify the possible alternatives for intervention, providing indications on the technological solutions and the benefits that can be achieved both from an economic and environmental point of view.

8.3 The decision-making process in renovation of buildings

The barriers of the energy efficiency market in the civil sector can be fully analyzed, and hopefully overcome, only by becoming aware of the processes through which decisions are made. This is because, as highlighted in recent studies, it is not only important to know what the barriers are and what the weight they have, but it is also important to know how and when they arise in decision-making processes (Cattaneo, 2019) (Azizi, Nair, & Olofsson, 2019) (Trianni, Cagno, & Farné, 2016) (Ebrahimigharehbaghi, Qian, Meijer, & Visscher, 2019) (Mlecnik, Straub, & Haavik, 2019) (Schleich, XavierGassmann, CorinneFaure, & ThomasMeissner, Making the implicit explicit: A look inside the implicit discount rate, 2016) (Palm & Reindl, Understanding barriers to energy-efficiency renovations of multifamily dwellings, 2018) (Wilson, Pettifor, & Chryssochoidis, Quantitative modelling of why and how homeowners decide to renovate energy efficiently, 2018) (Kastnera & Sternb, 2014) (Chiaroni D. , Chiesa, Franzò, Frattini, & Latilla, 2017).

With reference to small and medium-sized enterprises, (Trianni, Cagno, & Farné, 2016) believes that the decision-making process can be divided into the following 6 distinct phases, Figure 8-1: *1. Awareness, 2. Needs and opportunity identification, 3. Technology identification, 4. Planning, 5. Financial Analysis and financing, 6. Installation startup and training.*

Of particular interest is the fact that in this study, through an empirical analysis, the authors found that, Figure 8-2:

1. the total weight of the barriers is greater in the early stages and decreases along the process
2. although economic barriers have the greatest weight ever, their effect is almost exclusively limited to the fifth step (financial analysis and evaluation).

On the contrary, many other barriers have a greater effect than economic ones at the beginning of the decision-making process: awareness, lack of information and organization. Subsequently (Chiaroni D. , et al., 2016) specializes this model by emphasizing the fundamental role in the energy audit industries to identify the best investment opportunities, dividing the decision-making process as follows: 1. Idea generation, 2. Investment evaluation, 3. Energy audit, 4. Design, 5. Financing, 6. Execution.

The authors have also shown that in the early stages of the decision-making process (idea generation and Investment evaluation), the figures participating in the planning of the project are almost always only internal(Figure 8-3). This becomes even more evident as the size and organization of the company decreases, altough skills and sensitivity of the subject also decrease.

As regard residential and small businesses, the high indirect costs due to information retrieval in the very early stages (the so-called transaction costs) are often decisive in determining the stopping in the evaluation process. (Ebrahimigharehbaghi, Qian, Meijer, & Visscher, 2019).

Moreover, unlike the decision-making processes described so far, in the micro-companies or in the residential sector, the opportunity identification phase is often not formalized through an audit: this is often skipped by going directly to the design of an intervention identified directly by the customer (Palm & Reindl, Understanding barriers to energy-efficiency renovations of multifamily dwellings, 2018).

It follows that the application of the models seen so far in the market of energy renovation in the real estate sector is not at all immediate. This is because, as seen in the previous Section , the potential final customers, understood as the subjects interested in the intervention, present very different characteristics and organizational models and the major investments are not linked to the medium-large industry but rather to the PA, small and medium businesses, condominiums and private individuals.

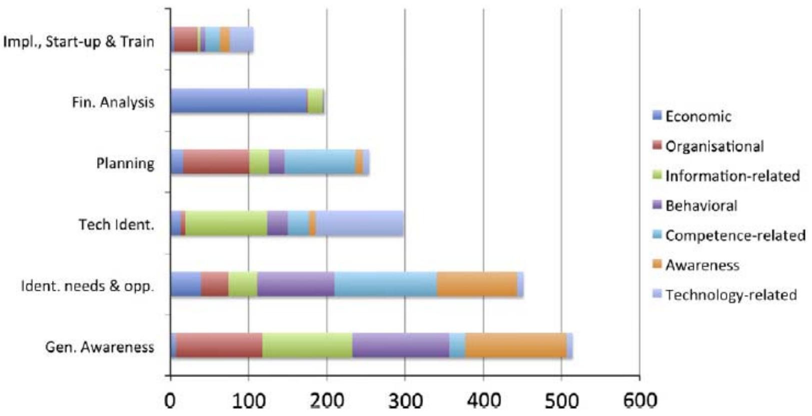
Table8-1: le barriere al mercato dell'efficienza energetica nel settore civile. Barriers to the adoption of EEMs

Origin	Category	Barrier	Main sector where barriere is particulary strong
External	Market	Energy prices distortion	All sectors
		Low diffusion of technologies	Industrial Sectors
		Low diffusion of information	Low energy intense industrial sector, PA and residential
		Market risks	All sectors
		Difficult in gathering external skills	Low energy intense industrial sector, PA and residential
		Fragmented industry and temporary coalitions, issues with subcontracting	All sectors - particulary for small interventions
		Designers, consultants and subcontractors lack long-term interest in a building	All sectors - particulary for small interventions
		Lack of project integration and communication between involved actors	All sectors - particulary for small interventions
	Government/ politics	Lack of proper regulation	All sectors
		Distortion in fiscal policies	All sectors
	Technology/service suppliers	Lack of interest in energy efficiency	All sectors - low energy intense
		Technology suppliers not updated	All sectors
		Scarce communication skills	All sectors
	Manufacturer	Technical characteristics not adequate	Industrial Sectors
		High initial costs	Industrial Sectors - high energy intense sector
	Energy suppliers	Scarce communication skills	Low energy intense industrial sector, PA and residential
		Distortion in energy policies	All sectors
		Lack of interest in energy efficiency	Low energy intense industrial sector, PA and residential
	Capital suppliers	Cost for investing capital availability	High energy intense industrial sector
		Difficult in identifying the quality of the investment	Low energy intense industrial sector, PA and residential
Internal	Economic	Low capital availability	All sectors
		Hidden costs	Low energy intense industrial sector, PA and residential
		Intervention-related risks	High energy intense industrial sector
		Interventions non sufficiently profitable	All sectors
		Valutation on life cycle	All sectors
	Behavioral	Lack of interest in energy efficiency	Low energy intense industrial sector, PA and residential
		Other priorities	Low energy intense industrial sector, PA and residential
		Split incentive	Low energy intense industrial sector, PA and residential
		Inertia	Low energy intense industrial sector, PA and residential
		Imperfect evaluation criteria	Low energy intense industrial sector, PA and residential
		Lack of sharing the objectives	Low energy intense industrial sector, PA and residential
		Reference dependent preferences	Residential
		Rational inattention	Residential
		Bounded rationality	Residential
	Organizational	Low status of energy efficiency	Industrial sector - low energy intense
		Divergent interests	Industrial sectors
		Complex decision chain	Industrial and PA sectors
		Lack of time	Industrial and PA sectors
		Lack of internal control	Industrial and PA sectors
	Barriers related to competence	Identifying the inefficiencies	Industrial sectors
		Identifying the opportuinies	Low energy intense industrial sector, PA and residential
		Implementing the interventions	All sectors
		Imperfect evaluation criteria	All sectors
	Awareness	Lack of awareness or ignorance	All sectors

Source: Adapted from (Chiaroni D. , Chiesa, Franzò, Frattini, & Latilla, 2017) and (Cagno, E.Worrell, A.Trianni, & G.Pugliese, 2013)

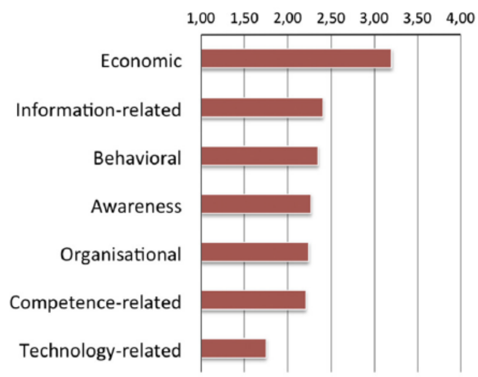
	(green)	Economic barriers / access to credit
	(orange)	Lack of qualified information
	(blue)	Lack of adequate decision support tools

Figure 8-1: Effect of barriers on the decision-making process of investing in an EEM.



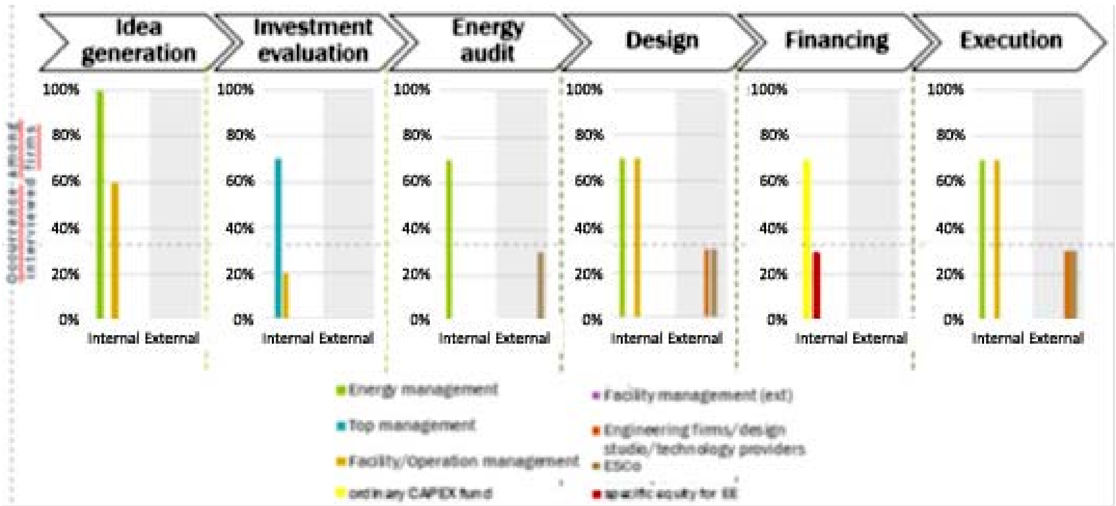
The bars report the total summated scores given to a barrier (by category) with respect to the specific decision-making step. Source: (Trianni, Cagno, & Farné, 2016)

Figure 8-2: Barriers to energy efficiency – average values



Source: (Trianni, Cagno, & Farné, 2016)

Figure 8-3: Involvement of different categories of actors in the energy efficiency decision-making process



Source: (Chiaroni D. , et al., 2016)

As part of this study, it was therefore deemed necessary to specialize the models of (Trianni, Cagno, & Farné, 2016) and (Chiaroni D. , et al., 2016) in the 3 main decision-making pathways shown in Table8-2.

These paths seek to characterize the real behaviors observable in potential end customers:

1. The path “Audit Oriented”, referable to model (Chiaroni D. , et al., 2016), in which the problem is analyzed without any prejudice, usually through an assignment given to an experienced professional, who, starting, from an energy audit provides an objective overview of the state of affairs and of the interventions that may be of interest to perform.
2. The path “Solution Oriented” in which, for different reasons, a specific solution is directly pursued without first evaluating possible alternatives.
3. The path “Self-Made” in which, despite the lack of specific technical skills, a solution is sought based only on its own knowledge and on the estimates provided by the various suppliers consulted.

Evidently, the path “Audit Oriented” is the most correct. Its use, however, is in fact limited to more structured companies whose corporate culture naturally directs to this type of path; besides they possess the economic resources necessary to sustain the costs of external consultancy, without having a priori the certainty that the final results may actually be of corporate interest.

On the other hand, the path “Self-Made” is typically adopted by small businesses and private individuals who, having limited economic resources, prefer to invest them directly in the realization of the project rather than employing them in preliminary studies. In these contexts, the lack of specific technical resources is probably added to the scarcity of economic resources.

The “path Solution Oriented” is typical of those intermediate-sized organizations, with a distinctly operational culture and with almost all economic resources allocated for projects considered concrete, which can be immediately implemented, mainly using the available internal resources and/or the regular suppliers. The concreteness assumes the immediate availability of a solution.

Each phase of the model described in Table8-2 has been subdivided into various sub-phases, in order to highlight every doubt / obstacle that the potential customer is called to overcome during the process.

Table8-2: The decision-making model for building energy requalification

<table>
<tr><th>Industrial sector</th><th colspan="3">Civil Sector</th><th>Web market</th></tr>
<tr><td rowspan="2">Cagno et al. 2016</td><td>Audit Oriented</td><td>Solution Oriented</td><td>Self-Made</td><td rowspan="2">Funnel Phase</td></tr>
<tr><td>Decision-making process based on an energy audit with a possible monitoring campaign</td><td>Decision making based on a predefined technology</td><td>Decision making process based solely on one's own knowledge and on the estimates provided by the various suppliers contacted</td></tr>
<tr><td rowspan="3">Awareness</td><td colspan="3">Awareness of the possibility of improving energy consumption</td><td rowspan="3">Awareness</td></tr>
<tr><td colspan="3">Preliminary investigation of a possible technical solution</td></tr>
<tr><td colspan="3">Search for a comparison</td></tr>
<tr><td>Needs and opportunity identification</td><td>Conferral of professional assignment for the preparation of the energy diagnosis from which to identify the interventions and technologies that optimize energy consumption</td><td></td><td rowspan="4"></td><td rowspan="4">Interest</td></tr>
<tr><td rowspan="2">Technology identification</td><td colspan="2">Choice of type of intervention and assignment of professional assignment for the preparation of the feasibility study</td></tr>
<tr><td colspan="2">Analysis of technical, economic and financial feasibility</td></tr>
<tr><td>Planning</td><td colspan="2">Conferral the preparation of the definitive project to designers</td></tr>
<tr><td rowspan="3">Financial Analysis and financing</td><td colspan="3">Collects and compares definitive technical solutions</td><td rowspan="3">Decision</td></tr>
<tr><td colspan="3">Comparison of financial solutions</td></tr>
<tr><td colspan="3">Look for guarantees</td></tr>
<tr><td rowspan="2">Installation startup and training</td><td colspan="3">Conferral the preparation of the exectutive project to designers</td><td rowspan="2">Implementation</td></tr>
<tr><td colspan="3">Results monitoring + continuous improvement</td></tr>
</table>

In particular, the red color indicates that this particular step may require an economic outlay by the end customer, as it is generally entrusted to specialized external consultants.

In any case, it is emphasized that each phase is not linear, but rather cyclical, as clearly shown by (Wilson, Pettifora, & Chryssochoidisb, 2018) (Cattaneo, 2019): each single passage corresponds to choices that risk impacting others maybe already established, making it necessary to continuously monitor the project with respect to the technical and economic parameters to be achieved.

9 The WEB to break down the barriers of awareness and knowledge

9.1 Introduction

As previous Chapters highlighted, the energy efficiency Gap is not only a technical problem but it is also, and perhaps above all, a problem of knowledge of the real technological possibilities and/or of the economic convenience of the investment that have resulted in a negative decision.

Nowadays, and even more so in the future, the web certainly represents the means that is most of all able to spread information and knowledge: just think that 87% of decision-making processes involve a search on the web (Fleishman-Hillard & Interactive, 2012).

To verify the potential of spreading informative content through the web in Italy, this Chapter reports the study conducted to assess the interest shown by users regarding the keywords related to energy efficiency in Italy. In particular, the study shows that: A) the research volume certainly stands on interesting numbers - about 1.1 million searches per month for words related to solutions such as tax deductions, photovoltaic, condensing boilers, home automation and heat pumps, B) 84% of the pages best positioned on Google for keywords related to energy efficiency deal with informative content and not purely commercial offers.

This potential interest does not necessarily or immediately turn into concrete actions of renovation. In fact it is necessary to elaborate sophisticated communication processes, known as *inbound marketing*, which gradually catch the interest and trust of visitors. On the other hand, although the most popular contents as commonly conceived may be appreciable (articles, videos, lectures, etc.), they are unlikely to be able to provide a potential customer with sufficient elements to be able to make an informed choice on their own.

Therefore, an essential element for a successful conclusion of the decision-making process is the provision of tools that allow the parties involved to independently assess the cost and benefits of the intervention.

9.2 The potential of Digital Marketing for energy requalification of buildings

The analysis presented in Chapter 0 shows that the lack of awareness and knowledge represents a significant obstacle to the widespread of Energy Efficiency Interventions: these barriers play a fundamental role especially in the early stages of decision-making process, with a greater weight than the most studied economic-financial barriers.

This gap is evidently caused, on the one hand, by not very effective communication strategies by companies in the sector and, on the other, by difficult access to information by end users.

In this sense, the web represents the channel with the highest disclosure potential. In this regard, we report some data extracted from the 2019 Digital Global report, which shows that in Europe, 86% of the population has access to internet and 47% is an active user on social networks (Hootsuite & We are social, 2019).

In Italy, users are as much as 92%, of which 88% use the internet every day.

Table9-1: Statistics on the use of internet and social media in the world, in Europe and in Italy.

	Worldwide	EU	Italy
Population [Bln€]	7.67	0.85	0.06
Internet Users	57% (+9.1%)	86% (+7.6%)	92% (27%)
Social Media Users	42% (+10%)	47% (+4.5%)	52% (+3.3%)
Source: (Hootsuite & We are social, 2019)			

These figures justify the exponential growth in the interest of companies in all sectors towards the so-called “Digital Marketing”, i.e. the set of marketing activities that use digital technologies (Kotler, Kartajaya, & Setiawan, 2017).

Among the Digital Marketing activities, of particular interest is the so-called "Digital Inbound Marketing": it is a strategy that focuses on winning the confidence of potential customers, who use the internet to acquire information (Halligan & Shah, 2010).

The creation of information and content is the basis of a good "Digital Inbound Marketing" strategy: this activity commonly takes the name of "Digital Content Marketing" (Rowley, 2008).

The strategic relevance of this discipline is based on the fact that almost all (93%) of internet users search for information through so-called search engines (Hootsuite & We are social, 2019).

Such research plays a fundamental role in users' purchasing decisions: in fact, 89% of customers start their purchasing process with an online search (Fleishman-Hillard & Interactive, 2012).

On the other hand, search engines reward content that best meets the users' needs, positioning them at the top along the SERP (Search Engine Result Page - or any page that appears after "Query"). The positioning, which is also called "indexing", takes place according to specific algorithms, capable of measuring the relevance and effectiveness of the content, monitoring among other things: time spent on the site, number of clicks, number of quotes from others sites, etc. It follows that a company to increase its visibility - and consequently propose its solutions more effectively – a company must produce content deemed valid by users. (Yalçin & Köse, 2010)

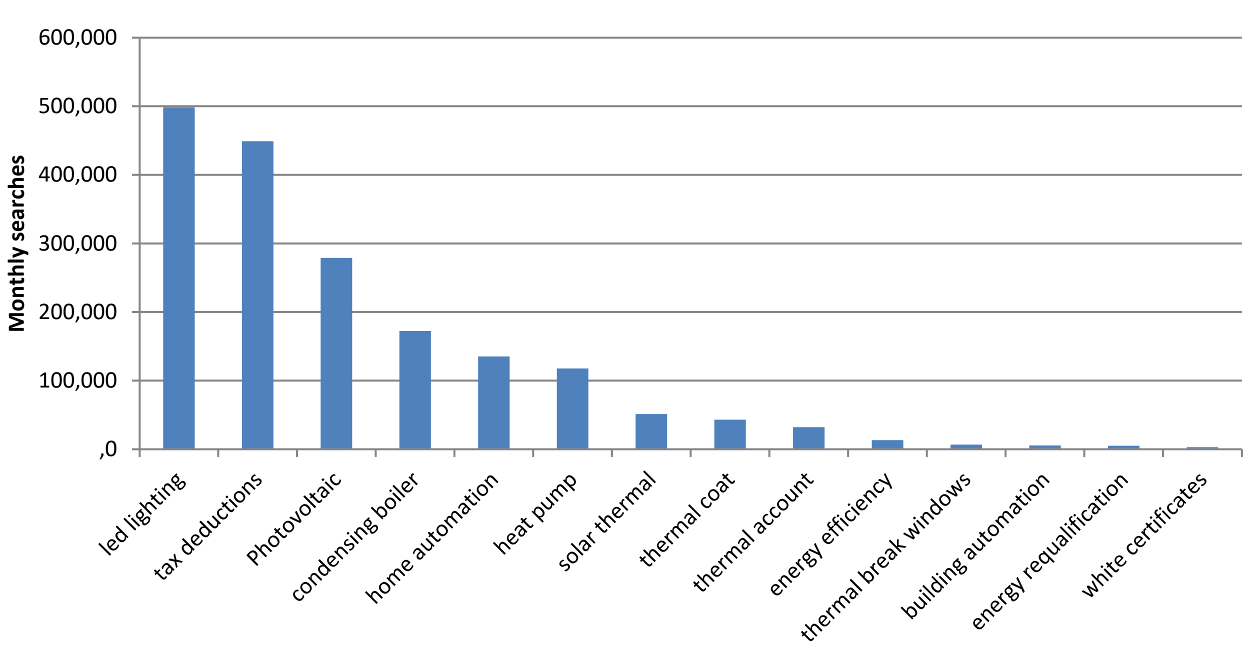
9.3 Analysis of web search volume of words related to energy upgrading in Italy

The following discussion reports an analysis aimed at providing a first indication about the audience that can be reached via the Web in Italy. Specifically Figure 9-1 shows the monthly trend of research related to the energy efficiency sector obtained in 2019 through the Google Ads "Keywords Planner" tool: it is a tool able to indicate how often certain words are searched for on Google.it and how their search has changed over time.

In particular, search for the following 14 Queries have been considered, which include:

- *Generic keywords* - Energy requalification, Energy Efficiency,
- *Technological solutions* - Photovoltaic, Condensing boilers, Heat pumps, Solar thermal, Thermal coat, LED lighting, Building Automation, Thermal cut windows and Domotics
- *Incentive mechanisms* -Tax Deductions , White Certificates , Thermal Account.

Figure 9-1: Monthly volume in Italy for words related to Queries.



Source: Analysis carried out through the "keyword planning" tool developed by Google ADS

The most sought-after solution is LED lighting with nearly 500,000 searches a month, followed by the tax deductions, photovoltaic, condensing boiler, home automation and heat pumps.

In particular, tax deductions are the only Query with a relatively high search volume that cannot be referred to a technology, reflecting the interest gained in this incentive.

9.4 Analysis of the type of web content for research related to energy renovation in Italy

For each of the 14 Queries defined in Section 9.3, the first 10 results in the Google.it SERP[5] were analyzed by studying the in-depth pages proposed by the search engine. These 140 (14 x 10) in-depth pages were then classified according to the following categories:

1. Page content
   a. Informative;
   b. Commercial;
   c. Configurator + Informative Content (pages with some sort of pre-sizing tool of the searched object and with some informative content)
2. Site ownership
   a. Commercial company
   b. Business information (Wikipedia, online newspapers, etc.)
   c. Trade association
   d. Government agency
   e. Price comparator.

The analysis shows that:

- Figure 9-2. Most sites (45%) belong to Commercial companies and (34%) to Business information companies, followed by the Government Agencies (11%) - especially for information regarding incentives, Price comparator (6%) and Trade association (4%).
- Figure 9-3 and Figure 9-4. Sites with informative contents are the vast majority (86%), while the commercial ones are a minority (10%).
- Figure 9-5. 65% of the sites with purely commercial contents, where the main information regards the price of the single products (catalog type), deal with “LED Lighting”. The other 13 topics share the remaining 35%, never exceeding 7% for each. This could be due to the fact that the LED is perceived as a well known and enstablished technology so that the only information of interest is the price. On the other hand, for more complicated and expensive technologies, users still need information on the application before than on the price. Figure 9-6. Price comparators hold the best position in SERP on average (3.8), followed by Government Agencies (4.00).

Specifically, Price comparators are portals that typically offer the potential customer the opportunity to get more quotes for the same service in order to choose the more fitting one. The added value that the potential customer perceives lies in the fact that these platform act as a "virtual consultant" able to guide him/her towards the most convenient choice, and enabling him/her to independently compare the various solutions (Boston Counsalting Group & Google, 2015).

These types of platform are now very used in “commodity” sectors that end users consider as “less transparent”, such as insurance, bank loans, ADSL or electricity and gas supply. As evidence of the key role that the comparators are assuming in these sectors, it is pointed out that in 2014 the “European Insurance Supervisory Authority and Pension Funds (Eiopa)” published the “Report on Good Practices on Comparison Websites” to promote the adoption of a code of conduct that guarantee the correctness of the comparison and the transparency of the information. In the same year, the National Supervisory Authority (Ivass) promoted a survey on the comparator sites and the Italian Competition Authority launched two procedures to ascertain any unfair commercial practices of two sites operating in the national territory (Porrini, 2017).

From an analysis conducted in this study, it was found that in Italy, 4 of the most used comparators (operating in Insurance, Banks, ADSL and Light-Gas sectors) are able to attract almost 7 million users per month on their pages: for each of these sites , Figure 9-8 shows the monthly visits obtained through the analysis tool called "Seozoom" (Nobili, 2017). It can be noted that in this case, only a site (“facile.it”) collects more than half of the visits, showing a certain dominant position on the market.

[5] SERPs, which stands for “Search Engine Results Page”, are web page listings that return search results based on a keyword query. The first positions of the SERP are the most sought after because they are an index of interest for web users. In addition, not only will it be possible to obtain a greater number of visits on the site, but they will be visits made by users who consider the site as an answer to their question.

Figure 9-2: Ownership of the sites dealing with energy requalification

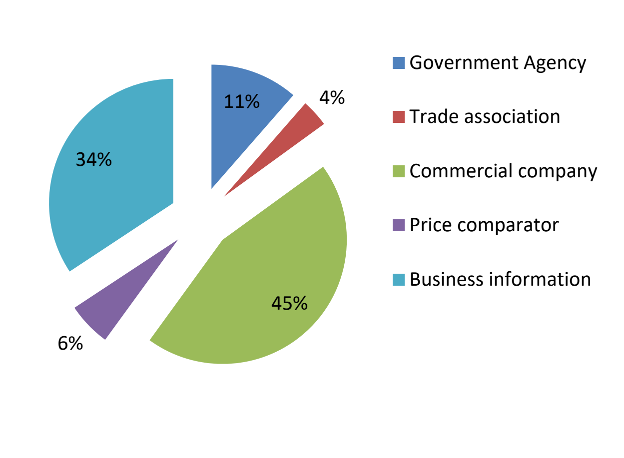


Figure 9-3: : Pages type dealing with energy requalification

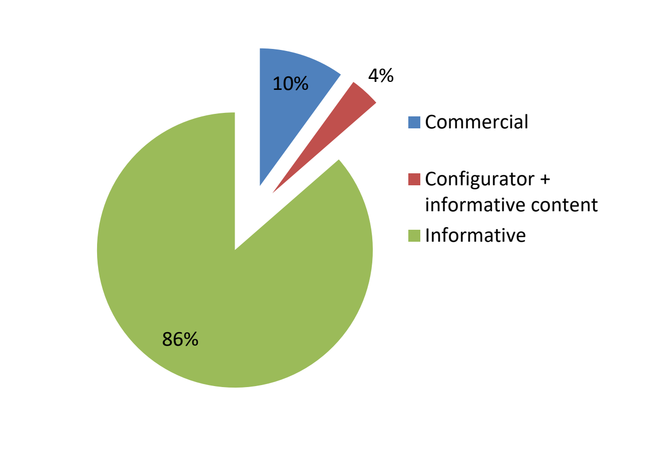


Figure 9-4: : Pages type & Ownership of the sites dealing with energy requalification

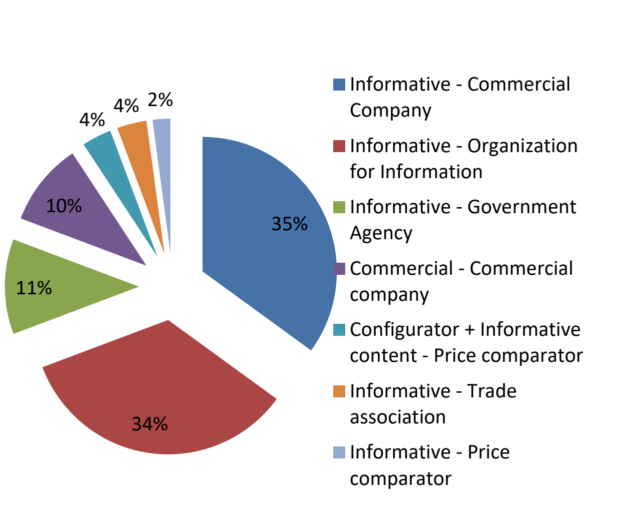


Figure 9-5: : topics that commercial sites deal with

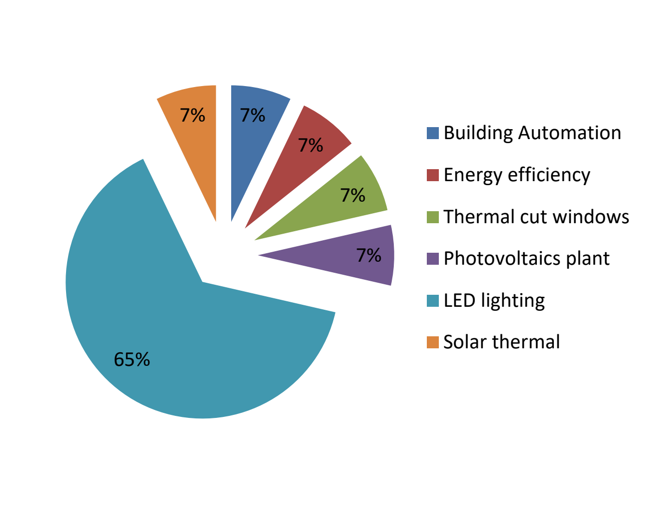


Figure 9-6: Average SERP position of the contents based on the site to which they belong

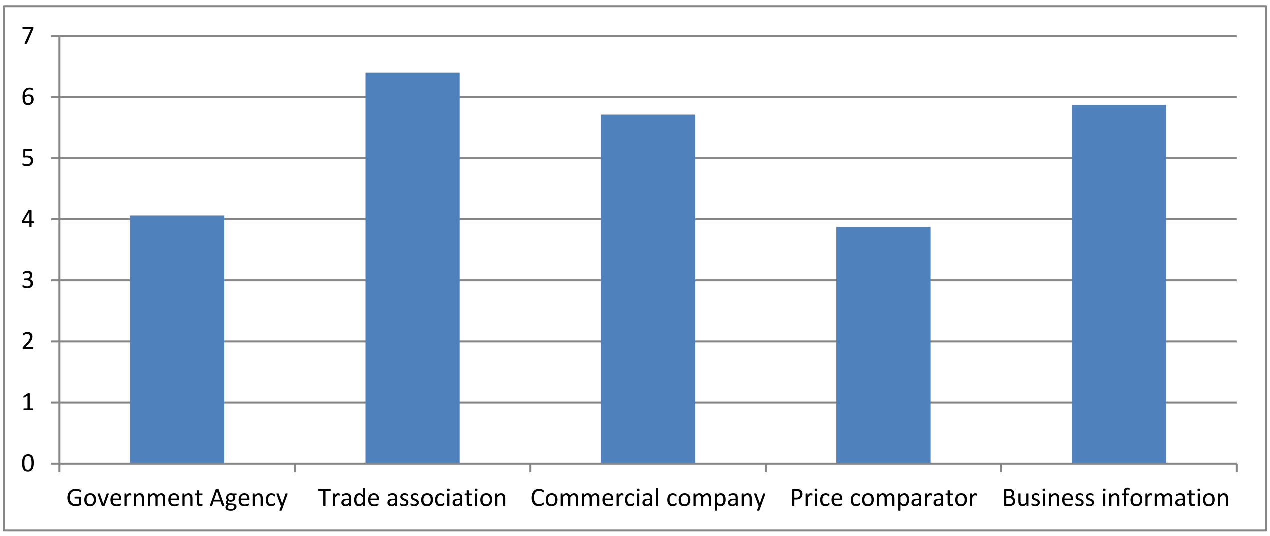
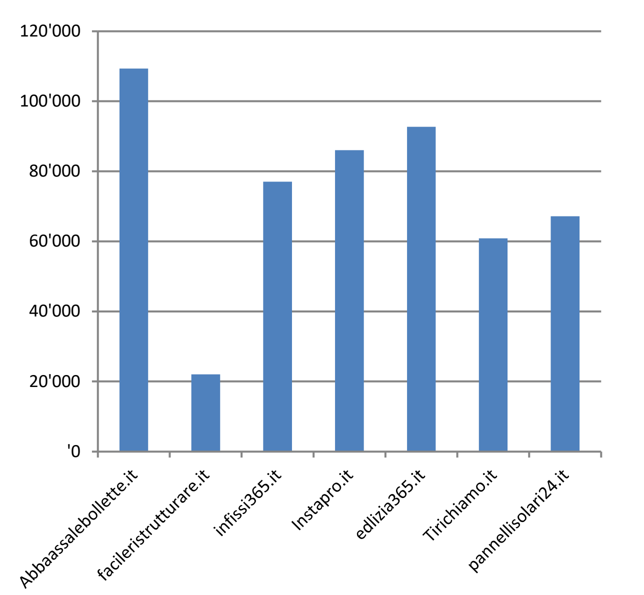
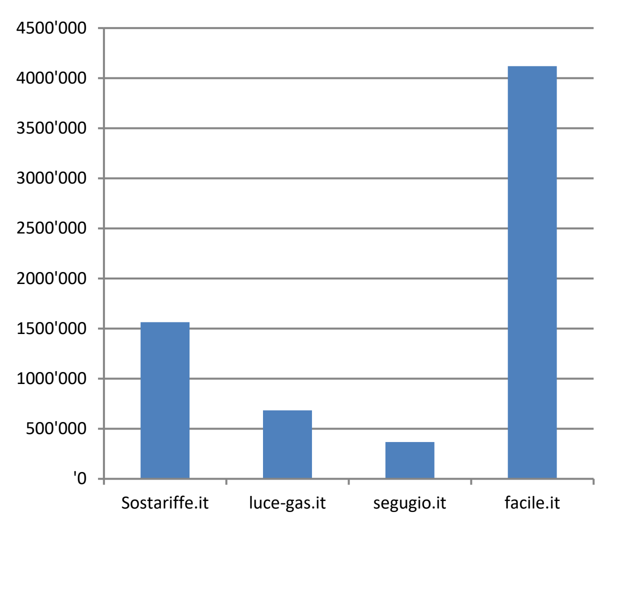


Figure 9-7: Monthly visits in the energy renovation Price Comparator sites	Figure 9-8: Monthly visits in the commodity Price Comparator sites
	

However, it is easy to foresee a constant increase of this type of platforms in all sectors where access to information is particularly complex, such as that of renewal and energy efficiency and, in particular, that relating to residential buildings, where normally potential customers (ie individual condominiums) tend to get their own idea only on the basis of the proposal at lower costs (“Self-made” paths in Table8-2).

In this sense, Figure 9-7 shows the monthly visits of 7 Price comparators in Italy already operating in the renovation market. In this case, the total search volume for all the selected sites is around 500,000 visitors a month. Compared with the Price comparators, in Figure 9-8 the number of visits is 10 times less but the distribution appears more homogeneous: this could mean that at the moment no service is considered more satisfactory than the others.

Unlike the “commodity” case, the business model of these portals does not provide for the provision of a quote directly online: usually the sites provide only information content with general information on the price, or, in the case of relatively simple technologies such as photovoltaics, they provide simple configurators to give the first information about cost and savings, based on some data that the user is required to input.

On the contrary, the service that is offered is typically to provide the contact of the user who shows his interest to professional partners or affiliates of the platform: these figures therefore contact the customer directly and provide a personalized quote after an interview or an inspection.

This is because, building renovation requires more in-depth assessments than simply comparing a unit price, unlike what happens for sectors such as telephony or energy and gas, in which it is sufficient to compare unit prices and a list of services to make a choice.

9.5 The funnel applied to the renovation market

In marketing, especially on the web, the decision-making processes that lead a potential customer to the actual purchase of the marketed product are represented through the so-called "funnel", Figure 9-9. This is a graphic representation in the shape of a truncated cone (funnel) of the decision path that starts at the top, at the wide opening of the funnel, and ends at the bottom, at the narrow outlet of the funnel

The funnel shape conveys two important messages. The first one indicates that in order to sell on the internet it is necessary to follow the so-called "inbounding" process, i.e. channeling the occasional visitor's interest in the products marketed on the site towards the purchase of product.

Figure 9-9: funnel marketing framework


This type of process is characterized in the following phases:

1. *Awareness* - Awareness that there is a product that can be useful to me.
2. *Interest* - Acknowledgment that the product can be useful.
3. *Consideration* - Evaluation. Product study to assess whether it really meets my needs.
4. *Intent* - Intention to purchase (ready to buy). Since the assessment is positive, I express my intention to purchase and request the final information.
5. *Purchase* - Since the information obtained in the phase Intent convinced me, I proceed with the purchase.

It is of interest to note that the transition from one phase to another always assumes that the user has progressively improved his/her knowledge of and confidence in the proposed product.

Back to the particular geometric shape of the funnel, the progressive reduction of the width represents the progressive reduction in the number of individuals who, proceeding with the decision-making process, continue to show interest in the final purchase of the product. This reduction in the number of visitors is absolutely normal because, along the decision-making path, the user has the opportunity to deepen his knowledge of the product, verify the fulfillment of his needs and / or identify more convenient alternative products.

It is of interest to note that this path only apparently sees the user as the sole protagonist. Indeed, for a user to acquire awareness, the seller must be able to use the information channels to disclose the existence of that specific product. Likewise the Conscious user will be encouraged to continue his process only if the seller is able to provide all the information requested in the clearest and most convincing way possible.

The funnel can be, and indeed is, used to describe many other processes such as, for example, the connotation of the site visitor as his decision-making path approaches a positive outcome of the sale:

- *User*: an individual or organization with a potential product or service need;
- *Lead*: an individual or organization partially interested in the product or service;
- *Prospect*: an individual or organization highly interested in the product or service;
- *Customer*: an individual or organization that has already purchased a product or service.

Like all decision-making processes, even those concerning the energy upgrading of buildings can be represented through a specialist funnel. In this study it was considered that its phases can be declined as follows:

1. Awareness,
2. Interest,
3. Decision,
4. Implementation
5. Evidently these phases appear completely similar to the classic ones mentioned above, referring to a sales process of a product, with the only difference that for the final phase the term Purchase was substituted with Implementation. In fact, by giving the right meaning to each single term, the two processes are formally identical. This is confirmed referring to Table8-2.

9.6 Conclusion

Traditionally, marketing was mainly based on proposing continuously of the product. In fact, the effectiveness of a marketing campaign was measured on the basis of the presence of the product on the communication channels. Nowadays, however, this type of marketing has lost much of its attractiveness, as people are now persecuted by repeated advertising messages, which are conveyed by more and more different platforms (banners, e-mails on computers and mobile phones, TV commercials , screens on the streets ...).

According to a recent research by "Digital Marketing Expert", these are thousands of advertisements per day.

This sensory overstimulation creates indifference among users because stimuli are perceived as heavily invasive. Not only the attention has dropped, but we are constantly led to erect "barriers": just think of the anti spam and ADV block solutions that have spread in most companies or how many times we hang up the phone as soon as we hear that it is a telephone call for commercial purposes.

For this reason, marketing techniques are evolving in the direction of "listening to needs" abandoning the technique of "undifferentiated proposition".

The idea is to intercept customers by giving qualified answers to the questions (needs) that they formulate through the media.

Therefore it is becoming increasingly important for companies to be able to provide answers to potential customers when they express interest or doubts towards a topic (and not directly towards a product) providing , first of all, valuable content and starting so to establish a relationship of trust.

Since the internet has now become the first and main place to find information, it therefore becomes necessary to be present online with the answers to the questions that users ask the most: these positioning and digital content creation activities are called ***Digital Content Marketing***.

In order to convert a potential customer into an own customer, however, the company must be able to accompany the user along the so-called *“funnel marketing”*, bringing the "*User*" first to the "*Lead*" state, then to that of "*Prospect*" and, only at the end, to the status of "*Customer*", eliminating along the way the various qualms that the user typically raises during the process.

Unlike other sectors, the energy requalification of a building requires specialist technical skills that a potential customer does not have and which he cannot hope to acquire simply reading the content (articles, videos, etc) posted in the web without any confrontation with a technician. It is therefore difficult to think that the funnel for this type of activity can be carried out just online.

For this reason, within this research work, it has been built a tool capable of overcoming the barriers that still hinder the implementation of projects for energy efficiency using Digital Content Marketing techniques to capture the attention of web users, demonstrating the benefits obtainable with the existing technologies and the financial incentives made available by the Italian government.

10 Actions necessary to strengthen the energy efficiency plan

10.1 Introduction

The objective of this Chapter is to summarize the evidence emerged in the 2nd Part of the thesis. In particular, the innovative tools discussed so far (design methodologies, BIM and BA) can certainly have a significant impact on the decision-making process of the final customer: however these benefits can be perceived especially by the technicians or by the end customers who rely on external professionals from the early stages of the decision-making process.

These tools therefore have little impact on what currently appears to be the main barrier of the market: ***the lack of awareness and knowledge by the end customers.***

This is even more evident in those types of customers that does not involve external consultants during their decision making process, because they trust only on their (scarce) technical skills.

From here, the need to develop a Decision Support System (DSS) able to take into account all the critical aspects of an energy requalification such as compliance with regulations, the choice of the right technology and economic-financial evaluation. Since it is aimed at non-expert end customers, this tool must therefore be easy to use and easily accessible, perhaps exploiting the potential of the web.

10.2 Adequacy of economic incentives

The energy renovation of buildings for civil use is fundamental to reduce emissions and mitigate the phenomenon of global warming. For these reasons, the European Directive 31/2010/EC introduces the concept of nearly Zero Energy Buildings (nZEB). In addition to the requirements of excellent thermal insulation, these buildings also require that the energy demand should be met by very efficient systems powered by energy produced for a mainly from renewable sources on site (The EU Parliament and the Council of the EU, 2010).

With the DLGS of 4.06.2013, Italy has fully implemented the European Directive extending the application also to the renovation of existing public and private buildings (Ministero Economia e Finanza, 2013). Furthermore, to favor the achievement of these energy efficiency objectives, the national government has issued a series of regulations that considerably reduce the cost of the intervention through various incentives.

In particular, the Government has introduced new mechanisms to facilitate this type of intervention, strengthening both the Ecobonus through the so called “Transfer of Credit” and the New Thermal Account 2.0 through a dedicated mechanism for nZEB combined with EPC.

The first 2 case studies, reported in Chapters 5 and 6 respectively, have tested these mechanisms, both from the point of view of the final customer and investors or suppliers (i.e. buyer of the Credit in Ecobonus case or ESCO in EPC case). These case studies show how, thanks to this type of incentive, redeveloping a building at the nZEB level can cost equal or even less than requalify it only respecting the requirement to reach the performance of the so-called “reference building”.

In any case, mainly due to the high cost of the thermal coat, it remains that the savings that can be obtained by a deep renovation (nZEB or standard) can hardly contain the PBT below 8 - 12 years: this implies that the residual part of the investment can hardly be financed by an ESCO through an *EPC - “shared savings contract”* .

In fact, this type of contract requires that the savings have to be higher than the fee to repay the initial investment of the ESCO. If the fee is too high - or the savings are too low - the user does not save money and the EPC stops to have meaning: as discussed in Section 5.6.6, it seems that only the EPC – “guaranteed savings contract” can be reasonably used, in which the customer finances the intervention and the ESCO guarantees only to achieve the expected savings.

At the moment, therefore, the residual part of an nZEB intervention can be financed only through equity or bank financing, since, in this case, the loan installment does not necessarily have to be less than the savings, but it has only to be acceptable by the user: in this sense it is necessary to be able to study the best compromise between installment and duration, in order to make acceptable the annual extra-cost deriving from the difference between the loan installment and the benefits in the bill.

Last but not least, it should be added that there is a widespread sense of distrust regarding the possibility of actually taking advantage of government incentives due to:

- the complexity of the rules governing the mechanisms for assigning and controlling incentives and their constant modification risks;

- the fear that at the end of the work, after having fully sustained the costs of restructuring, due to a defect in form or a material error caused by the complexity (and variability) of the rules, the incentives will not be effectively paid out.

10.3 The need of a new project development approach

It is interesting to underline that the Incentives such as New thermal Account and Ecobonus are strategically important not only for their economic contribution, but also because they also grant the monitoring of the process in both customer and legislator perspective.

In fact, these incentives require a compliance with a series of technical requirements that guarantee the quality of the intervention. This would be even more relevant in the case of involvement of an ESCO, which currently base their business plan on obtaining energy savings.

On the other hand, the whole evaluation of the profitability of the interventions, and in particular of baseline, savings, comfort, safety, investment and incentives, requires a solid methodology and the use of tools that are still not common in the industry's standard practice, as much in Italy as in other countries around Europe.

Given the difficulty of developing such complex projects characterized by the need to coordinate and integrate different skillsets and software, a general methodology has been proposed in Section 5.3 to allocate every required step into a general flow chart and to correctly elaborate the more interesting project in terms of profitability and energy savings, complete of all the documents a call for tender needs.

The PFAM methodology (Project Feasibility Assessment Methodology) proposed in Chapter 5.3 allows the integration of multiple analyses, ranging from advanced building performance simulation to financial viability assessment, in order to evaluate the convenience of an energy renovation project both from the point of view of the building owner and a potential ESCO that could fund the costs through the application of an EPC.

This methodology allows customers and designers to maintain the general overview of the project and and to segment its analysis in various phases. Each phase can be talked through the most suitable models, but at the same time setting the inputs and outputs beforehand, in order to better manage the various phases of the work. In this sense, the authors consider the current development of the Building Information Modelling (BIM) of enormous interest.

The IFC protocol, indeed, allows the exchange of all information pertaining to the structural elements of the building in a CAD drawing based on BIM: this may allow to dramatically simplify the interaction and interfacing problems addressed by the proposed methodology and, above all, it may dramatically simplify the required management of such projects by the customer.

This potential is also confirmed by the fact that, with the new public procurement law coming into force, Public Administrations may require the use of BIM for new project bids exceeding a certain threshold. On the other hand, although BIM tools capable of carrying out the required specific tasks are becoming increasingly available, there are only few studies concerning a multidisciplinary project, which combines architectural and energy performance capabilities and, in case, seismic analyses that are very important in high risk regions such as in Italy and other European countries.

In this context, building automation must also be taken into consideration as it can play a fundamental role in:

- optimizing costs, allowing to use most of the free energy produced from renewable sources, as discussed in Chapter 7.4;
- verifying the savings obtained, that is a fundamental aspect to account the savings both in the perspective of ESCOs for the EPCs and of Government for the incentives delivery;
- optimizing the comfort: this is an increasingly important aspect, especially in buildings subject to major investments (i.e. nZEB renovation) and from which an adequate level of comfort is also expected

10.4 The impact on decision making process

As far as the design methodology and the tools discussed so far can be useful and efficient, they are certainly not immediate solutions to fulfill the current energy efficiency gap: this is due to the fact that because they require the diffusion of specific knowledge, collaboration between different professionals and a certain awareness by the final customers to be appreciated (and so requested).

More specifically, with reference to the decision-making process described in Section 8.3, these tools (BIM Design, BA, PFAM methodology etc) can certainly have a relevant impact on those paths where design covers a significant role within the decision making process, i.e. “audit oriented” and “solution oriented” in Table8-2.

Table10-1: BIM and BA impact on the decision-making model for building energy requalification in Table8-2

Industrial sector	**Civil Sector**			**Impact**
Cagno et al. 2016	**Audit Oriented**	**Solution Oriented**	**Self-Made**	**Funnel Phase**
	Decision-making process based on an energy audit with a possible monitoring campaign	**Decision making based on a predefined technology**	**Decision making process based solely on one's own knowledge and on the estimates provided by the various suppliers contacted**	
Awareness	Awareness of the possibility of improving energy consumption Preliminary investigation of a possible technical solution Search for a comparison			Awareness
Needs and opportunity identification	**Confe… assignmen… the energy… to identify technologi…** **…al …tion of …which …s and …energy** **BIM and BA Impact**			Interest
Technology identification	**Choice of professiona… feasibility s…** **…tion an… …r the pr…** Analys… …onomic …ility	**BIM and BA Impact**		
Planning	**Conferral t… designers** **…f the det…**			
Financial Analysis and financing	…compare …nparison Look	…ical …ions	**BIM and BA Impact**	Decision
Installation startup and training	**Conf…** **…tion of t… imp…**	**…oject**		Implementation

Evidently, in those paths the design phase can benefit of an adequate budget to conduct this kind of activities.

10.5 The need for a Decision Support System in the early stages of decision-making

As clearly represented in Table10-1 , the new design methodologies BIM and BA have a relatively limited impact in the very early stages of the decision-making process.

On the other, as highlighted in Section 8.2, it is precisely these phases that present the strongest barrier: the lack of qualified information. This aspect can only be tackled through a (more) effective communication by all stakeholders about the advantages and benefits of this type of intervention.

In this sense the WEB and Digital Marketing (DM) can play, in general, a primary role in the dissemination of information: as already analyzed in Chapter 9, search engines as “Google” are already rewarding informative content through a high ranking in SERP: this represents a clear indication that users are already actually looking for this type of content.

The informative content available online is useful in the early stages of awareness generation, to make users aware of the possible opportunities that the renovation market can offer.

However, the energy renovation of a building requires specialized technical skills that a potential customer does not have and that he cannot hope to acquire simply through these informative contents, without a solid technical background.

Yet, as highlighted in Section 8.3, potential customers with less structured organizations (small businesses or private individuals) are more likely to rely on their own (scarce) internal skills, moving from the "Audit Oriented" to "Solution Oriented" or "Self-Made" path.

Still referring to the elaborated decision-making model reported in Table8-2, the following Table10-2 represents the impact that Digital marketing (DM) and Decision Support System (DSS) can have on the decision-making process.

Table10-2: DM and DSS impact on the decision-making model for building energy requalification in Table8-2

Industrial sector	Civil Sector			Impact
Cagno et al. 2016	**Audit Oriented**	**Solution Oriented**	**Self-Made**	Funnel Phase
	Decision-making process based on an energy audit with a possible monitoring campaign	Decision making based on a predefined technology	Decision making process based solely on one's own knowledge and on the estimates provided by the various suppliers contacted	
Awareness	DM and DSS Impact e possibilit nvestigatio Search f	DM and DSS Impact	ergy c chnical DM and DSS Impact	Awareness
Needs and opportunity identification	Conferral of professional assignment for the preparation of the energy diagnosis from which to identify the interventions and technologies that optimize energy consumption			Interest
Technology identification	Choice of type of intervention and assignment of professional assignment for the preparation of the feasibility study Analysis of technical, economic and financial feasibility			
Planning	Conferral the preparation of the definitive project to designers			
Financial Analysis and financing	Collects and compares definitive technical solutions Comparison of financial solutions Look for guarantees			Decision
Installation startup and training	Conferral the preparation of the exectutive project to designers and implementation			Implementation

From this scheme clearly emerges the relevance that these tools play especially in potential customers with "Self-Made" or "Solution Oriented" Path type (the most of the market). In fact, these end customers move from the "awareness phase" to the "decision phase" without having ever confronted with an external expert: this jump is represented by the yellow color.

Then, these types of users, who represent the majority of the market, need decision-making support different from those following the "Audit Oriented" path who are helped by expert advisors.

This leads to the conclusion that these final customers' needs to have easy access from the earliest stages of assessment to a framework as complete and low cost as possible. From here, the need to develop a Decision Support System (DSS) able to simultaneously analyze all the main problems related to the intervention (from the technological choice to normative requirements and the financial cost) using the various specialist calculation procedures.

It is interesting to note that DM and DSS have a significant impact on the decision-making process in a completely complementary way to BIM and BA.

3rd PART

11 The developed Decision Support System (DSS) platform

11.1 Introduction

This work is part of a much broader research project focused on the study of the technological and communication tools necessary to overcome the Energy Efficiency Gap in the real estate sector. The RRE platform was developed in 4 years: design, implementation and testing activities involved 6 different people including various engineers and programmers.

Given the above, this research project has led to the development of a web portal, freely available online, called www.reterisparmioenergia.it. Moreover, it provides the basis on which has been recently founded some industrial applications. This thesis has provided the theoretical guidelines to these developments.

Figure 11-1: Platform's home page

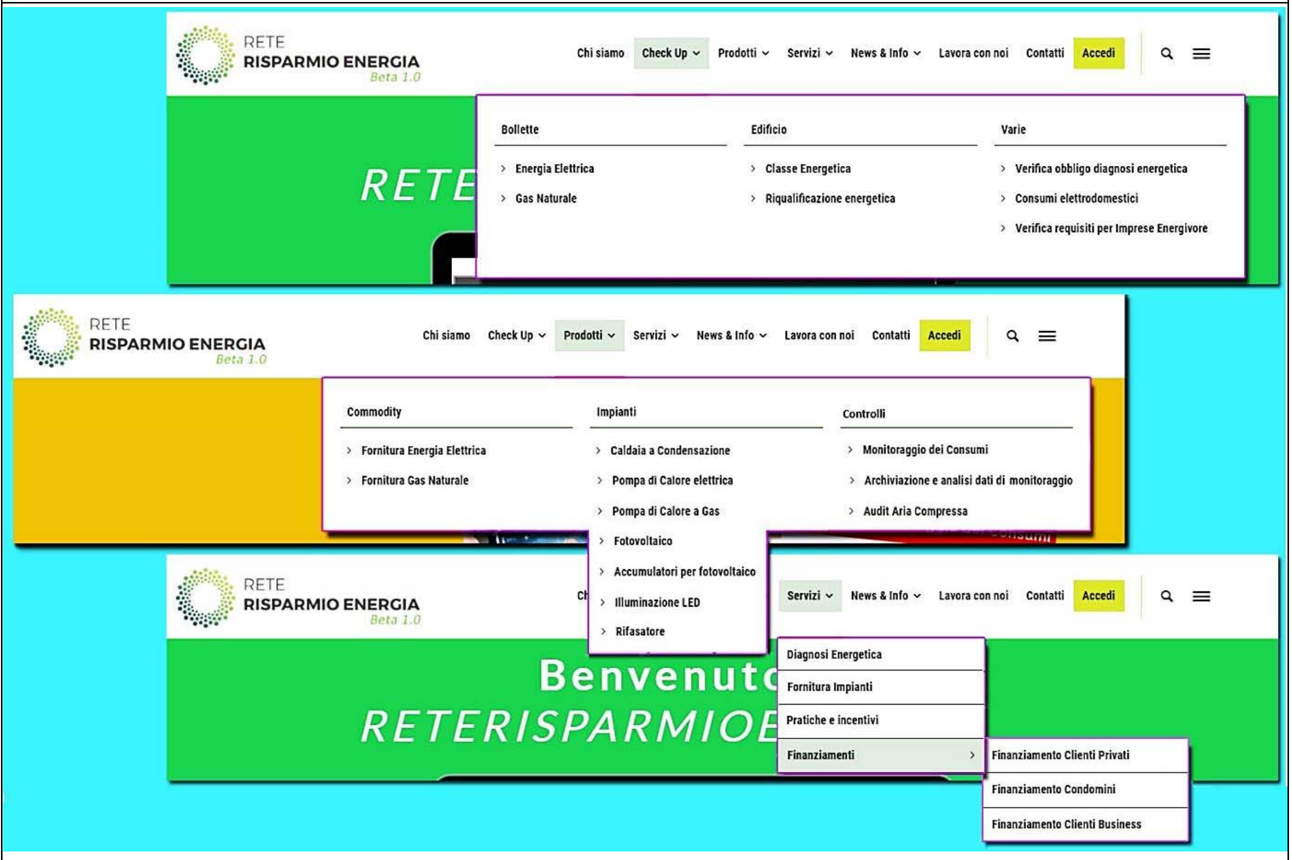
The aim of the platform is to provide a decision support for energy renovation interventions to both end users and technicians. At present the portal has three main functions:

1. Carry out an information and training function that is able to spread awareness of the opportunities for energy upgrading of buildings, highlighting both their economic and environmental benefits.
2. Provide analysis tools able to support, from the early stages of the decision-making process, the main technical, economic and financial issues.
3. Technical and economic dimensioning of energy efficiency interventions by providing a turnkey cost for the supply and installation taking into account the tax incentives.

Figure 11-2 shows the screenshot of the menu with the list of about 30 different applications already implemented whose functionalities are summarized in the next Section 11.2. Many of these applications are interconnected so that the results of one application can be used as input data for another one.

All the engineering applications have the common characteristic of being easy and immediate to use even by users without specialized thermo-technical background. This required considerable study to simplify the engineering analysis used in design practice and still keep the results sufficiently accurate.

Figure 11-2: Screenshot ot main menu



Furthermore, for all the applications, smart input dynamic procedures have been developed, equipped with on-line help, which have the function to guide the user in choosing the right options, by selecting them among all those available in the SW, through logical analysis of the data already provided. Just as interactive graphical tools have been developed to analyze the output data.

Parallel to engineering applications, applications for information and training have been developed as well as for communication with the inclusion of a CRM (Customer Relationship Management) that allows managing all relationships with users.

At the moment over 40 videos have been developed that document the use of the applications, with different levels of technical depth. Communication procedures based on the so-called "*inbounding process*" referred to in Section 9.5 are now being developed to convey the interest of potential users to the services offered by the portal.

Thanks to these features the portal can be useful not only for end customers, but also for companies and technicians belonging to the building constructions and plant supply chain in order to:

- develop a pre-assessment of the requalification interventions and compare alternative technical, economic and financial solutions;
- develop market assessments, to investigate in which cases a solution is more convenient than another;
- create special content marketing campaigns;
- have a commercial support able to help assess the various opportunities;
- support selling processes.

As a matter of fact, the portal has 5 level of different entry permissions: 1) Free entry, 2) User, 3) Technician and 4) Commercial, 5) Administrator. Higher level has access to more functionality regarding, for example, in the dimensioning of plant, **Free entry** have access only to the summary of the calculation results; the **User** has his own memory space in which he can store the performed analysis; the **Technician** can view the computational details; the **Commercial** can view the budget details. Finally, the **Administrator** can access everywhere from the plant layout to the relative sales contract.

To accommodate all these features and make the applications inter-communicating, an important work of design and development of the SW architecture has been necessary. Among the main requirements placed at the base of the project, is that of making the platform, once developed, easily updatable directly by the managers of the various activities, assumed by definition without any specialized computer knowledge.

This has strongly influenced the choice of the development platform and the systematic use of reliable SW libraries that allow the writing of IT procedures through user friendly interfaces (and not computer programming languages known only to the specialized SW developers).

These choices have proved extremely useful as they have made it possible to greatly speed up the development time and contain the cost significantly. In fact, direct implementation not only eliminates the cost of software developers but also the time necessary to transfer to them the work instructions and to control the correctness of their implementation.

Properly documenting the developed IT structure and the various applications is outside the scope of this doctoral thesis. Therefore in this Chapter only the general architecture of the platform and the basic characteristics of its main components are described.

Then, the following Chapters 12 ÷ 14 report the detail of the theoretical development that has made it possible to implement all the engineering applications concerning the air conditioning of buildings in the DDS. This is the calculation procedure envisaged by the current legislation to maintain constant climatic comfort in the building and to determine the Energy consumption by the Thermal Generator used to meet this requirement. Finally, Chapter 15 presents the outputs produced by the DDS in a real application, illustrating the input procedure and the various graphical interactive tools for the analysis of the technical, economic and financial results.

11.2 The Applications present in the DSS-RRE

Figure 11-2shows the screen-shots of the RRE portal with the menu of the three main functions currently available:

- **Check up** - containing tools to evaluate the current energy consumption of the building, verify the correctness of the costs on the bill and identify energy efficiency measures.
- **Prodotti** - containing tools for sizing and budgeting plant solutions capable of improving the environmental impact and the economic cost of energy supply.
- **Servizi** - containing information and activities to support the interventions.

In particular,

1. **Check up/Bollette** allows to verify the correctness of all the cost items shown in the bill (energy, transport, system charges and taxes) starting from the measured consumption..
2. **Check up/Edificio** allows to calculate, based on a brief description of the building, the current energy performance and indicates possible redevelopment measures, quantifying the cost of the intervention, energy and economic savings on operating costs.
3. **Prodotti/Controlli** allows to size an energy consumption monitoring system and evaluate the cost of implementation. It also provides tools for analyzing the acquired data and returning useful graphs for energy diagnosis.
4. **Prodotti/Impianti** allows to dimension and economically evaluate the realization of plants able to optimize energy consumption. In particular:
    a. Based on a brief description of the building, it is possible to assess the heat requirement and, therefore, to size the most suitable air conditioning system (condensing boiler, electric or gas heat pump).
    b. On the basis of electricity consumption (such as those calculated with the electric heat pump climate system), size the optimal photovoltaic system and, if necessary, the electric storage system.
    c. Based on the existing lighting plant, designing an equivalent one with LED lights that can drastically reduce the cost of the bill and the power of the system providing the same brightness.
    d. Based on the consumption data in the bill or measured by the monitoring system, size the suitable electric rephaser to cancel the reactive component of electricity consumption.

All the applications in points 2, 4.a e 4.b use the same procedure for calculating the thermal requirements and energy consumption illustrated in the following Chapters 11.8 ÷ 15.

All plant design tools provide:

- the sizing of all the system components;
- the cost estimate for the turnkey construction of the plant;

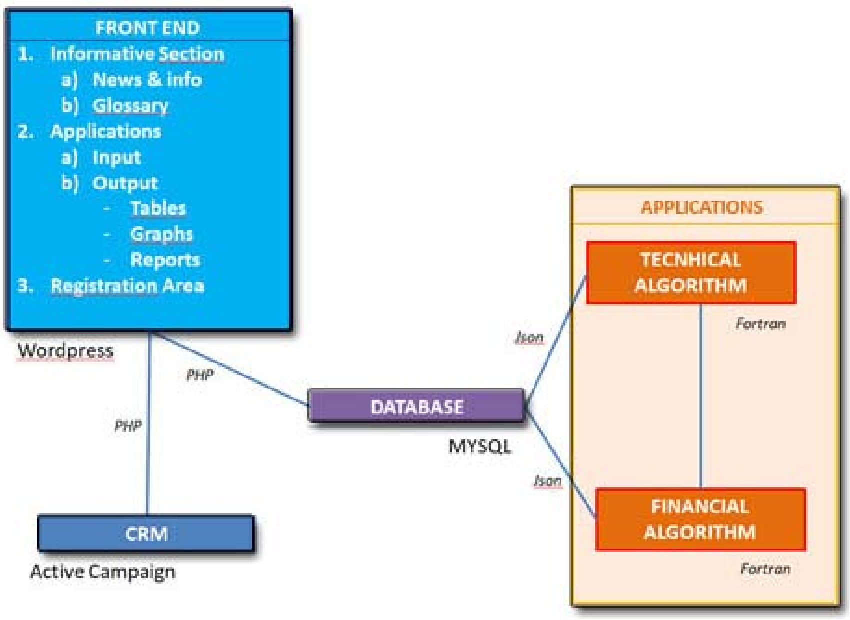
- the plant layout;
- the analysis of the performance and energy consumption before and after the intervention;
- the assessment of tax incentives;
- the estimation of economic convenience;
- the evaluation of the best financial strategy taking into consideration the possibility of Credit Assignment and bank financing for the part not covered by the incentives.

11.3 The portal RRE Software architecture

The portal consists of 4 main elements that interact as reported in Figure 11-3:

- The **FRONT END** that permits the user to interact with the portal, allowing to navigate inside it, to activate the available applications, to supply the input data necessary for the calculations and to view the achieved results.
- the **APPLICATIONS** containing all the calculation procedures available in the DDS
- the **DATABASE** that, besides storing the data, acts as an interface between the FRONT END and the APPLICATIONS: the input data are stored in the DB from where they are taken from the APPLICATION to perform their own calculations; finally, the results calculated by the APPLICATIONS are deposited in the DB from where they are taken to the FRONTEND.
- the **CRM** (Customer Relationship Management) that allows managing all relationships with users.

Figure 11-3: The platform's Software architecture



From an IT point of view, each of these blocks has its own programming languages and logics. To further complicate the situation, in recent years there has been a swirling development of these programming languages that in many cases have in turn generated "dialects". However, if on the one hand these new languages manage to make IT procedures more efficient, on the other they generate a series of other problems such as:

- Need for frequent updates of compilers and libraries.
- Presence of "bugs" in the compiler and lack of documentation.
- Extreme specialization of computer programmers and difficulty in recruiting them.

So developing the portal following the traditional way of using specialist software developers involves high development and updating costs, whether the work is performed outside by a specialized company or in-house. So the choice was to use reliable SW libraries that allow the writing of IT procedures through "*user friendly*" interfaces avoiding the need to learn "*obscure*" programming languages and techniques.

Due to the purchase of these platforms, the initial investment cost is greater and perhaps the product obtained is less efficient and have a less appealing interface. On the other hand, this choice allows the SW product to become a shared corporate asset where the managers of the various utilities can directly make the portal evolve.

Therefore, when the portal becomes fully operational, after the first phase of its creation, the investment cost for this type of architecture is fully repaid, with the savings generated not only due to the absence of the cost of software developers but also because of the time saved to check the correctness of their implementation.

Therefore it was initially created a group composed of experts in energy saving, communication, graphics and information technology that defined the portal layout, the site map, created the IT structure shown in Figure 11-3 and developed the IT procedures of communication between the various components. In particular:

- The portal is written with the general-purpose standard programming language PHP (Hypertext Preprocessor) version 7.3 of 06.12.2018, embedded into HTML code
- The protocol used for data exchange between the Applications block and the DataBase is the JSON standard (JavaScript Object Notation).

Completed this work of creating the main structure of the portal, the commitment of the software developers was drastically reduced and the development of the individual functions was left to the sole experts in energy saving and communication.

11.4 Front End and Database

IT professionals create websites using HTML directly, which is a formatting language that describes the layout or graphic display (layout) of the textual and non-textual content of a web page through formatting tags. Although HTML supports the insertion of scripts and external objects such as images or videos, it is not a programming language: since it does not provide for any definition of variables, data structures, functions or control structures that can implement programs, its code is only able to structure and decorate textual data.

To develop the site's features traditional programmers use PHP (recursive acronym of "PHP: Hypertext Preprocessor", hypertext preprocessor; originally an acronym for "Personal Home Page") which is an interpreted scripting language, originally conceived for programming of dynamic web pages.

PHP is able to interface with countless DBMSs including MySQL, PostgreSQL, MariaDB, Oracle, Firebird, IBM DB2, Microsoft SQL Server and even NoSql database like MongoDB. It supports numerous technologies such as XML, SOAP, IMAP, FTP, CORBA. It also integrates with other languages / platforms such as Java and .NET and there is a wrapper for all the most popular libraries such as CURL, GD, Gettext, GMP, Ming, OpenSSL and more.

It provides a specific API for interacting with Apache, although it works naturally with many other web servers. It is also optimally integrated with the MySQL DBMS for which it has more than one API (mysql, mysqli, PDO). For this reason there is a huge amount of scripts and libraries in PHP available freely on the Internet. Version 5 integrates a small embedded database, SQLite.

It has an archive called PEAR which provides a framework of reusable libraries for the development of PHP and PECL applications that collects all known extensions written in C.

In the last decade other languages have been developed such as Java, Node.js, Angular CLI, AdonisJs, Express, Fastify,, NestJS, Next.js, Nx Socket.io and others that in waves seem to take over existing ones but that however they are in turn overcome by new or relegated to small niches of specific applications.

Evidently the knowledge of the languages and technologies just mentioned, as well as being able to keep up to date with the tumultuous evolution of the IT world, is only possible for those who work as full-time programmers.

The strong market demand for tools that give the possibility of creating web sites without specialist knowledge has given rise to "user-friendly" development platforms that allow you to build Internet sites using predefined models, which can be customized by means of simple and intuitive so-called "builders".

Surely the results obtainable with these platforms are limited to what the predefined models allow, whereas, instead, there are no limits to the results obtainable using the “professional” programming techniques mentioned above.

For the development of DSS_RRE, the **WordPress 5** platform was chosen, integrated by a series of plugins that perform specific functions; among these the main ones are:

- **Formidable Form**, a front end editor that allows users to interact with the DSS_REE applications through quasi-steady and dynamic conditional logic forms.
- **WP Table**, a tool to create responsive tables and charts.
- **AM Charts**, a graphical library that allows to create interactive graphs.

Technically, WordPress is a *Content Management System* (CMS): a program that, running on the server side, allows the creation and distribution of an Internet site consisting of textual or multimedia content, easily manageable and updatable dynamically. Released publicly in 2003, it is an open source "blog" software platform developed in PHP with the support of the MySQL DB database. WordPress allows you to create web portals with the help of appropriate plugins. These are modules that extend the functionality of the application and add new features and elements to the sites created.

The Formidable Form plugin is in DSS-RRE used to create "*input forms*" through which to acquire the data from the user necessary to run the applications activated by the user and store them in the MySQL DB, Figure 11-4 Through Formidable Form it is possible to construct logical procedures that dynamically modify the requests contained in the forms according to the data already acquired. The basic IT construct is: *get A: If A = <alphanumeric value> get B else get C.*

Vice versa, the WP Table plugin is in DSS-RRE used as an output tool as it is able to collect data stored in the MySQL DB and represent them on the FrontEnd in table form allowing: searches and sorting of tabulated data, graphic representations, output files in various formats such as, for example, excel, xml, text, Figure 11-5.

Finally, the AM Charts graphics library is used to create complex graphics and / or with a significant number of points to represent, Figure 11-6 and Figure 11-7.

Figure 11-4: Formidable form front-end example

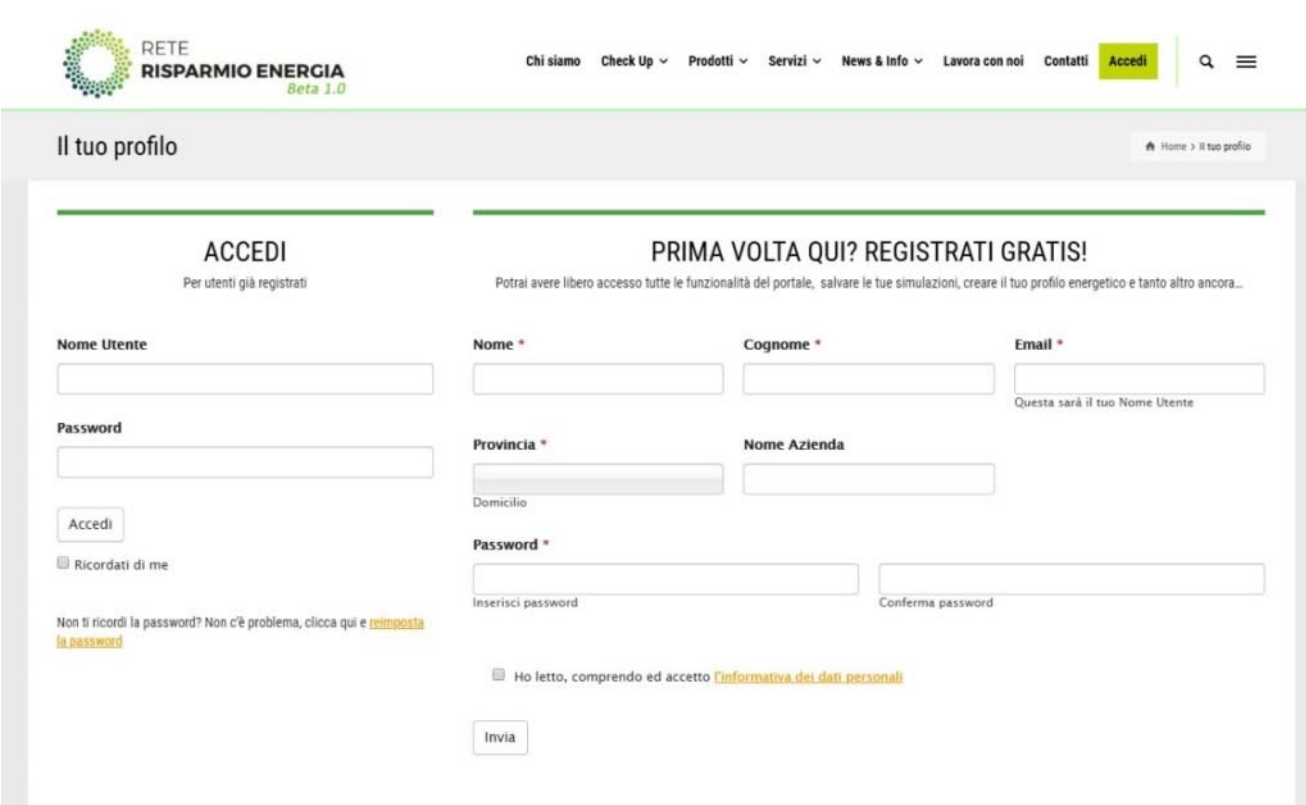
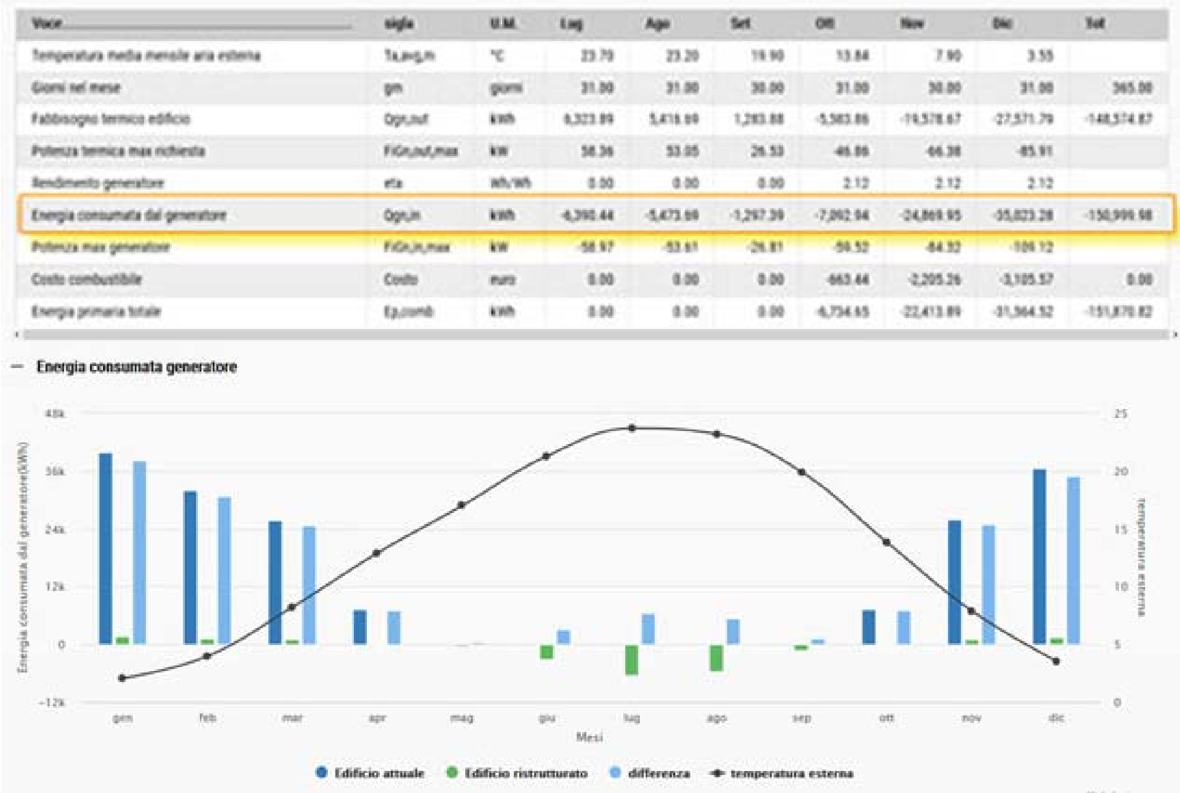


Figure 11-5: WP Table table and chart example



Voce	sigla	U.M.	Lug	Ago	Set	Ott	Nov	Dic	Tot
Temperatura media mensile aria esterna	Ta,avg,m	°C	23.70	23.20	19.90	13.84	7.90	3.55	
Giorni nel mese	gm	giorni	31.00	31.00	30.00	31.00	30.00	31.00	365.00
Fabbisogno termico edificio	Qgn,out	kWh	6,323.89	5,416.69	1,283.88	-5,583.86	-19,578.67	-27,571.79	-148,574.87
Potenza termica max richiesta	FiGn,out,max	kW	58.36	53.05	26.53	-46.86	-66.38	-85.91	
Rendimento generatore	eta	Wh/Wh	0.00	0.00	0.00	2.12	2.12	2.12	
Energia consumata dal generatore	Qgn,in	kWh	-6,390.44	-5,473.69	-1,297.39	-7,092.94	-24,869.95	-35,023.28	-150,999.98
Potenza max generatore	FiGn,in,max	kW	-58.97	-53.61	-26.81	-59.52	-84.32	-109.12	
Costo combustibile	Costo	euro	0.00	0.00	0.00	-663.44	-2,205.26	-3,105.57	0.00
Energia primaria totale	Ep,comb	kWh	0.00	0.00	0.00	-6,734.65	-22,413.89	-31,364.52	-151,870.82

Figure 11-6: AM Charts library based graphical example 1 - Electrical consumption monitoring system

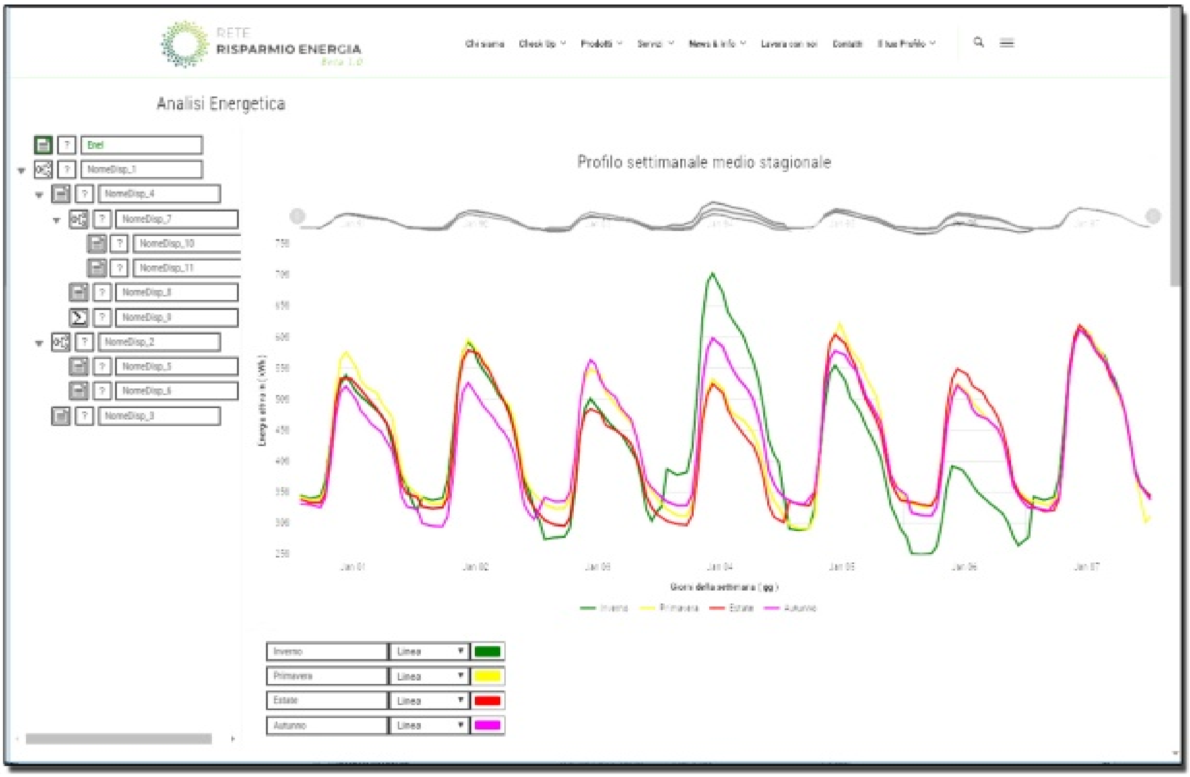
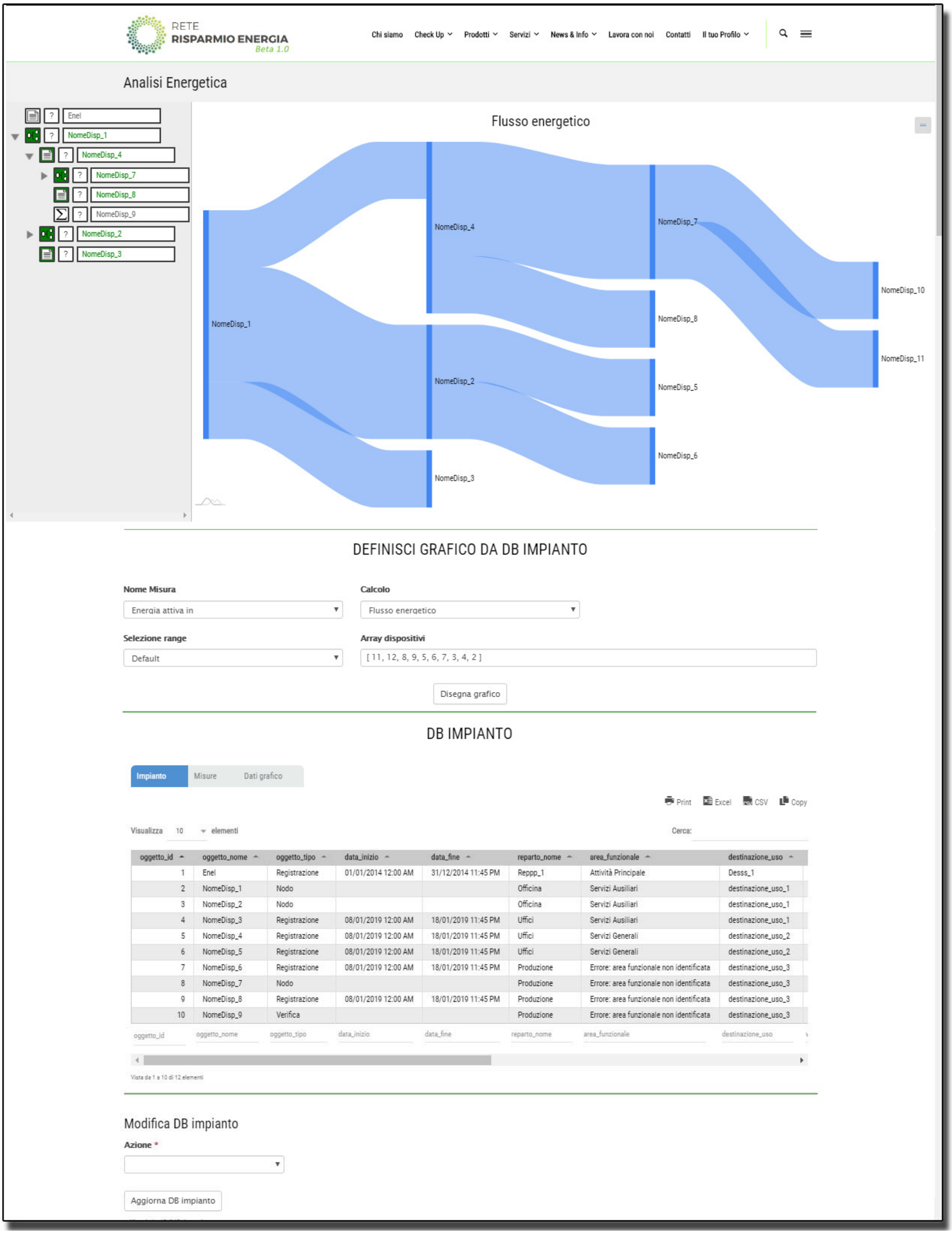


Figure 11-7: AM Charts library based graphical example 2 - Electrical consumption monitoring system



11.5 The structure of the applications computer programs

All the applications developed for the DSS-RRE are entirely implemented through the programming language called "Fortran 90". Acronym of FORmula TRANslation (or TRANslator).

The choice was imposed by the fact that these applications usually solve complex engineering and economic-financial problems. Furthermore, some applications require the processing of a considerable amount of data such as, for example, the analysis of energy consumption monitoring data aimed at energy diagnosis where it is necessary to process annual data of several variables measured every 15 min.

Thus, the need is to develop software able to exploit all the available computing power of computers. Moreover, it is considered strategic that these SW developments are directly carried out by the engineers in charge of their applications.

The characteristics of Fortran have been essentially designed on scientific and numerical calculation, rather than on software development. So from Fortran 95, for example, there are very short commands that allow you to perform mathematical operations on arrays, which not only make the programs much more readable but also to speed up considerably the numerical calculations: in fact Fortran 95 allows the computer, in case it is able to, to performs vector and / or parallel mathematical operations..

For the reasons mentioned the Fortran, even if it is little used for applications extraneous to the scientific and numerical calculation, still remains the language of choice in these fields, above all because persons with technical background ,even with poor programming knowledge, can easily learn to write an efficient code.

Since Fortran has existed for half a century now, the programs still used written in this language (especially in FORTRAN 77, its most important dialect) are countless. Fortran also remains the language of choice for programs designed to run on supercomputers, such as those used for weather forecasting, based on mathematical models of atmospheric physics.

Thanks to the innumerable application programs developed over the years and to the huge libraries of functions (which can also be recalled by programs written with other programming languages), Fortran is still a widely used language.

There are variants for parallel computing in scientific calculus: simulation of fluids, interactions between particles, weather forecasts, etc .; moreover, even if originally designed as a procedural language, some of its more recent versions allow the use of object-oriented programming (such as BIM).

Unlike many other languages, the rigorous programming by Fortran allows for the use of programming logic to solve specific problems: this feature is fundamental to allow engineers to directly implement algorithms without necessarily involving a computer scientist.

Unfortunately Fortran is not equipped with native interface tools with DataBase and, in particular, with MySQL DBMS adopted in DSS-RRE. To overcome this obstacle it was necessary to develop a specific library, using the C ++ programming language, which allows to carry out the main functions such as: storing, retrieving, searching and deleting data in the MySQL DBMS.

The interchange of data between client / server applications is based on the JSON protocol, an acronym for JavaScript Object Notation.

Therefore the functional scheme of all the applications implemented in the DSS-REE is structured as follows:

1) Get input data through forms built with Formidable Forms and store them in the DB
2) Run the computer program written in FORTRAN through an API (Application Programming Interface) written in PHP.
    a) Read the input data from the MySQL DBMS
    b) Execute the computation
    c) Write the results in the MySQL DBMS
3) Get the results in the MySQL DBMS and Output them on the FrontEnd by means of tables and graphs built with WP Table or with graphs built with the graphic library using AM Charts.

11.6 Economic and financial analysis tools

All applications that have as their objective investments to carry out energy saving interventions are programmed to:

1) calculate the technical characteristics of the intervention;
2) formulate a cost estimate;
3) assess the savings obtained in energy consumption.

Therefore, based on the cost of the installation and the consequent economic savings, all these applications are able to support the establish the best strategy to maximize economic convenience through:

4) the identification of the incentives available in relation to the type of intervention and the applicant;
5) the calculation of the cost of any loans;
6) the evaluation of economic-financial indices.

These economic evaluations are performed through a calculation procedure developed in this research and which is common to all applications.

Figure 11-8 shows the form that governs this procedure where the following 3 sections are distinguished:

Input A. **Incentivi Fiscali:** Tax Incentives which, depending on the type of applicant (public or private) and of the type of intervention (building or energetic renovation) identifies the possible tax incentive available and its value. In case, if the right conditions exist, it proposes the possibility of the transfer the tax credit.

Input B. **IVA:** VAT which, depending on the type of applicant , identifies the percentage of VAT to be applied to the invoice.

Input C. **Finanziamento ed attualizzazione:** Financing and discounting which allows to take into account any request for a bank loan.

Therefore, Figure 11-9 shows some of the output of these analyzes and, in particular:

Ouput A. **Finanza:** Finance which summarizes the terms of the investment (Cost, VAT, own financing, bank financing, ect.), The change in the energy cost and the profitability of the investment.

Ouput B. **Agevolazioni fiscali:** Tax benefits that show the type of tax relief requested and its its economic effects.

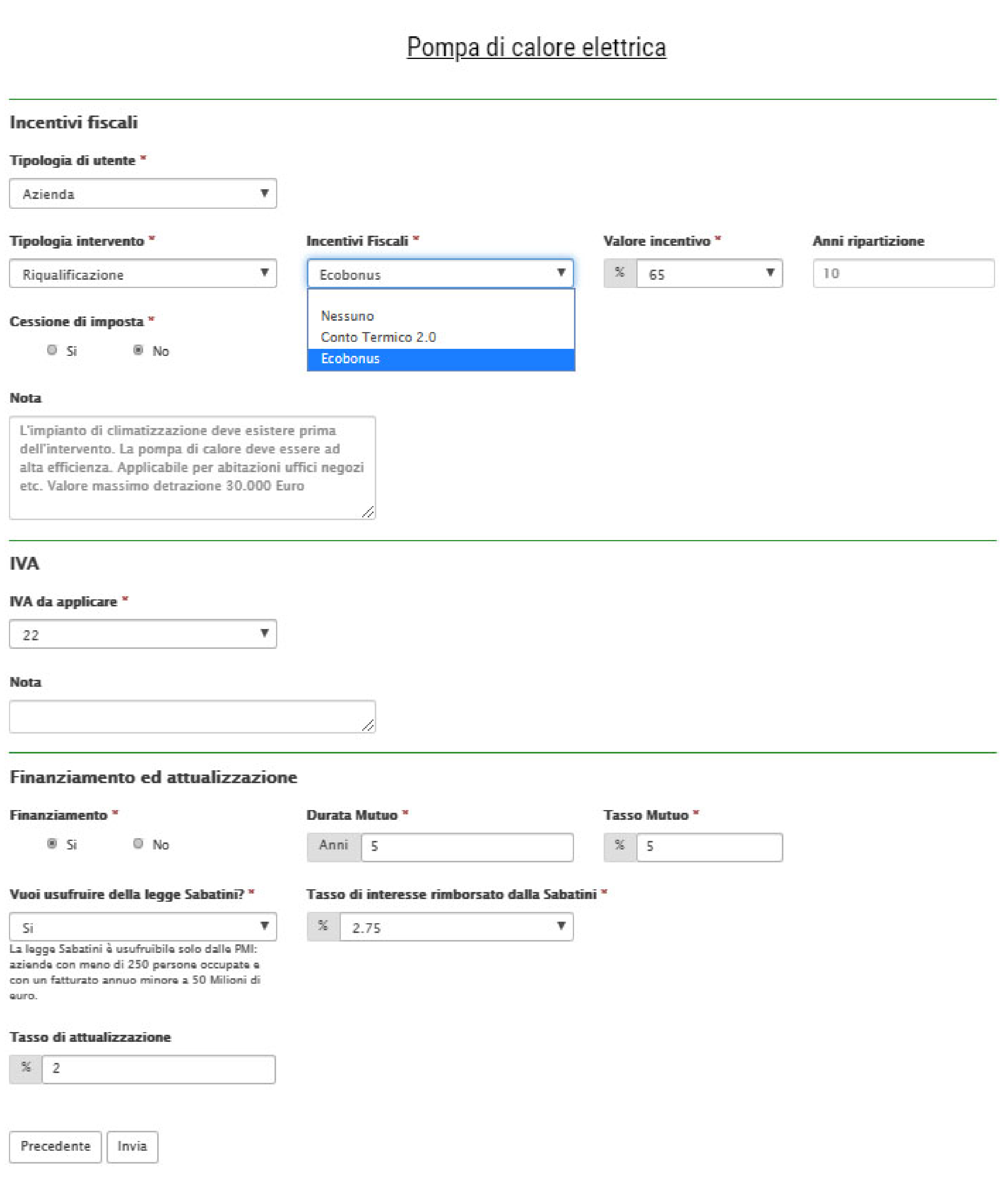
The most common indicators for the evaluation of an investment in energy efficiency are the cost and the time of return: however, these indicators penalize energy efficiency projects, as they do not take into account some important benefits (Chiaroni D. , Chiesa, Chiesa, Franzò, & Toletti, 2016).

Indeed, energy efficiency measures often have high investment costs and relatively long payback times. At the same time, however, they have long useful lives and low technological risks: therefore the benefits can be considered relatively constant over the years. Furthermore, by decreasing the amount of energy to be purchased on the market, interventions in efficiency make investors less exposed to external risk factors (increase in the price of fuels, increase in taxes, etc.). For this reason, the model also provides indicators capable of taking into account long-term economic effects such as NPV (Net Present Value) and IRR (Internal Rate of Return).

It should be noted that:

- Details on Thermal Account, Ecobonus and Credit Assignment are reported in Chapter 3.
- Super-amortization and over-amortization (Decree-Law No. 34/2019, converted into law on June 27, 2019,): these are incentives aimed at supporting companies that invest in new capital goods, in tangible and intangible assets (software and IT systems) functional to the technological and digital transformation of production processes.
- Sabatini Law (Decree-Law 34/2019 Growth Decree): This is a measure to encourage financing of interventions operated by industries. The measure supports investments to buy or lease machinery, equipment, facilities, capital goods for production and hardware, as well as software and digital technologies.

Figure 11-8: Economic-financial parameters and incentives input form



Pompa di calore elettrica

Incentivi fiscali

Tipologia di utente *

Azienda

Tipologia intervento *

Riqualificazione

Incentivi Fiscali *

Ecobonus

Nessuno

Conto Termico 2.0

Ecobonus

Valore incentivo *

% 65

Anni ripartizione

10

Cessione di imposta *

Si No

Nota

L'impianto di climatizzazione deve esistere prima dell'intervento. La pompa di calore deve essere ad alta efficienza. Applicabile per abitazioni uffici negozi etc. Valore massimo detrazione 30.000 Euro

IVA

IVA da applicare *

22

Nota

Finanziamento ed attualizzazione

Finanziamento *

Si No

Durata Mutuo *

Anni 5

Tasso Mutuo *

% 5

Vuoi usufruire della legge Sabatini? *

Si

La legge Sabatini è usufruibile solo dalle PMI: aziende con meno di 250 persone occupate e con un fatturato annuo minore a 50 Milioni di euro.

Tasso di interesse rimborsato dalla Sabatini *

% 2.75

Tasso di attualizzazione

% 2

Precedente Invia

Figure 11-9: Economic-financial parameters and incentives output

Finanza

+ **Investimento**

+ **Variazione costo energetico**

– **Redditività**

Nota	Voce	U.M.	Valore
	CONVENIENZA ECONOMICA		
	Vita impianto	Anni	25.00
	Tempo di ritorno investimento	Anni	13.32
E	VAN - Valore investimento Attualizzato Netto	Euro	43,157.28
	Tasso di attualizzazione	%	2.00
E = E / B	IP - Indice di Profitto (VAN/Prezzo netto)		1.60
	TIR - Rendimento dell investimento	%	14.01

Agevolazioni fiscali

+ **Cessione del credito**

– **Iper ammortamento**

Print Excel CSV Copy

Nota	Voce	u.m.	Ammortamento ordinario	Super/iper ammortamento
A	Costo bene (imponibile)	Euro	24,535.08	24,535.08
B	Aliquota ammortamento	%	100.00	0.00
C = A * B	Valore investimento da ammortizzare negli anni	Euro	24,535.08	0.00
D	Aliquota ammortamento	%	10.00	10.00
E = 1 / D	Numero anni ammortamento	Anni	10.00	10.00
F = C * D	Investimeno iscritto nel bilancio annuale	Euro	2,453.51	0.00
G	Aliquota IRES (anno 2017)	%	24.00	24.00
H = F * G	Deduzione annuali	Euro	588.84	0.00
I = H - H_Ordinario	Vantaggio fiscale anno	Euro	0.00	-588.84
L = I * E	Vantaggio fiscale totale	Euro	0.00	-5,888.42
N = L / B	Risparmio	% costo bene	0.00	-24.00
			0.00	0.00

+ Legge Sabatini

11.7 CRM

The CRM (Client Relationship Management) is an IT system that is able to manage all customer relationship management strategies and it is fundamental for:

1. maintain constant and valuable relationships with users,
2. understand (and in some cases anticipate) their needs,
3. develop products and services that increase customer satisfaction.

In particular, Chapter 9 has shown that according to the decision-making phase, the decision maker faces different barriers: several types of information are therefore needed depending on the phase.

Furthermore, it must be considered that the more progress is made in the decision-making process, the greater the level of detail required. At the same time, too high a level of detail at the beginning of the decision-making process can even be detrimental to the user, as it can lead to confusion.

In light of these considerations, through CRM the type and amount of information coming out from the applications tried have been calibrated depending on the decision-making phase of each user.

In particular:

a. all users can freely use the platform; once a simulation has been performed, users have access to a brief summary of the main technical, economic and financial results;
b. once the interest is gained, the user has the possibility to register itself to the platform and access to a specific section, in which a more detailed series of tables and graphs are made available;
c. from this section, it is also possible to download a complete report of the simulation;

Moreover, CRM allows to monitor for each users the number of accesses, the pages visited by each user, the simulation carried out and so on.

Thus, a series of communication strategies are currently being studied in order to better calibrate and automate messages based on the history of the individual user.

Finally the technical users have the possibility to access to a further section, which also contains more detailed information regarding the complete information about the simulations.

The platform adopted is called “Active Campaign”.

11.8 Comparison between RRE platform and existing DSSs

Due to their nature, DSSs require “*quick*” calculation tools, that is characterized by small numbers of simple input data for immediate use and response. This implies that, where the problem presents excessive complexity, the models used must be quite simplified while maintaining a high approximation of the exact result calculable with the complete theory.

Technical literature presents numerous speedy calculation models, but almost all of them are conceived as a tool to support the early stage design of technicians and, therefore, require specialist knowledge (Picco, Marengo, & Beltrami, 2015).

Most IT tools available are usually designed to analyze a single issue (for example one of the many problems of an engineering nature or, the heat demand, or, alternatively, a financial nature) and are not included in a system capable of communicating with the others calculation instruments needed to evaluate all relevant aspects of the investment.

At this regard (Wen & Hiyama, 2016) and (Han, Huang, Zhang, & Zhang, 2018) in 2 recent papers explored 27 existing simulation tools and analyzed them according to their characteristics and functions.

The following Table 11-1: Comparison between DSS-RRE and other similar already available platforms summarizes the main differences between the DSS RRE and the currently available design support tools as reviewed in (Wen & Hiyama, 2016) and (Han, Huang, Zhang, & Zhang, 2018): the objective of this table is not to elaborate a precise comparison with every instrument currently available on the market, but to highlight the difference in approach and purpose between those developed so far and the DSS-RRE model.

In practice, the available tools are excellent for providing indications to the technicians from the design point of view and permitting the simplification of some otherwise complicated technical analyzes.

At the same time it is unlikely that these tools now available can be used by end customers and provide a general idea of the entire restructuring project: 1) evaluation of the current situation, 2) selection of a technology among the many available, 3) selection incentive guide and financial analysis.

Table 11-1: Comparison between DSS-RRE and other similar already available platforms

	Tools Reviewed in (Wen & Hiyama, 2016) **and** (Han, Huang, Zhang, & Zhang, 2018)	**RRE Model**
Freely available as WEB APP	No	Yes
Simplification addressed to final customer	No	Yes
Profitability computation	Some Times	Yes
Cost estimation for renovation interventions	No	Yes
National incentive computation	No	Yes
Based on current national normative	No	Yes
Bank Loan evaluation	No	Yes
Hourly demand	If present, through Dynamic Simulation	Bin Method
Specific Algorithm for PV + Heat Pump	No	Yes

12 The thermal energy demand of a building

12.1 Introduction

All the applications concerning the air conditioning of buildings present in the DSS-RRE platform use a single calculation procedure to determine the Thermal Energy Demand and, therefore, the Energy Consumption. This procedure fully complies with the quasi-steady method UNI / TS 11300 as adopted by the current Italian legislation listed in Section 12.2. However it contains the following important peculiarities:

1. Drastic reduction of input data so as to allow an easy and immediate use of the application even by privy user of specialized thermo-technical knowledge.
2. Full application of the method also to the Summer period for cooling.
3. Calculation based on an hourly discretization that provides more accurate results than the current monthly one, as it allows a more precise integration of the efficiency functions of the thermal generators, especially regarding heat pumps (Chapter 0).
4. Coupled calculation Electric Heat Pump with Photovoltaic Electric Generation System, Chapter 14.6 - 14.7

This and the subsequent Chapters 12 and 13 show the mathematical basis on which it was possible to obtain the aforementioned results. Finally, Chapter 14 reports some of the most significant tests carried out to validate the correctness of the numerical implementation.

This documentation work, initially created to expose only the innovative aspects of research, has resulted in a complete description and, apparently, simple and essential, to the entire "quasi-steady" theory. If this were confirmed, it would be in itself a result by no means trivial, considering the difficulty of finding a complete and easy understandable reference on the subject.

To provide an element of evaluation, only the work of reconstruction of the normative puzzle and the definitive verification of the correct implementation of the calculation procedure required by law, took about 3 years. Also noteworthy was the cost of purchasing the plethora of documents that provide the technical details imposed by current legislation, Section 12.2, as well as that of commercial software that was finally necessary to purchase to verify the correctness of the results obtained.

The serious lack of appropriate documentation makes the subject particularly complicated and the professional calculation is now entirely entrusted to specialized software, mostly poorly documented from a technical point of view, which are used as black-boxes. The hope is that this work could help those who intend to fully govern technical analysis by limiting the dogmatic aspect with which they now "*simply run a software*".

12.2 The Italian legislation

In order to standardize the calculation of the Thermal Demand, i.e. the thermal energy needed to maintain the set point temperature along an year, starting in the early 2000s, the EU promoted the development of a calculation method based on the so-called "quasi-steady" method (someone also uses the term "quasi-steady "). In these 19 years the method has been intensively developed with subsequent additions, revisions and modifications.

Currently, the part concerning the heating allows the complete calculation of the Thermal Demand in almost all the conditions of practical interest. On the other hand, the part concerning cooling appears in many aspects still incomplete.

Unfortunately, as shown in the following, the technical and legal norms that regulate its implementation in Italy are contained in a plethora of documentation, often contradictory and /or incomplete and/or unclear. The situation is aggravated by the fact that this huge amount of technical documentation is accessible only paying a high cost, and moreover repeated over time due to the continuous updates. A rough estimate of the costs needed to access the technical documentation used in this research work is around € 1'600.

In fact, the legislative framework that in Italy regulates the calculation of the Energy Requirements of buildings is essentially composed by:

- **Law 10/91**: Rules for the implementation of the National Energy Plan on the rational use of energy, energy savings and the development of renewable energy sources.
- **D.Lgs. 192/05:** Implementation of the 2002/91/EC Directive on Energy Efficiency in Construction
- **DM 26/6/2009** of the Mise, *National Guidelines for Energy Certification of Buildings* (G.U. 10/7/2009 No 158 – effective from 25/7/2009

- **Law 90/2013**: Conversion into law, with amendments, of the Decree-Law 4 June 2013, No 63, bearing urgent provisions for the implementation of the 2010/31/EU Directive of the European Parliament and the Council of 19 May 2010, on energy performance In the case of the European Commission, as well as other social cohesion provisions.
- **D.Lgs. 102/2014:** Implementation of the 2012/27/EU Energy Efficiency Directive, which modifies the 2009/125/CE and 2010/30/EU directives and repeals the 2004/8/EC and 2006/32/EC directives.
- **DM 26/6/2015**, so-called "Minimum *Requirements Decree*", and related Attachments 1 to 4
- **DGR No. 2456 of 8 March 2017 of the Lombardy Region**: Integration of the provisions for the energy efficiency of buildings approved by Decree 176 of 12.1.2017 and overall re-approval of the provisions relating to the energy efficiency of buildings of buildings and the energy performance certificate and related Attachments from A to H
- **Implementation** Decrees related to DM 26 June 2015

DL 192/2005, Exhibit 1, Chapter 4 stipulates that the following technical documentation have to be used to calculate the thermal requirements of a building:

1. CTI 14/2013 recommendation "Building Energy Performance – Determining Primary Energy and Energy Performance EP for Building Classification", or equivalent UNI legislation and subsequent technical standards that follow;
2. UNI/TS 11300 – 1 Building Energy Performance – Part 1: Determining the building's thermal energy needs for summer and winter air conditioning;
3. UNI/TS 11300 – 2 Building Energy Performance – Part 2: Determining primary energy needs and efficiencies for heating, sanitary hot water production, ventilation and lighting;
4. UNI/TS 11300 – 3 Building Energy Performance – Part 3: Determining primary energy needs and cooling efficiencies;
5. UNI/TS 11300 – 4 Building Energy Performance – Part 4: Using renewable energy and other generation methods for heating and domestic hot water;
6. UNI EN 15193 - Energy performance of buildings - Energy requirements for lighting. The design calculation method is applicable to all building types, both for new and existing buildings, regardless of their size.

to which we need to add a large number of integrations and corrections that have been published since 2005 to the present, such as

7. UNI/TS 11300-5: Calculating primary energy and renewable energy share
8. UNI/TS 11300-6: Determining energy needs for elevators, escalators and moving sidewalks
9. UNI EN 15459: Energy Performance of Buildings - Economic Assessment Of Buildings Energy Systems
10. UNI CEI EN 16247-1: 2012 "Energy Diagnosis - Part 1: General Requirements" defining requirements, methodology and reporting common to all DEs
11. UNI CEI EN 16247-2: 2014 "Energy Diagnosis - Part 2: Buildings" that applies to building-specific energy diagnoses, defining their requirements, methodology and reporting. It also applies to the service sector
12. UNI CEI EN 16247-5: 2015 "Energy Diagnosis - Part 5: Energy Auditor Skills" that specifies the skills that auditor must possess
13. UNI/TR 11328-1:2009 Solar energy - Calculating contributions for construction applications - Part 1: Evaluation of radiant energy received.

The following documents are available for the standard climate values to be used in the calculation:

14. D.P.R. 412/93 Annex Table A, updated to 31 October 2009 - Climate zones and winter degrees-days for the 8'119 Italian municipalities;
15. UNI 10379 - Average seasonal climatic data;
16. UNI 5364 - Maximum outside and average design temperatures for winter;
17. UNI 10339 - Maximum outside and average design temperatures for summer;

18. Law 10/1991 and DPR 412/1993 and subsequent changes. Period ignited winter heating in

Table 12-1: Definition of winter heating period		
Climate zone	Start	End
A	December 1st	15 March
B	December 1st	31 March
C	15th November	31 March
D	1 November	15th April
e	15th October	15th April
F	October 5	April 22

19. The UNI 10349/Mar 1994, last update 31 March 2016 - Data referring to the 110 provinces:
    a) Schedule VI - Average monthly values of the average daily outdoor air temperature.
    b) Schedule VII - Geographical coordinates: Altitude, Latitude, Longitude.
    c) Schedule VIII - Direct and diffuse monthly average solar irradiation on horizontal surface;
    d) Schedule IX, - XIII Global monthly solar irradiation on vertical surface;
    e) Schedule XVI - Maximum summer temperature and amplitude
20. Italian Atlas of Solar Radiation, average daily solar radiation on a horizontal surface

12.3 The primal heat demand relationship

The normative assumes that ideally the air conditioning system must be able to maintain the internal temperature of the building at a constant value 24 hours a day continuously. The calculation of the demand is defined according to the external average monthly temperature T_j and, consequently, the calendar year is divided into two distinct periods:

- The **winter period** where on average $T_{int,des} > T_j$: to keep the internal temperature constant, it is necessary to heat the room to compensate for the heat moved to the external environment which is at a lower temperature
- The **summer period** where on average $T_{int,des} < T_j$: to keep the internal temperature constant, the environment must be cooled to compensate for the heat coming from the external environment which is at a higher temperature.

where $T_{int,des}$ is the set point temperature at which the building is to be kept. This temperature, in general, differs for the winter and summer seasons.

12.3.1 Winter period – heating

The UNI/TS 11300-1 defines the ideal thermal energy demand for heating $Q_{H,nd}$ as the total energy required (H = *heat*, nd = *need*) to keep the project temperature constant throughout the winter period in heated rooms equal to $T_{int,des} = 20$ °C. Mathematically:

$$Q_{H,nd} = Q_{ls} - \eta_{H,gn} \times Q_{gn}; \text{ [kWh]}$$

where

$$Q_{ls} = Q_{tr} + Q_{ve} + Q_{\emptyset} - Q_{sol,op}; \text{ [kWh]}$$

represents the heat loss (*ls* = losses), or the total heat exchange from the inside towards the outside of the building, and

- Q_{tr} = heat losses by transmission;
- Q_{ve} = heat thermal dispersion for ventilation;
- $Q_{\emptyset}$ = thermal dispersion (known as extra-thermal flow) due to infrared radiation towards the sky;
- $Q_{sol,op}$ = solar heat gain from opaque surfaces ;

while

$$Q_{gn} = Q_{int} + Q_{sol,w}; \text{ [kWh]}$$

represents the energy gain (*gn* = gain), or the total thermal gain for heating, and

- Q_{int} = internal heat gain;
- $Q_{sol,w}$ = solar heat gain from glazed surfaces ;

and finally

- $\eta_{H,gn}$ = utilization factor of thermal gains;

The calculation of the demand is carried out on a monthly basis assuming

- h = the number of daily heating hours equal to 24;
- T_j = external temperature equal to the average monthly temperature of the site according with UNI 10349 Schedule VI [° C];
- Calculation period defined as reported in Table 12-1.

12.3.2 Summer period - cooling

Similarly to the winter period, the ideal thermal energy requirement for cooling Q_ (C, nd) is defined as the total energy required (*C* = cold, *nd* = need) to maintain the design temperature throughout the summer in cooled rooms constantly equal to °C. $T_{int,des} = 26°C$. Mathematically:

$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} \times Q_{ls}; \text{ [kWh]}$$

Where

- Q_{gn} and Q_{ls} are defined as reported in the previous Section 12.3;
- $\eta_{C,gn}$ = is the utilization factor;

The calculation of the demand is carried out on a monthly basis assuming:

- h = the number of heating daily hours equal to 24;
- T_j = external temperature equal to the average monthly temperature of the site UNI 10349 according with Prospect VI [°C].

The legislation still does not define exactly the summer period. Therefore in the DSS-RRE simulator it has been established that it is the period not covered (complementary) by the winter one.

12.3.3 Degree days

The UNI EN ISO 15927-6: 2008 standard requires that the calculation of the thermal needs in the winter must refer to the so-called Winter Degrees Days defined as

$$GG = \sum_{j=1}^{n_{months}} GG_j$$

where

$$GG_j = \left(T_{int,des} - T_j\right) \times g_j$$

- T_j = the average monthly temperature of the *j*-th month
- $T_{int,des}$ = 20 °C is the winter design temperature;
- g_j =number of heating days in *j-th* month;
- n_{months} =number of months of the heating period.

In Italy the values of the winter degree-days values are established by the D.P.R. 26 August 1993, n 412.

It is of interest to report that the Values of The Degree-Days defined by D.P.R 412/1993 for the Italian territory and those that can be calculated by referring to the average monthly temperatures provided by UNI standards do not match. As this is a source of problems in the calculation procedure, in the DSS-RRE simulator the average temperature values provided by UNI are scaled as

$$\bar{T} = T_{int,des} - k \times \left(T_{int,des} - T_j\right)$$

where

$k = \widetilde{GG}/GG$

- $\widetilde{GG}$ =value of law
- GG =calculated according to the monthly T_j values provided by UNI

for which

$$\overline{GG} = \sum_j [(T_{int,des} - \bar{T}_j) \times gg_j] =$$
$$= \sum_j [(T_{int,des} - \{T_{int,des} - k \times (T_{int,des} - T_j)\}) \times gg_j] =$$
$$= k \times \left[\sum_j (T_{int,des} - T_j) \times gg_j\right] =$$
$$= \frac{\widetilde{GG}}{GG} \times GG = \widetilde{GG}$$

Although not yet explicitly defined by the legislation, by analogy the DSS-RRE simulator also implements the **Summer Day Degrees** as defined above, however, referring to the summer period and the summer design temperature.

12.4 Thermal exchange by transmission

The thermal exchange by transmission is calculated as

$$Q_{tr} = H_{tr} \times GG \times h; \text{ [kWh]}$$

where

- $H_{tr} = \sum_{i=1}^{n-elem} H_{tr,i}$;
- $H_{tr,i}$ =coefficient of dispersion of the *i*-th element of the envelope to the external environment;

This expression originates from the definition that each *i*-th element of the envelope is subject to a thermal flow at *j*-th month equal to

$$Q_{tr,i,j} = H_{tr,i} \times (T_{int} - T_j) \times g_j \times h; \text{ [kWh]}$$

that yearly is equivalent to

$$Q_{tr,i} = \sum_{j=1}^{n-months} Q_{tr,i,j} =$$
$$= \sum_{j=1}^{n-months} [H_{tr,i} \times (T_{int} - T_j) \times g_j \times h] = H_{tr,i} \left[\sum_{j=1}^{n-months} [(T_{int} - T_j) \times g_j]\right] \times h =$$
$$= H_{tr,i} \times GG \times h$$

Finally, the total flow is obtained by summing all the elements

$$Q_{tr} = \sum_{i=1}^{n-elem} Q_{tr,i} =$$
$$= \sum_{i=1}^{n-elem} [H_{tr,i} \times GG \times h] = \left[\sum_{i=1}^{n-elem} H_{tr,i}\right] \times GG \times h =$$
$$= H_{tr} \times GG \times h$$

12.4.1 Coefficient of thermal dispersion

In general, thermal dispersion coefficient is defined as

$$H_{tr,i} = [U_i \times S_i \times K_i]/1000; \text{ [kW/°K]}$$

where

- U_i = thermal transmittances for the *i*-th element [W/m^2 °K];
- S_i = surface of the *i*-th element subject to thermal flow [m^2];

- K_i = reduction coefficient of temperature difference$(T_{int} - T_j)$ defined by UNI TS 11300 – schedule 7;

This reduction coefficient was introduced to take into account those particular situations, such as the case of the floor that separates the ground-floor from the under-floor cavity, where the T_j in the thermal exchange transmission formula is not that of the external air but that of the ground. In RRE the following particular cases have been implemented:

Outer external space	1.00
Heated interior space	0.00
Unheated interior space	0.80
Attic	0.90
Under-floor cavity (Crawl space)	0.45

12.4.2 The transmittance calculation

In general, the UNI EN ISO 6946 defines the transmittance as the flow of heat that crosses a unit surface subjected to a temperature of 1 °C and it is linked to the characteristics of the material that constitutes the structure; in particular, it is assumed to be equal to the inverse of the sum of the thermal resistances of the layers

$$U = \frac{1}{R_T}$$

where

$$R_T = R_{si} + R_1 + R_2 + +R_n + R_{se}$$

and

- R_{si} = Internal surface resistance;
- $R_1; R_2; \dots; R_n$ = thermal resistances of each layer;
- R_{se} = External surface resistance;

The thermal resistance of the *i*-th each layers is calculated as:

$$R_i = \frac{d_i}{\lambda_i}$$

where

- d_i = thickness of the component layer;
- λ_i = thermal conductivity.

In the particular case of windows, the transmittance is calculated as indicated in the UNI EN ISO 10077-1:

$$U_w = \frac{\sum U_g \times A_g + \sum U_p \times A_p + \sum U_f \times A_f + \sum I_g \times \Psi_g + \sum I_p \times \Psi_p}{\sum A_g + \sum A_p + \sum A_f}$$

where

- (A_g, A_p, A_f) = areas respectively of transparent surfaces (g = glass), opaque panels (p = panel) and frame of fixtures (f = frame);
- (U_g, U_p, U_f) = thermal transmittance of transparent surfaces, panels and frame of the frames;
- (I_g, I_p) = perimeter of transparent surfaces and opaque panels;
- (Ψ_g, Ψ_p) = linear transmittance on the edge between transparent surfaces and opaque panels;

Nowadays, windows are usually made with standardized industrial processes and are provided with a certification in which the value U_w is directly indicated.

12.4.3 The transmittance values in the DSS-RRE model

The transmittance of the various elements of the envelope depends on the epoch of construction. In particular, considering only the last historical period since the post-war reconstruction, where about 78% (see Section 2.2) of the existing buildings have been built, we can identify the following three main dates:

- Year 1991 where Law No.10 of 9 January 1991 (Lg. 10/91) has been approved: "*Rules for the implementation of the National Energy Plan on the rational use of energy, energy savings and development of renewable energy sources*", significantly improving the insulation of buildings.
- Year 2005, where the level of building insulation is gradually being raised to current standards with the approval of D.Lgs. 192/2005, which incorporates the 2002/91/CE Directive.
- year 2015, where the so-called "*Minimum Requirements Decree*", entered into force, establishing a new minim level for the efficiency of the entire building-plant systems and introducing in Italy the concept of “*reference building*” and “*nZEB* ”.

Of interest to note that the Lg. 10/1991 draws its origins from the law No 373/76 enacted to contain the energy crisis of the 1970s caused by the sharp rise in the price of crude oil following the Middle Eastern war called *kippur*: Before this law, there were no obligations regarding energy consumption in buildings.

Based on these considerations, the DSS-RRE simulator provides simplified input based on the following three alternative levels (Table 12-2):

1. **Mediocre (or poor)**, intending to represent the quality level of envelopes before 1991 in which
    a. The walls have a stratigraphy of the type shown in Table 12-12.
    b. The windows have poorly airtight closures and single-layer windows with overall transmittance as in Table 12-19 and Table 12-20
2. **“Standard”** that aims to represent the quality of the envelopes made in the period 1991 – 2015 in which
    a. Walls have a stratigraphy of the type shown in Table 12-11: Standard wall
    b. The windows have airtight closures and double-layered windows with a total of with overall transmittance as in Table 12-17 Table 12-18
3. **Optimal** that intends to represent the quality level of the envelopes made after 2015 and which therefore have values of the transmittances in accordance with the current legislation.

The use of Optimal materials allows you to calculate in addition to the energy requirements of new buildings, also that of the *reference building*, allowing the evaluation of the Energy Class of the building subject of analysis.

12.5 Thermal loss for ventilation

Similar to the thermal loss for transmission, the thermal loss for ventilation of the building is also calculated as

$$Q_{ve} = H_{ve} \times GG \times h; \text{ [kWh]}$$

where

$$H_{ve} = V_{air} \times C_{air}/1000\,; \text{ [kW/°K]}$$

$$V_{air} = N \times V; \ [m^3]$$

$$C_{air} = 0.\overline{33}\,; \ [W/m^3 \ °K]$$

and

- H_{ve} = the dispersion coefficient due to the natural ventilation of the building;
- C_{air} = the specific heat (unitary thermal capacity) of dry air;
- V = the useful volume of the building;
- N = the number of air changes per hour which, depending on the use of the building, takes on the following values;

Table 12-2: Construction element transittance values				
Element	Quality	Type	Climate zone	U
				W/(m² °K)
Walls	Mediocre	uninsulated wall		0.925
	Standard	Little-insulated wall		0.671
	Optimal	Regulatory compliance	A	0.400
			B	0.400
			C	0.360
			D	0.320
			e	0.260
			F	0.240
Windows	Mediocre	Single non-insulated glass fixture		5.000
	Standard	Double-glass with good insulation		3.000
	Optimal	Regulatory compliance	A	3.000
			B	3.000
			C	2.000
			D	1.800
			e	1.400
			F	1.000
Floor slab	Mediocre	Not insulated		1.427
	Standard	Floor slab little insulated		0.854
	Optimal	Regulatory compliance	A	0.420
			B	0.420
			C	0.380
			D	0.320
			e	0.260
			F	0.240
Roof	Mediocre	Not insulated		1.460
	Standard	Little insulated		0.890
	Optimal	Regulatory compliance	A	0.320
			B	0.320
			C	0.320
			D	0.260
			e	0.220
			F	0.200

Table12-3: air exchange depending on type of use	
User type	n$[\mathbf{m}^3/\mathbf{h}]$
Residential	0.30
Similar gyms	0.80
Similar barracks e s	0.80
Locker rooms of establishments	0.80
Hotels and similar	0.80
Offices and-similar	0.80
Clinical	0.80
Hospitals	0.80

12.6 Extra thermal flow for infrared radiation to the celestial vault

The extra thermal flow for infrared radiation to the celestial vault is defined as

$$Q_{\emptyset} = H_{\emptyset} \times \widehat{GG} \times h; \text{ [kWh]}$$

where

$$H_{\emptyset} = R_{se} \times \sum_{i=1}^{n-elem} \left(\tilde{h}_i \times F_{r,i} \times H_{tr,i}\right)$$

$$\widehat{GG} = \sum_{j=1}^{n-months} \left(\Delta T_{sky} \times g_j\right) = \Delta T_{sky} \times gg$$

$$\Delta T_{sky} = T_{sky} - T_{air}$$

and, according to UNI/TS 11300-1

$$R_{se} = 0.04 \text{ [m}^3 \text{ °K/W]}$$

$$T_{sky} = 18.0 - 51.6 \times e^{-p_{v,e}/1000} [°K] =$$

$$\cong 11. [°K] \text{ approximation used in practice in the intermediate areas of the tropics and subpolar areas}$$

and

- R_{se} = external surface thermal resistance of the envelope components, determined according to UNI EN 6946;
- $\tilde{h}_i$ = external thermal exchange coefficient by radiation of the *i-element* of the envelope (Section 12.6.1)
- $F_{r,i}$ = Form factor (Section 12.6.2)
- $H_{tr,i}$ = coefficient of dispersion of the *i*-element of the envelope separating the heated area from the external ones (Section 12.4.1);
- ΔT_{sky} = difference between the outside air temperature and the apparent temperature of the sky [°K];
- gg = number of days in the heating period;
- $p_{v,e}$ = partial water vapor pressure average of the month considered;

This expression originates from the definition that at the monthly level each *i*-th element of the envelope is subject to a thermal flow equal to

$$Q_{\emptyset,i,j} = H_{H,\emptyset,i} \times \Delta T_{sky} \times g_j \times h$$

which in yearly terms is equivalent to

$$Q_{\emptyset,i} = \sum_{j=1}^{n-months} Q_{\emptyset,i,j} =$$

$$= \sum_{jmonths=1}^{n-months} \left[H_{\emptyset,i} \times \Delta T_{sky} \times g_j \times h\right] = H_{\emptyset,i} \times \left[\Delta T_{sky} \times \sum_{j=1}^{n-months} [g_j]\right] \times h =$$

$$= H_{\emptyset,i} \times \Delta T_{sky} \times gg \times h =$$

$$= H_{\emptyset,i} \times \widehat{GG} \times h$$

Finally, by summing the flow of all the elements, you get

$$Q_{\emptyset} = \sum_{i=1}^{n-elem} Q_{\emptyset,i} =$$

$$= \sum_{i=1}^{n-elem} \left[H_{\emptyset,i} \times \widehat{GG} \times h\right] = R_{se} \times \left[\sum_{i=1}^{n-elem} H_{\emptyset,i}\right] \times \widehat{GG} \times h =$$

$$= H_{\emptyset} \times \widehat{GG} \times h$$

12.6.1 External thermal exchange coefficient for radiation

The UNI TS 11300-1 defines the external thermal exchange coefficient for radiation as

$$\tilde{h}_i = \varepsilon\sigma \frac{(T_{air}+273)^4-(T_{sky}+273)^4}{(T_{air}-T_{sky})} \cong 5\varepsilon_i; \left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{°K}}\right]$$

where

- ε_i = The emissivity of the *i*-th surface
- $\sigma = 5.67\ x\ 10^{-8}; \left[\frac{\mathrm{W}}{(\mathrm{m}^2 * \mathrm{K}^4)}\right]$ is Stefan-Boltzmann's constant

And, in particular,

$$\varepsilon_i = \begin{cases} 0.9; & \text{for opaque materials} \\ 0.837; & \text{for glasses} \end{cases} ; \left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{°K}}\right]$$

Therefore, in the DSS-RRE model, the radiation emissivity value is set equal to

$$\tilde{h}_i = 5\varepsilon_i = \begin{cases} 4.5; & \text{for opaque materials} \\ 4.185; & \text{for glasses} \end{cases} ; \left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{°K}}\right]$$

12.6.2 Form factor

UNI EN ISO 13790 defines the form factor between the *i-th* element and the celestial vault defined as

$$F_{r,i} = F_{omb}(1 + \cos\alpha_i)/2$$

Where:

- F_{omb} = the reduction factor for shading relative to diffuse radiation, equal to 1 in the absence of shadows by external elements;
- α_i = The inclination of solar radiation between the *i-th* surface considered and the horizon line;

Therefore, in the DSS-RRE simulator,

$$F_{r,i} = \begin{cases} 0.5; & \alpha = 90° \text{ for vertical surfaces;} \\ 0.837; & \alpha = 0° \text{ for horizontal surfaces;} \end{cases}$$

12.7 Internal gains

The internal gains represent the contributions of thermal energy to the building due to the presence of light fixtures, electrical equipment and the occupants metabolism. Mathematically they are defined as

$$Q_{int} = \bar{Q}_{int} \times g \times h; \ [\mathrm{kWh}]$$

where, for dwellings, category residential e.1 (1) and E.1 (2)

$$\bar{Q}_{int} = \begin{cases} (7.987 \times S - 0.0353 \times S^2)/1000; & \text{per } S \leq 120\ m^2 \\ 0.450 & \text{per } S > 120\ m^2 \end{cases} ; [\mathrm{kW}]$$

while for all other categories

$$\bar{Q}_{int} = [U_{int} \times S]/1000; \ [\mathrm{kW}]$$

where

- U_{int} = the free unit gain defined according to the type of user considered; [W/m^2]
- S = the total floor area of the calculation building; [m^2]

In RRE simulator U_{int} is defined as reported in Table 12-4

Table 12-4: Values of gains depending on the type of user		
Building category	Target of use	U_{int} $[\mathrm{W/m^2}]$
E.1 (1), E.1 (2)	Residential for$S \cong 110\ m^2$	4.0
E.1 (3)	Hotels, guesthouses and similar activities	6.0
E.2	Offices and similar	6.0
E.3	Hospitals, clinics or nursing homes and similar	8.0
E.4 (1)	Cinemas and theatres, meeting rooms for congresses	8.0
E.4 (2)	Exhibitions, museums and libraries, places of worship	8.0
E.4 (3)	Bars, restaurants, ballrooms	10.0
E.5	Buildings used for commercial and similar activities	8.0
E.6 (1)	Pools, sauna and similar	10.0
E.6 (2)	Gyms and similar	5.0
E.6 (3)	Sports Support Services	4.0
E.7	School activities at all levels and comparable	4.0
E.8	Industrial and craft and similar activities	6.0
Source: UNI-TS 11300-1, schedule E.3		

12.8 Solar heat gain through glazed surface

The solar gain due to the presence of windows depend on the amount of thermal energy per radiation passing through their glazed surfaces. Mathematically it is defined as

$$Q_{sol,w} = \sum_{i=1}^{n-elem} Q_{sol,w,i}\ ;\ [\text{kWh}]$$

where

$$Q_{sol,w,i} = \sum_{j=1}^{n-mesi} \left[\left(\frac{I_{sol,i,j} \times g_j}{3.6}\right) \times F_{hor,i,j} \times F_{ov,i,j} \times F_{fin,i,j} \times A_{sol,w,i,j}\right]\ ; [\text{kWh/m}^2]$$

and

- $F_{sh,ob,i}$ = reduction factor for shading relative to external elements for the actual solar capture area of the *i*-th surface:
  - F_{hor} = shading factor related to external obstructions;
  - $\mathrm{F_{ov}}$ = shading factor related to horizontal overhangs;
  - F_{fin} = shading factor related to vertical overhangs;
- $A_{sol,w,i,j}$ = solar capture area at the month *j-th*, on the surface *i*-th.
- $I_{sol,i,j}$ = average monthly solar radiation of the month *j-th*, on the surface *i*-th, as defined in UNI 10349 as

  $I_{sol,i,j}$ = $I_{sol,i,j}$(i-Orientation, j-month); [MJ/mq]
- g_j = the number of days in the *j*-th month;

The shading factors are defined by UNI-TS 11300 part 1 as

$F_{hor,i,j} = F_{hor,i,j}(\varphi$-latitude, i-Orientation, α_i, j-month)

$F_{ov,i,j} = F_{ov,i,j}(\varphi$-latitude, i-Orientation, β_i, j-month)

$F_{fin,i,j} = F_{fin,i,j}(\varphi$-latitude, i-Orientation, γ_i, j-month)

where

- φ-latitudine = latitude of the site where the building is located,
- *i*-Orientation = geographical orientation (North, South, East, West) of the *i-th* element;
- $(\alpha_i, \beta_i, \gamma_i)$ = the shading angles shown in Figure 12-1 and Figure 12-2;
- *j*-months = *j*-th month of the heating/cooling period;

Figure 12-1: Horizontal angle, α

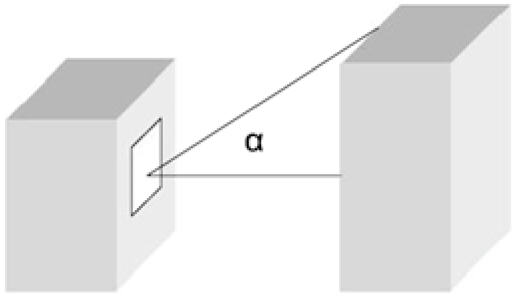
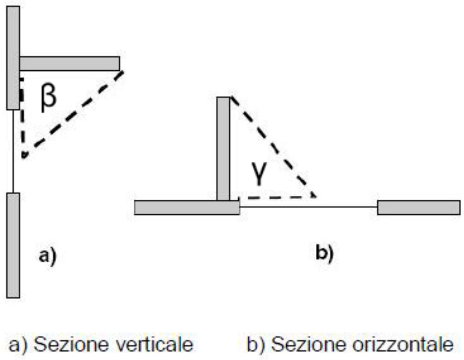


Figure 12-2: β = vertical overhang corner; γ = horizontal overhang corner



12.8.1 Solar capture area

For glazed surfaces, the rule is that, in addition to the orientation and characteristics of the glass, it is necessary to consider the presence of any shields that filter the sun's rays, reducing the gain. Thus the solar area for glazed surfaces is calculated as:

$$A_{sol,w,i,j} = F_{sh,gl} \times F_{w,i,j} \times U_{gl,i} \times S_{w,i} \times \left(1 - F_f\right)$$

where

$$F_{sh,gl} = \begin{cases} 1.0; & \text{fixtures without shields} \\ \left[\left(1 - f_{sh,with}\right) \times g_{gl,n} + f_{sh,with} \times g_{gl+sh}\right] / g_{gl}\,; & \text{fixtures with shields} \end{cases}$$

$$\left(1 - F_f\right) = 0.8$$

where

- $F_{sh,gl}$ = solar gains reduction factor related to the use of mobile shields (e.g. curtains).
- $F_{w,i,j}$ = exposure factor that considers the variation of the total solar energy transmittance as a function of the i-th month and j-th orientation, Table 12-5.
- $U_{gl,i}$ = total solar energy transmittance values for normal incidence, Table 12-6.
- $S_{w,i}$ = total projected area of the glazed component (window space area);
- F_f = fraction of area relative to the frame: ratio between the projected area of the frame and the total projected area of the windowed component
- $g_{gl,n}$ = transmittance of the total solar energy of the window when solar shading is not used. In the case of mobile screens, the transmittance value can be obtained from the table values provided by UNI / TS 11300-1, Table 12-7.
- g_{gl+sh} = transmittance of the total solar energy of the window when solar shading is used. In the case of mobile screens, the transmittance value can be obtained from the table values provided by UNI / TS 11300-1, Table 12-7.
- $f_{sh,with}$ = fraction of time in which solar shading is used, weighed on the incident solar radiation. In the standard evaluation its values are taken from Table 12-8.

12.8.2 Simplification in the UNI TS 13790

Having acknowledged that the values of $F_{w,i,j}$ reported in Table 12-5 do not vary significantly and that their impact on the calculated exposure factor is mediated over the months, the UNI TS 13790 proposes to assume

$F_{w,i,j} = 0.9$, constant on time

so in this case the solar area becomes constant.

For simplicity, the DSS-RRE model assumes that:

- There are no shading i.e.

  $F_{hor,i,j} = F_{ov,i,j} = F_{fin,i,j} = 1;\ \forall i,j$

- There are no shields, i.e.

  $F_{sh,gl} = 1$

Table 12-5: Exposure factor for glazed surfaces: Table 20 of the UNI / TS 11330-1												
	Single glass				Double glasses				Triple glasses			
Mese	S	E/O	N	Orizz.	S	E/0	N	Orizz.	S	E/0	N	Orizz.
January	0.984	0.902	0.932	0.876	0.978	0.861	0.901	0.812	0.972	0.833	0.880	0.770
February	0.967	0.923	0.932	0.902	0.950	0.890	0.901	0.851	0.937	0.868	0.880	0.817
March	0.933	0.932	0.931	0.931	0.897	0.904	0.901	0.895	0.872	0.884	0.879	0.871
April	0.888	0.938	0.921	0.949	0.833	0.912	0.890	0.923	0.796	0.894	0.868	0.906
May	0.852	0.941	0.895	0.955	0.787	0.916	0.854	0.933	0.747	0.898	0.828	0.918
June	0.838	0.941	0.877	0.955	0.770	0.915	0.831	0.934	0.731	0.898	0.802	0.920
July	0.835	0.941	0.877	0.956	0.766	0.915	0.831	0.935	0.724	0.898	0.801	0.921
August	0.861	0.940	0.905	0.952	0.797	0.915	0.870	0.928	0.756	0.898	0.646	0.912
September	0.911	0.935	0.930	0.940	0.865	0.907	0.899	0.909	0.833	0.888	0.877	0.887
October	0.957	0.925	0.931	0.912	0.933	0.894	0.900	0.865	0.915	0.872	0.878	0.833
November	0.981	0.912	0.931	0.880	0.971	0.876	0.901	0.818	0.964	0.851	0.879	0.776
December	0.987	0.903	0.932	0.858	0.982	0.862	0.901	0.789	0.977	0.834	0.880	0.744

Table 12-6: Total solar energy transmitting values for normal incidence used, Prospetto B.5 dell' UNI/TS 11330-1		
Quality	Type	$g_{gl,n}$ [W/m²]
Mediocre	Single glass	0.85
Standard	Double normal glass	0.75
Optimal	Double glass with low emissive coating	0.67

Table 12-7: Reduction Factors for Certain Tent Types				
Type of tent	Optical properties of the tent		Reduction factors with	
	Absorption	transmission	Inner tent	Outdoor curtain
White Venetians	0.1	0.05	0.25	0.10
		0.10	0.30	0.15
		0.30	0.45	0.35
White curtains	0.1	0.50	0.65	0.55
		0.70	0.80	0.75
		0.90	0.95	0.95
Colorful fabrics	0.3	0.10	0.42	0.17
		0.30	0.57	0.37
		0.50	0.77	0.57
Aluminium-coated fabrics	0.2	0.05	0.20	0.08

Table 12-8: Reduction factor for mobile shielding, Prospectus 21 UNI-TS 11300 - 1				
Month	North	East	South	West
January	0.00	0.52	0.81	0.39
February	0.00	0.48	0.82	0.55
March	0.00	0.66	0.81	0.63
April	0.00	0.71	0.74	0.62
May	0.00	0.71	0.62	0.64
June	0.00	0.75	0.56	0.68
July	0.00	0.74	0.62	0.73
August	0.00	0.75	0.76	0.72
September	0.00	0.73	0.82	9.67
October	0.00	0.72	0.86	0.60
November	0.00	0.62	0.84	0.30
December	0.00	0.50	0.86	0.42

12.9 Solar heat gain through opaque surfaces

Apart from windows, walls and roofs also serve as pathways for solar gain. In these components heat transfer is entirely due to absorptance, conduction, and re-radiation since all transmittance is blocked in opaque materials. . Mathematically the solar heat gain through opaque surfaces is defined as

$$Q_{sol,op} = \sum_{i=1}^{n-elem} \left(F_{sh,ob,i} \times A_{sol,op,i}\right);\ \text{[kWh]}$$

where

$$F_{sh,ob,i} = \sum_{j=1}^{n-mesi} \left[\left(\frac{I_{sol,i,j} \times g_j}{3.6}\right) \times F_{hor,i,j} \times F_{ov,i,j} \times F_{fin,i,j}\right];\ \text{[kWh/m}^2\text{]}$$

and all the terms in $F_{sh,ob,i}$ are the same defined in Section 12.8 for the glazed surfaces. Instead the solar capture area is calculated as:

$$A_{sol,op,i} = R_{se} \times \alpha_{sol,i} \times U_i \times S_i$$

where

$$R_{se} = 0.04\ [\text{m}^3\ °\text{K/W}]$$

$$\alpha_{sol,i} = \begin{cases} 0.3; & \text{light colour} \\ 0.6; & \text{medium colour} \\ 0.9; & \text{dark colour} \end{cases}$$

and

- R_{se} = External surface thermal resistance of the envelope components, determined according to UNI EN 6946;
- $\alpha_{sol,i}$ = solar absorption factor of the opaque component, provided by UNI EN ISO 13791 (UNI TS 11300-1) depending on the color *of the* opaque surface;
- U_i = Transmittance of the *i*-th surface as already defined in Section 12.3; [W/m^2 °K]
- S_i = surface of the opaque surface; [m^2]

This formulation can be obtained from that of the glazed surface setting the solar area constant over time, i.e.

$$\mathrm{A_{sol,op,i}} = \mathrm{A_{sol,w,i,j}};\quad \forall \mathrm{j}$$

being the total solar energy transmittance value not influenced by the solar orientation *j*, so that so that $F_{w,i,j}$ can be set equal 1.0

12.10 The Utilization Factor of thermal gain

The winter utilization factor $\eta_{H,gn}$, defined in Section 12.2 for the thermal demand calculation in the winter period

$$Q_{H,nd} = Q_{ls} - \eta_{H,gn} \times Q_{gn};\ \text{[kWh]}$$

and the summer Usage Factor $\eta_{HC,ls}$, defined for the thermal demand calculation in the summer period

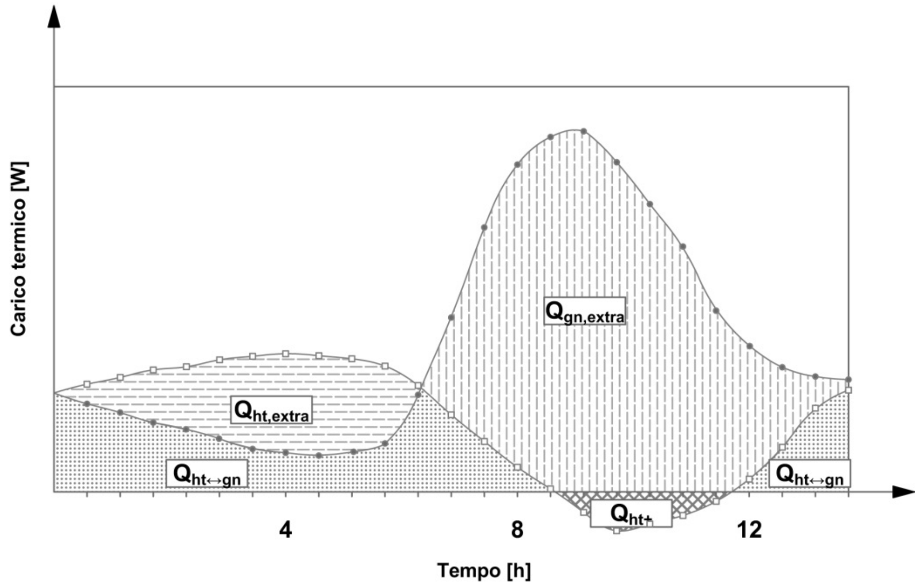
$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} \times Q_{ls};\ \text{[kWh]}$$

were introduced to take into account the phenomenon of time mismatch between gains and dispersions that is schematically highlighted in Figure 12-3, (Corrado & Fabrizio, 2008)

Therefore, as you will see in the following, their mathematical definition is such that their value increases with the thermal capacity of the ZT (thermal zone or net air-conditioned area): in other words, it increases with the ability of the ZT to accumulate the heat relative to the gains and deferred its use, thus reducing the mismatch between supply and demand.

In addition, in winter the Utilization Factor $\eta_{H,gn}$serves to compensate for the additional dispersions that occur due to the higher internal temperatures reached, when the gains Q_{gn} are greater than the dispersions Q_{ls}. Therefore its mathematical definition must also consider that its value decreases as the ratio of gains and dispersions $\gamma_h = Q_{gn}/Q_{ls}$ increases.

Figure 12-3: Hourly profile of the two components of the heating/cooling load for a typical day



$Q_{ht\leftrightarrow gn}$ = Dispersions that compensate for the thermal gain
$Q_{ht,extra}$ = Extra-dispersions with respect to the thermal gain
$Q_{gn,extra}$ = Extra-gain with respect to the dispersion
Q_{ht+int} = Incoming thermal energy in the building due to the increase of the external temperature above that of the internal

Source Corrado & Fabrizio (2008)

Similarly, in summer the Utilization Factor $\eta_{C,ls}$serves to compensate for the additional gains that occur, due to the lower internal temperatures reached, when the dispersions Q_{ls} are greater than the gains Q_{gn}. Therefore its mathematical definition must also consider that its value decrease as the ratio between dispersions and gains $1/\gamma_h = Q_{ls}/Q_{gn}$ increases.

The following Sections contain the complete definition given by UNI TS 11300-1. However RRE-simulator, according to Annex 2 of DM 26-09-2009, sets

$$\eta_{H,gn} = \eta_{C,ls} = 0.95$$

12.10.1 Winter period

The utilization factor for heating period is calculated according to the UNI TS 11300-1 standard:

$$\eta_{H,gn} = \begin{cases} \dfrac{1-{\gamma_h}^{a_h}}{1-{\gamma_h}^{a_h+1}}; & \gamma_h > 0 \; e \; \gamma_h \neq 1 \\ \dfrac{a_h}{a_h+1}; & \gamma_h = 1 \\ 1 & \gamma_h = 0 \end{cases}$$

where:

$$\gamma_h = Q_{gn}/Q_{ls}$$

$$a_h = a_{h,0} + \tau/\tau_{h,0}$$

$$\tau = (C_m/3600)/((H_{tr} + H_{ve})); \text{[h]}$$

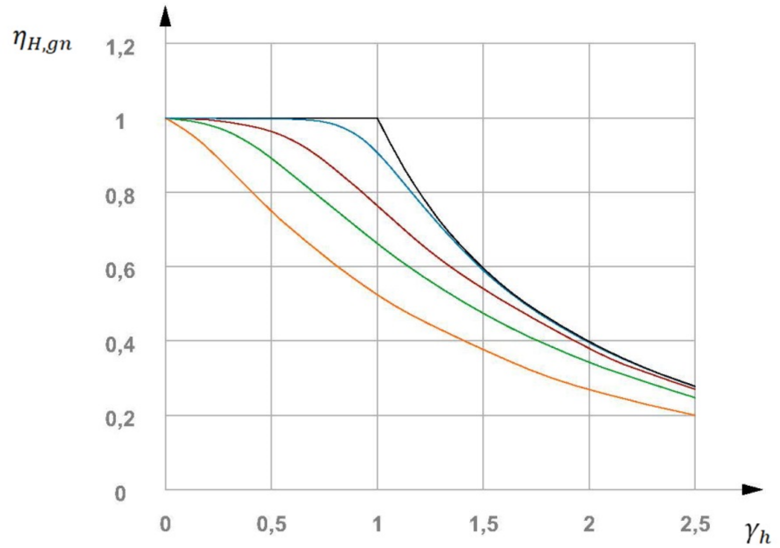
and, as indicated by the UNI TS 11300-1 standard, for continuous operation of the plant over 24 hours and monthly calculation, they are assumed as

$\tau_{h,0} = 15.0$ and $a_{h,0} = 1.0$

where

- $\left(Q_{ls}\,, Q_{gn}\right)$ = heat loss and energy gain defined in Section 12.3; [kWh].
- $(H_{tr}, H_{ve}\,)$ = the thermal exchange coefficient for transmission and ventilation, as defined in Section 12.4 and 12.5 respectively, [kW/°K];
- C_m = building's internal thermal capacity, [J/°K];

Figure 12-4: The Utilization Factor for the winter period



Time constant of 8h (low inertia) Time constant of 1 d Time constant of 2 d	Time constant of 7 d Infinite time constant (high inertia)

12.10.2 Summer

The Utilization Factor for the cooling period is calculated according to the normative:

$$\eta_{C,gn} = \begin{cases} \dfrac{1-\gamma_c{}^{-a_c}}{1-\gamma_c{}^{-(a_c+1)}}; & \gamma_c > 0 \; e \; \gamma_c \neq 1 \\ \dfrac{a_c}{a_c+1}; & \gamma_c = 1 \\ 1 & \gamma_c \leq 0 \end{cases}$$

where:

$$\gamma_c = Q_{gn}/Q_{ls}$$

$$a_c = \begin{cases} a_{c,0} + \tau/\tau_{c,0} - k\,A_w/A_f\,; & a_c > 0 \\ 0; & a_c \leq 0 \end{cases}$$

$$\tau = (C_m/3600)/((H_{tr} + H_{ve}));\ [\text{h}]$$

and, as indicated by Prospect 9 of UNI EN ISO 13790, for continuous operation of the plant over 24 hours and monthly calculation,

$$\tau_{c,0} = 17.0;\ a_{c,0} = 8.1 \text{ and } k = 13.0$$

where

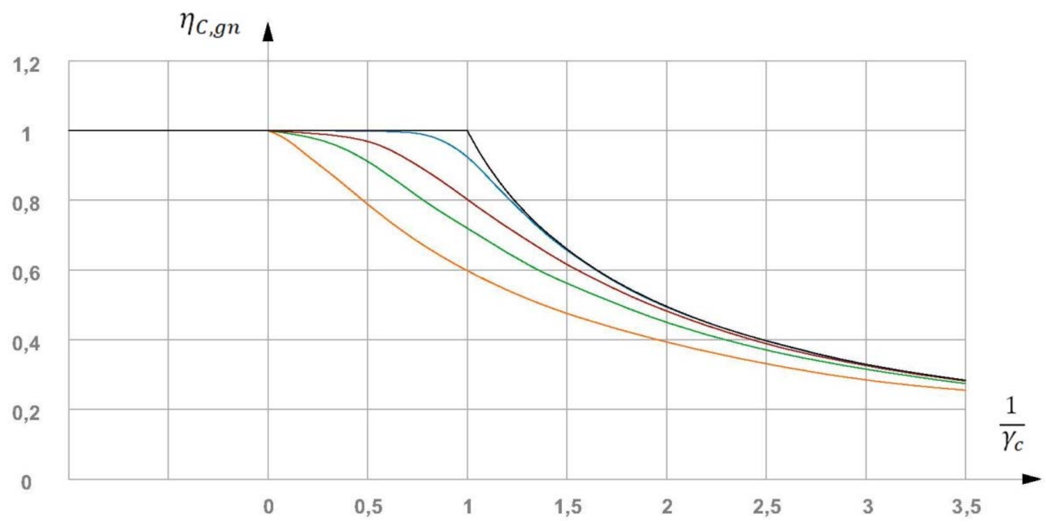
- $\left(Q_{ls}\,, Q_{gn}\right)$ = heat loss and energy gain defined in Section 12.3; [kWh].
- $(H_{tr}, H_{ve}\,)$ = the thermal exchange coefficient for transmission and ventilation, as defined in Section 12.4 and 12.5 respectively, [kW/°K];

- C_m = areal heat capacity, [J/°K];

and

- τ = thermal zone time constant in hours; [h]
- (A_w, A_f) = windowed area and air-conditioned area respectively, [mq]

Figure 12-5: The Utilization Factor for the summer period



● Time constant of 8h (low inertia) ● Time constant of 1 d ● Time constant of 2 d	● Time constant of 7 d ● Infinite time constant (high inertia)

12.10.3 The internal thermal capacity of the building

The internal *areal heat capacity* of the building C_m required to calculate the time constant of the thermal zone, and therefore of the utilization factor, can be determined analytically by adding the thermal capabilities of all building elements in direct contact with the internal air of the area under consideration:

$$C_m = \sum_j \chi_j A_{f,j} = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_{f,j}$$

where:

- χ_j =surface thermal capacity of the j-th building element [J/(mq·°K)],
- $A_{f,i}$ =area of the *j*-th element [mq],
- ρ_{ij} =density of the material that is the i-th layer of the *j*-th element [kg/m^3],
- c_{ij} = specific thermal capacity of layer *i*-th of the j-th material [J/(kg-K)],
- d_{ij} =thickness of the i-th layer of the j-th element.

The legislation requires that the sum is extended to all the layers of each element, starting from the inner surface and proceeding to the first layer of insulation. The maximum thickness to consider is that of half the thickness of the element

If it is less, you have to consider a thickness of 10 cm when you want to calculate the factor of use (of gains), or a thickness of three cm when you want to calculate the effect of the intermittency. Further details are provided by UNI EN ISO 13786.

Alternatively, it is possible to refer directly to the C_m average values defined in UNI/TS 11300-1 by building type and reported in the DDG Lombardy No. 5796 of June 11, 2009, as shown below. In the DSS-RRE model, taking into account the narrow variability of the values shown in Table 12-9 practical interest, the thermal capacity of the building is estimated with the following expression.

$$C_m = 155 \left[\frac{kJ}{\mathrm{m}^2\ \mathrm{°K}}\right] \times A_f[\mathrm{m}^2]\ ; \left[\frac{\mathrm{kJ}}{\mathrm{°K}}\right]$$

Table 12-9: Thermal capacity per casing surface unit, Cm (Source: UNI TS 11300-1:2008)						
Features of building components				**Number of floors**		
Plasters	**Insulation**	**Outdoor walls**	**Floors**	**1**	**2**	**≥3**
				Areal heat capacity [kJ/(m² K)]		
Chalk	Internal	Any	Textile	75	75	85
	Internal	Any	Wood	85	95	105
	Internal	Any	Tiles	95	105	115
	Absent/external	Read/Blocks	Textile	95	95	95
	Absent/external	Medium/blocks	Textile	105	95	95
	Absent/external	Read/Blocks	Wood	115	115	115
	Absent/external	Medium/blocks	Wood	115	125	125
	Absent/external	Read/Blocks	Tiles	115	125	135
	Absent/external	Medium/blocks	Tiles	125	135	135
Malta	Internal	Any	Textile	105	105	105
	Internal	Any	Wood	115	125	135
	Internal	Any	Tiles	125	135	135
	Absent/external	Read/Blocks	Textile	125	125	115
	Absent/external	Medium	Textile	135	135	125
	Absent/external	Heavy	Textile	145	135	125
	Absent/external	Read/Blocks	Wood	145	145	145
	Absent/external	Medium	Wood	155	155	155
	Absent/external	Heavy	Wood	165	165	165
	Absent/external	Read/Blocks	Tiles	145	155	155
	Absent/external	Medium	Tiles	155	165	165
	Absent/external	Heavy	Tiles	165	165	165
Source: UNI TS 11300-1:2008						

12.11 The monthly thermal energy demand

According to UNI 11300, the calculation of the Energy Demand presented so far in this Chapter has actually the following monthly based analytical form

$$Q_{H,nd,j} = Q_{ls,j} - \eta_{H,gn,j} \times Q_{gn,j} \qquad \text{Eq. 12.A}$$

where

$$Q_{ls,j} = Q_{tr,j} + Q_{ve,j} + Q_{\emptyset,j} - Q_{sol,op,j} \qquad Q_{gn,j} = Q_{int,j} + Q_{sol,w,j}$$

and

$$Q_{tr,j} = H_{tr} \times GG_j \times h \qquad Q_{int,j} = \bar{Q}_{int} \times g_j \times h$$

$$Q_{ve,j} = H_{ve} \times GG_j \times h \qquad Q_{sol,w,j} = \bar{Q}_{sol,w,j} \times g_j$$

$$Q_{\emptyset,j} = H_{\emptyset} \times \widehat{GG}_j \times h \qquad Q_{op,w,j} = \bar{Q}_{op,w,j} \times g_j$$

being

$$GG_j = (T_{int,des} - T_j) \times g_j \qquad \widehat{GG}_j = \Delta T_{sky} \times g_j$$

and

g_j =number of heating (cooling) days in *j-th* month;

T_j = the average monthly temperature of the *j*-th month

For the purposes of DSS-RRE, which will be clarify in the next Chapter 0, it was deemed more useful to adopt the following alternative simplified formulation

$$Q_{H,nd,j} = \frac{GG_j}{GG} \times Q_{H,nd} \qquad \text{Eq. 12.B}$$

where

$$Q_{H,nd} = \sum_{j=1}^{n-mesi} Q_{H,nd,j} = \sum_{j=1}^{n-mesi} Q_{ls,j} - \eta_{H,gn} \times \sum_{j=1}^{n-mesi} Q_{gn,j}$$

$$GG = \sum_{j=1}^{\bar{n}} GG_j$$

and

$$Q_{H,nd} = \sum_{j=1}^{n-mesi} Q_{H,nd,j} = \sum_{j=1}^{n-mesi} Q_{ls,j} - \eta_{H,gn} \times \sum_{j=1}^{n-mesi} Q_{gn,j}$$

In which, according to the simplifying hypothesis reported in the previous Section 12.10, it is assumed

$$\eta_{H,gn,j} = \eta_{C,ls} = 0.95$$

Clearly, even in the hypothesis of constant $\eta_{H,gn,j}$, the monthly values in Eq. 12.B differ from that Eq. 12.B.

$$\tilde{Q}_{tr,j} = \frac{GG_j}{GG} \times \sum_k (H_{tr} \times GG_k \times h) = H_{tr}\left(\frac{GG_j}{GG} \times \sum_k GG_k\right) \times h = H_{tr} \times GG_j \times h = Q_{tr,j}$$

$$\tilde{Q}_{ve,j} = \frac{GG_j}{GG} \times \sum_k (H_{ve} \times GG_k \times h) = Q_{ve,j}$$

$$\tilde{Q}_{\emptyset,j} = \frac{GG_j}{GG} \times \sum_k \left(H_\emptyset \times \widehat{GG}_k \times h\right) = H_\emptyset \times \left(\frac{GG_j}{GG} \times \sum_k \widehat{GG}_k\right) \times h \neq H_\emptyset \times \widehat{GG}_j \times h = Q_{\emptyset,j}$$

$$\tilde{Q}_{int,j} = \frac{GG_j}{GG} \times \sum_k (\bar{Q}_{int} \times g_k \times h) = \bar{Q}_{int} \times \left(\frac{GG_j}{GG} \times \sum_k g_k\right) \times h \neq \bar{Q}_{int} \times g_j \times h = Q_{int,j}$$

$$\tilde{Q}_{sol,w,j} = \frac{GG_j}{GG} \times \sum_k (\bar{Q}_{sol,w,k} \times g_k) \neq \bar{Q}_{sol,w,j} \times g_j = Q_{sol,w,j}$$

$$\tilde{Q}_{op,w,j} = \frac{GG_j}{GG} \times \sum_k (\bar{Q}_{op,w,k} \times g_k) \neq \bar{Q}_{op,w,j} \times g_j = Q_{op,w,j}$$

However since $Q_{tr,j}$ and $Q_{ve,j}$ by far prevail over the other terms, the difference is quite contained. In any way the annual values calculated by the two formulations coincide since their analytical expression is identical.

$$\tilde{Q}_{H,nd} = \sum_j Q_{H,nd,j} = \sum_j \left(\frac{GG_j}{GG} \times Q_{H,nd}\right) = \frac{\sum_j GG_j}{GG} \times Q_{H,nd} = Q_{H,nd}$$

12.12 Thermal demand required by the generator

The previous Section has completed the presentation of all the factors to calculate the energy demand of the envelope defined in Section 12.1. In order to fill the need of this heating/cooling, the generator (e.g. the boiler or heat pump) must be able to provide the climate system with the following thermal energy

$$Q_{Gn,Out} = \frac{1}{\eta}\begin{cases} Q_{H,nd}; & \text{Heating} \\ Q_{C,nd}; & \text{Cooling} \end{cases}$$

where:

$$\eta = \eta_e \times \eta_{rg} \times \eta_d$$

and

- η = total efficiency of the plant subsets, equal to the ratio between the energy demand of the envelope and the total energy to be provided in output by the generator in order to be satisfied;
- η_e = emission efficiency from UNI/TS 11300-2, Schedule 17; it represents the efficiency of the plant terminals and its value depends on the type of terminal inside the building;
- η_{rg} = regulation efficiency values from UNI/TS/TS 20 11300-2; it represents the efficiency of the heating control system and its value depends on the type of technology used to manage and control the internal temperatures of the building;
- η_d = distribution efficiency, values reported in schedules 21 (a,b,c,d,e) of UNI/TS 11300-2; it depends on the efficiency of the distribution plant and its value depends on the age of the distribution system: the more the plant is obsolete, the more energy losses due to poorly insulated pipes increase.

For each of these types of efficiencies, the DSS-RRE model lists the following 3 chosen alternatives from UNI standards.

Table 12-10: Values of regulation, emission and distribution efficiencies

Regulation Efficiency		Emission Efficiency		Distribution efficiency	
Regulation type	η_{rg}	**Terminal type**	η_e	**Plant age**	η_d
None	0.85	Fan-coil units	0.96	10 to 20 years	0.97
Zone	0.97	Radiators	0.97	5 to 10 years	0.98
Environment	0.98	Floor heating	0.99	0 to 5 years	0.99

12.13 Conclusion

The numerical simulator available in the DSS-RRE platform, introduced in the previous Chapter 11 implements all the analytical relationship reported in this Chapter. Therefore, the numerical values calculated by this software in relation to the ***thermal energy demand*** of a building comply with the "***almost stationary***" method introduced by the UNI ISO 11300 standard, as it was implemented by the Italian government in the DM 26/6/2015, the so-called "Decree on minimum requirements".

However, in order to simplify the practical use of SW the following simplification have been adopted:

A) The *Extra thermal flow for infrared radiation to the celestial vault* in Section 12.6. According to the indication reported in UNI TS 11300-1, it Is assumed that

$$T_{sky} = 18.0 - 51.6 \times e^{-p_{v,e}/1000} \cong 11. [°K]$$

$$\tilde{h}_i = \varepsilon\sigma\frac{(T_{air}+273)^4 - (T_{sky}+273)^4}{(T_{air}-T_{sky})} = \begin{cases} 4.5; & \text{for opaque materials} \\ 4.185; & \text{for glasses} \end{cases} \quad ; \left[\frac{\text{W}}{\text{m}^2\ °\text{K}}\right]$$

which avoids the laborious calculation of T_{sky} due to the presence of the term $p_{v,e}$.

B) The *Utilization Factor* in Section 12.10. According to Annex 2 of DM 26-09-2009, the Utilization Factor is set equal to the constant value

$$\eta_{H,gn} = \eta_{C,ls} = 0.95$$

C) *The Monthly Thermal Energy Demand* Section 12.11. The UNI TS 11300-1 formulation in Eq. 12.A is replaced with

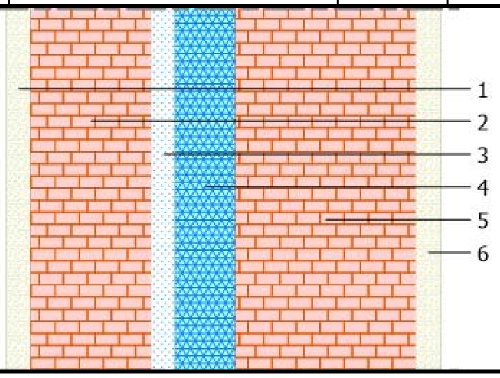
$$Q_{H,nd,j} = \frac{GG_j}{GG} \times Q_{H,nd}$$

Appendix 1: Thermal characteristics of envelope reference elements

12.13.1 Wall

Table 12-11: Standard wall

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m^{2}K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m^{2}K/W]
	Internal convective coefficient	0		7.7000				0.1299
1	Lime and chalk plaster	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
2	Full bricks, perforated, light - density 1400	100	0.5000	5.0000	140.00	7.5068	840	0.2000
3	Vertical 2cm air layer	20		5.7143	0.03	1.0000	1´008	0.1750
4	Average thermal insulation	50	0.0850	1.7000	1.50	3.0880	1´000	0.5882
5	Full bricks, perforated, light - density 1400	150	0.5000	3.3333	210.00	7.5068	840	0.3000
6	Lime and chalk plaster	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
	External convective coefficient	0		25.0000				0.0400



Total Thickness : 360 [mm]

Global thermal transmittance : 0.6710 [W/mqK]

Global Thermal Resistance : 1,4903 [mqK/W]

Global superficial Mass = 351.53 [kg/mq]

Areal thermal capacity : 61,863 [kJ/mqK]

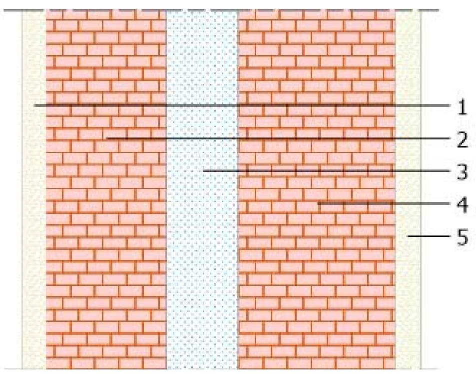
Periodic thermal transmittance : 0.15 [W/mqK]

Mitigation Factor : 0.22 [-]

Mismatch : 11.42 [h]

Table 12-12: Mediocre wall

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m^{2}K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m^{2}K/W]
	Internal convective coefficient	0		7.7000				0.1299
1	Lime and chalk plaster	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
2	Full bricks, perforated, light - density 1000	100	0.3552	3.5520	100.00	6.2541	840	0.2815
3	Vertical air layer of 6 cm	60		5.5556	0.08	1.0000	1´008	0.1800
4	Full bricks, perforated, light - density 1000	130	0.3552	2.7323	130.00	6.2541	840	0.3660
5	Pure plaster	20	0.3500	17.5000	24.00	10.7222	1´000	0.0571
	External convective coefficient	0		25.0000				0.0400



Total Thickness : 330 [mm]

Global thermal transmittance : 0.925 [W/mqK]

Global Thermal Resistance : 1.081 [mqK/W]

Global superficial Massa = 230.08 [kg/mq]

Isica thermal capacity : 56,336 [kJ/mqK]

Periodic thermal transmittance : 0.36 [W/mqK]

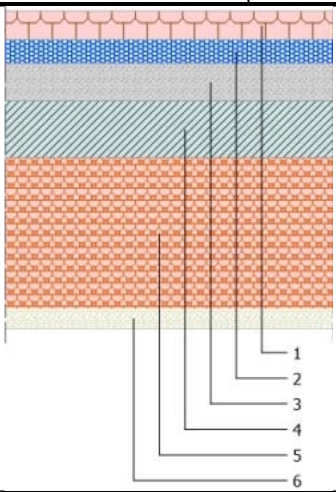
Mitigation factor : 0.39 [-]

Mismatch : 9.11 [h]

12.13.2 Roof covery

Table12-13 Standard roof covery

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m²K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m²K/W]
	External convective coefficient	0		25.0000				0.0400
1	Terracotta tiles	30	1.0000	33.3333	60.00	40.0000	800	0.0300
2	Styrofoam insulation panel	25	0.0450	1.8000	0.75	92.7885	1´220	0.5556
3	Concrete Malta	40	1.4000	35.0000	80.00	22.7059	1´000	0.0286
4	Reinforced Concrete	60	0.8500	14.1667	144.00	148.4615	1´000	0.0706
5	Brick Slab Lock - Resistance 0.27	160		3.7037	144.00	10.1579	1´000	0.2700
6	Internal plaster	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
	Internal convective coefficient	0		10.0000				0.1000



Total Thickness : 335 [mm]

Global thermal transmittance : 0.890 [W/mqK]

Global Thermal Resistance : 1.1235 [mqK/W]

Global superficial Mass = 428.75 [kg/mq]

Isica thermal capacity : 61,551 [kJ/mqK]

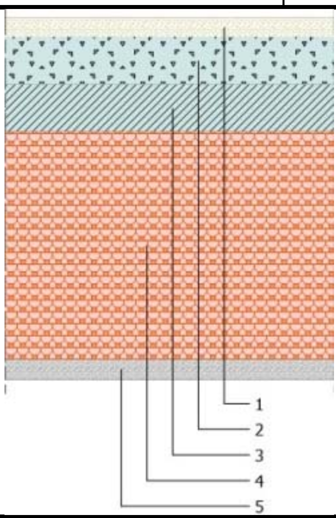
Periodic thermal transmittance : 0.13 [W/mqK]

Mitigation Factor 0.15 [-]

Disizing : 10.44 [h]

Table 12-14:Building elements mediocre coverage

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m²K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m²K/W]
	External convective coefficient	0		25.0000				0.0400
1	Internal plaster	20	0.7000	35.0000	28.00	10.7222	1´000	0.0286
2	Lightened concrete screed	50	0.5800	11.6000	45.00	74.2308	1´000	0.0862
3	Reinforced Concrete	50	0.8500	17.0000	120.00	148.4615	1´000	0.0588
4	Brick Slab Lock - Resistance 0.354	240		2.8249	216.00	10.1579	1´000	0.3540
5	Concrete Malta	20	1.4000	70.0000	40.00	22.7059	1´000	0.0143
	Internal convective coefficient	0		10.0000				0.1000



Total Thickness : 380 [mm]

Global thermal transmittance : 1.460 [W/mqK]

Global Thermal Resistance - 0.6849 [mqK/W]

Global superficial Massa = 421.00 [kg/mq]

Isica thermal capacity : 75,703 [kJ/mqK]

Periodic thermal transmittance : 0.40 [W/mqK]

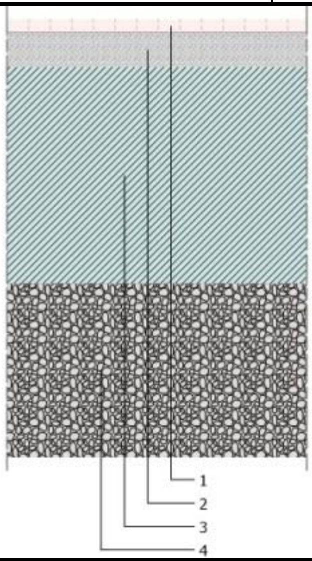
Mitigation Factor 0.27 [-]

Disizing : 10.25 [h]

12.13.3 Concrete slab floor vs. land

Table 12-15: Standard ground slab construction elements

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m²K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m²K/W]
	Internal convective coefficient	0		5.9000				0.1695
1	Internal flooring	15	1.4700	98.0000	25.50	205.3191	1´000	0.0102
2	Concrete Malta	40	1.4000	35.0000	80.00	22.7059	1´000	0.0286
3	Lightened concrete	250	0.3300	1.3200	300.00	86.5471	1´000	0.7576
4	Big gravel without clay	200	1.2000	6.0000	340.00	5.1467	840	0.1667
	External convective coefficient	0		25.0000				0.0400



Total Thickness : 505 [mm]

Global thermal transmittance : 0.854 [W/mqK]

Global Thermal Resistance 1.1709 [mqK/W]

Global superficial Massa = 745.50 [kg/mq]

Isica thermal capacity : 59,404 [kJ/mqK]

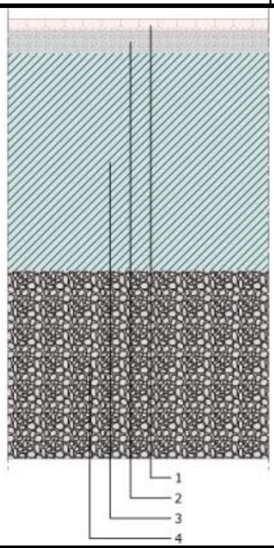
Periodic thermal transmittance : 0.06 [W/mqK]

Mitigation Factor : 0.07 [-]

Disizing : 17.60 [h]

Table 12-16: mediocre concrete slab floor vs. land

Layer	Description	Thickness [mm]	Conductivity [W/mK]	Conductance [W/m²K]	Surface mass [kg/mq]	Steam resistance [-]	Specific heat [J/kgK]	Resistance [m²K/W]
	Internal convective coefficient	0		5.9000				0.1695
1	Internal flooring	15	1.4700	98.0000	25.50	205.3191	1´000	0.0102
2	Concrete Malta	30	1.4000	46.6667	60.00	22.7059	1´000	0.0214
3	Ordinary concrete	290	1.1615	4.0052	580.00	74.2308	1´000	0.2497
4	Big gravel without clay	250	1.2000	4.8000	425.00	5.1467	840	0.2083
	External convective coefficient	0		25.0000				0.0400



Total Thickness : 585 [mm]

Global thermal transmittance : 1,427 [W/mqK]

Global Thermal Resistance - 0.700 [mqK/W]

Global superficial Massa = 1´ 090.50 [kg/mq]

Isica thermal capacity : 60,838 [kJ/mqK]

Periodic thermal transmittance : 0.08 [W/mqK]

Mitigation Factor : 0.06 [-]

Disizing : 16.27 [h]

12.13.4 Fixtures

Table 12-17: Standard window door technical features

INTERNAL FIXTURE		
Title	Window Door - Standard	
Description	Two-door window door with wooden or metal-wood frame and normal double glass	
	Glass Glass Type - Double Normal Area - Ag = 2.52 m^2 Perimeter - Lg – 7.2 m Transmittance - Ug = 3.4 W/m^2K Normal solar factor - fg - 0.75	Frame Frame Type - Wood or Metal-Wood Area - Af = 0.63 m^2 Transmittance - Uf = 4.9 W/m^2K Spacers type : METAL Spacer Transmittance = 0.06 W/m^2K
	Total Infix Area - Aw - 3.15 mq	
Dumpster	-	
Parapet	-	
Internal surface resistance	0.13	m^2K/W
External surface resistance	0.04	m^2K/W
Inter-hull resistance	0.10	m^2K/W
Frame area reduction coefficient	0.2	
Total Infix Transfix - Uw	3.7	W/ m^2K
Total Fixed Resistance - Rw	0.13	W/ m^2K

Table 12-18: Standard window technical features

INTERNAL FIXTURE		
Title	Window - standard	
Description	Window with wooden or wood-metal frame and normal double glass	
	Glass Glass Type - Double Normal Area - Ag = 1.08 m^2 Perimeter - Lg – 4.8 m Transmittance - Ug = 3.4 W/m^2K Normal solar factor - fg - 0.75	Frame Frame Type - Wood or Metal-Wood Area - Af = 0.27 m^2 Transmittance - Uf = 4.9 W/m^2K Spacers type : METAL Spacer Transmittance = 0.06 W/m^2K
	Total Fixture Area - Aw - 1.35 mq	
Dumpster	-	
Parapet	-	
Internal surface resistance	0.13	m^2K/W
External surface resistance	0.04	m^2K/W
Inter-hull resistance	0.10	m^2K/W
Frame area reduction coefficient	0.2	
Total Infix Transfix - Uw	3.7	W/ m^2K
Total Fixed Resistance - Rw	0.14	W/ m^2K

Table 12-19: Poor window door technical features

INTERNAL FIXTURE		
Title	Window door - mediocre	
Description	Two-door window door with metal frame without thermal cut and single glass	
	Glass Glass Type - Single Area - Ag = 2.52 m^2 Perimeter - Lg – 7.2 m Transmittance - Ug = 5.775 W/m^2K Normal solar factor - fg - 0.85	Frame Frame Type - Metal without thermal cut Area - Af = 0.63 m^2 Transmittance - Uf = 5.90 W/m^2K Spacers type : METAL Spacer Transmittance = 0.06 W/m^2K
	Total Infix Area - Aw - 3.15 mq	
Dumpster	-	
Parapet	-	
Internal surface resistance	0.13	m^2K/W
External surface resistance	0.04	m^2K/W
Inter-hull resistance	0.10	m^2K/W
Frame area reduction coefficient	0.34	
Total Infix Transfix - Uw	5.8	W/m^2K
Total Fixed Resistance - Rw	0.00	W/m^2K

Table 12-20: Poor window technical features

INTERNAL FIXTURE		
Title	Window - mediocre	
Description	Window with metal frame without thermal cut and single glass	
	Glass Glass Type - Single Area - Ag = 1.08 m^2 Perimeter - Lg – 4.8 m Transmittance - Ug = 5.775 W/m^2K Normal solar factor - fg - 0.85	Frame Frame Type - Metal without thermal cut Area - Af = 0.27 m^2 Transmittance - Uf = 5.90 W/m^2K Spacers type : METAL Spacer Transmittance = 0.06 W/m^2K
	Total Fixture Area - Aw - 1.35 mq	
Dumpster	-	
Parapet	-	
Internal surface resistance	0.13	m^2K/W
External surface resistance	0.04	m^2K/W
Inter-hull resistance	0.10	m^2K/W
Frame area reduction coefficient	0.51	
Total Infix Transfix - Uw	5.8	W/m^2K
Total Fixed Resistance - Rw	0.00	W/m^2K

13 The energy consumption of the climate generator

13.1 Introduction

UNITS 11300 defines the energy consumption $Q_{Gn,In}^{(1)}$ needed by the thermal generator to meet the demand of the building as

$$Q_{Gn,In}^{(1)} = \frac{Q_{Gn,Out}}{\eta_{gn}}$$

where

- $Q_{Gn,Out}$ = thermal energy required by the generator defined as reported in the Section 12.12
- η_{gn} = efficiency of the generator whose benchmarks proposed by the current legislation are set out in the next Sections 13.2 ÷ 13.4 of this Chapter.

In general, the efficiencies varies with the type of generator and, in any case, is a function of the environmental conditions in which it operates. In the DSS-RRE model, the choice of generators includes,

- Traditional and condensation boilers;
- Gas (absorption) heat pumps and Electric areo-thermal heat pumps

whose performance can be expressed as a, Sections 13.2 ÷ 13.4,

$$\eta_{gn} = \eta_{gn}(P_n, T_a, T_p)$$

where

- P_n thermal power under normal operating conditions
- T_a =Outdoor air temperature
- T_p =Temperature of the water produced

In the case of the Heat Pump in heating mode, (T_a, T_p) are also called as "*cold source temperature*" and "*hot source temperature*" respectively.

Normally $T_p$can be considered a parameter of the plant fixed to a constant value, almost always depending on the type of air conditioning.

Table 13-1: Output temperatur T_p as function of the season and of the conditioning system

Types of terminals	Winter delivery	Winter return	Summer delivery	Summer return
	°C	°C	°C	°C
Environment temperatures	20		26	
Tolerance	+2		-2	
Radiators	75	65		
Fan-coil units	45	55	7	12
Floor system	35	25	17	20

On the contrary, T_a heavily depends not only on the season but even on the hour in the day.

Being based on to the average monthly temperature $\bar{T}_j \in [\bar{T}_1, \bar{T}_2, \cdots, \bar{T}_{\bar{n}}]$, the UNITS 11300 allows to divide the generator demand $Q_{Gn,Out}$ into $\bar{n}$ monthly values and, therefore, to calculate the energy consumption as

$$Q_{Gn,In}^{(2)} = \sum_{j=1}^{\bar{n}} \left(\frac{Q_{Gn,Out,j}}{\eta_{gn,j}} \right)$$

However this formulation still does not solve correctly the problem of since it allows only to vary the efficiency value monthly.

For this reason, the DSS-RRE model implements the so-called "*Bin Hourly Method*", Sections 13.5, in which the thermal demand is not calculated on the basis of the average monthly temperature $\bar{T}_j$, but on the basis of the hourly temperature $\hat{T}_k \in [\hat{T}_1, \hat{T}_2, \cdots, \hat{T}_{\hat{n}}]$.

Thus, the monthly energy demand $Q_{Gn,Out,j}$ is in the following further subdivided into $\hat{n}$ hourly values and, therefore, the energy consumption can be calculate as, Sections 13.6

$$Q_{Gn,In}^{(3)} = \sum_{j=1}^{\bar{n}} \sum_{k=1}^{\hat{n}} \left(\frac{Q_{Gn,Out,j,k}}{\eta_{gn,j,k}} \right)$$

where

$$Q_{Gn,Out,j,k} = \frac{\widehat{GH}_{j,k}}{GG} \times Q_{Gn,Out}$$

- $\widehat{GH}_{j,k}$ = Degrees hour of the k-hour in a day of the *j*-month
- $\hat{n}$ = number of hours in a day of the heating season
- $\eta_{gn,j,k}$ = can be calculated on hourly based

Section 13.7 reports the proof that, if the monthly energy demand is defined as in in Section 12.11, all three methods allows to calculate the same correct value of the Thermal Demand $Q_{Gn,Out}$. However, if η_{gn} is not a constant value, each of these methods lead to a different assessment of the energy consumption $Q_{Gn,In}$ and, since the BIN Method operates an hourly basis $\hat{T}_k$, necessarily its evaluation has to be the most accurate.

Moreover, the BIN hourly Method time method brings the following inherent benefits, Section 13.8:

- it allows an hourly assessment of the power that the generator have to deliver;
- it determines the design power of the generator.

13.2 Traditional and condensing boilers efficiency evaluation

From the data available in the literature it appears that boilers, and in particular those powered by natural gas (methane), represent almost the entire market, Figure 4-3. Since 26 September 2015, implementing the Directive European2005/32 / EC, called "Eco-Design", the Italian legislation requires that boilers must be of the type condensation.

For this type of boiler the standard procedure assumes that the efficiency function has the trend shown in Figure 13-1, which can be expressed mathematically as

$$\eta_{gn} = \eta_{gn}(CR, T_p) = \begin{cases} \eta_{gn,30}; & CR \leq 30 \\ (CR - 100) * \dfrac{\eta_{gn,30} - \eta_{gn,100}}{30 - 100} + \eta_{gn,30}; & 30 < CR \leq 100 \end{cases}$$

where

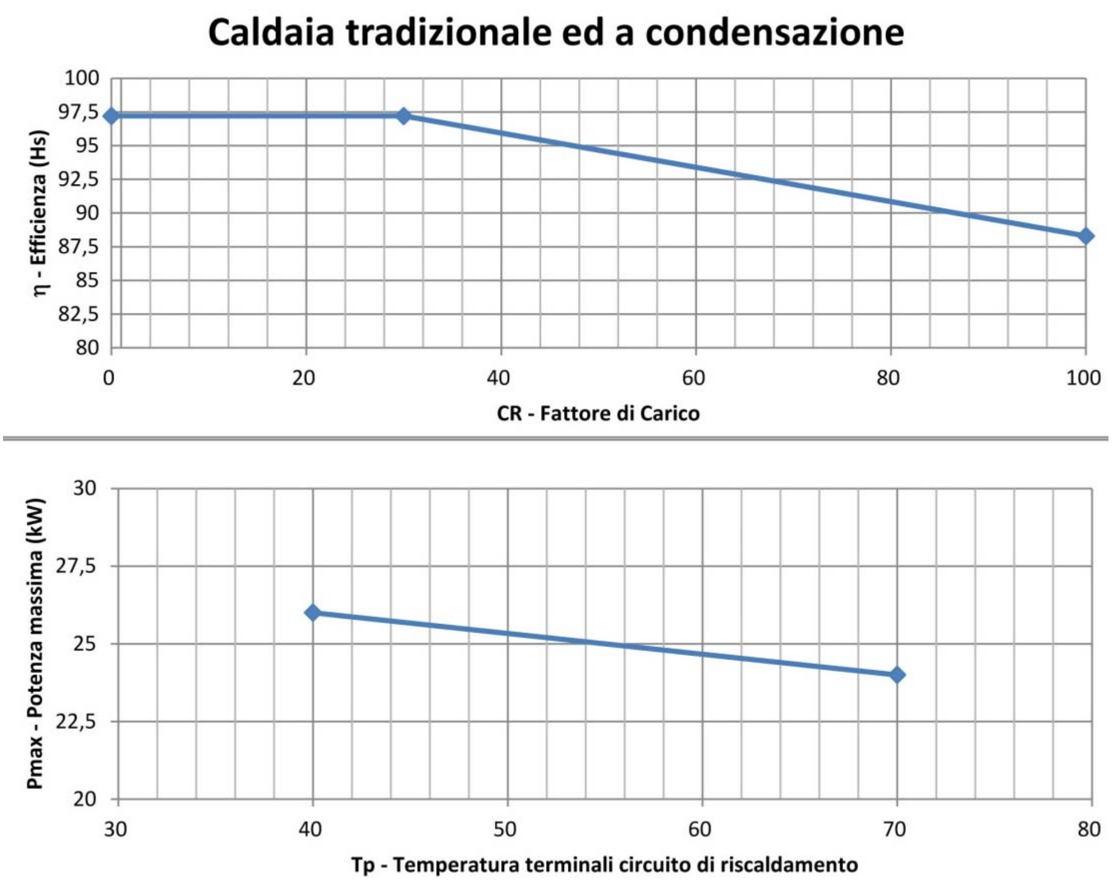
$$CR = \frac{P_n}{P_{max}} \in [0{,}100]$$
$$P_{max} = P_{max}(T_p)$$

- CR = load factor
- P_{max} = maximum thermal power produced by the boiler to the corresponding $CR = 100$

and

- $(\eta_{gn,30}, \eta_{gn,100})_T$ are parameters given by the manufacture

Figure 13-1: Boiler efficiency relationships - Original figure



Source: UNITS11300 - Original figure

According to D.Lgs. No. 192 dated 19/08/05 (as revised by art.7 of D.M. 26/06/09), the boilers combustion efficiency cannot be less than the limit values calculated as reported in the following Table.

Table 13-2: Minimum Performance Values for Water Heat Generators, DPR 74/2013

Installation date	Standard boiler	Condensation boiler
Before 29.10.1993	$(82 + 2\,log\,P_n)$	$(82 + 2\,log\,P_n)$
From 29.10.1993 to 31.12.1997	$(84 + 2\,log\,P_n)$	$(84 + 2\,log\,P_n)$
From 1.1.1998 to 8.10.2005	$(84 + 2\,log\,P_n)$	$(91 +\ log\,P_n)$
from 8.10.2005 to the present day	$(88 + 2\,log\,P_n) - 1$	$(90 + 2\,log\,P_n) - 1$

NB:

$$\log P_n = \begin{cases} 0.0, & P_n = 1 \\ 2.6, & P_n = 400 \end{cases} \text{ thus } \eta_{gn} = \begin{cases} (82 + 2\,log\,P_n) = 82, & P_n = 1 \\ (90 + 2\,log\,P_n) - 1 = 94 & P_n = 400 \end{cases}$$

Source: DPR 74/2013

These values are computed based on maximum thermal power P_n under normal operating conditions. For nominal powers greater than 400 kW, the combustion efficiency is calculated by applying the maximum limit of 400 kW.

In the RRE, when the technical data of the boiler are available, the calculation of the Energy Consumption is performed by accurately calculating the performance value from the above mathematical expression. Instead, when no other information are available, as in the case of old plants, the performance value are calculate as reported in Table 13-3:

Table 13-3: Minimum Performance Values for Water Heat Generators		
Years of installation	**Standard boiler**	**Condensation boiler**
0 to 10 years	$(88 + 2\, log\, P_n) - 1$	$(90 + 2\, log\, P_n) - 1$
10 to 20 years	$(84 + 2\, log\, P_n)$	$(91 +\, log\, P_n)$
For 20 years and more	$(84 + 2\, log\, P_n) - 1$	$(84 + 2\, log\, P_n)$

13.3 Gas (absorption) Heat Pumps efficiency evaluation

The efficiency of a gas-fired absorption heat pump (GAHP - Gas Absorption Heat Pumps) is defined as the ratio

$$\eta_{pdc\_gas} = GUE = \frac{P_{Gn,Out}}{P_{Gn,In}} \left[\frac{\text{kW}_{\text{thermic}}}{\text{kW}_{\text{thermic}}}\right]$$

where

- GUE = Gas Utilization Efficiency
- $P_{Gn,In}$ = Thermal power absorbed by the Heat Pump in $[\text{kW}_{\text{thermic}}]$
- $P_{Gn,Out}$ = Thermal power produced by the Heat Pump in $[\text{kW}_{\text{thermic}}]$

For gas heat pumps, according to Annex I of DM 06/09/2009 relating to the *Deductions provisions for the energy renovation costs of existing building stock, under the terms of the Article 1, Section 349, of the Act 27 December 2006, No 296*, the performance values cannot be less than the limit values reported in the following Table.

Table 13-4: Minimum performance coefficient values (GUE) for gas heat pumps			
Type of heat pump External/internal environment	External environment [°C]	Internal environment [°C]	GUE
air/air	Dry bulb at the entrance : 7 Wet bulb at the entrance: 6	Dry bulb at the entrance: 20	1.46
air/water	Dry bulb at the entrance : 7 Wet bulb at the entrance: 6	Input temperature: 30	1.38
brine/air	Input temperature: 0	Dry bulb at the entrance: 20	1.59
brine/water	Input temperature: 0	Input temperature: 30()	1.47
water/air	Input temperature: 10	Dry bulb at the entrance: 20	1.60
water/water	Input temperature: 10	Input temperature: 30	1.56
Source: Annex I of DM 06/09/2009			

In the DSS-RRE simulator, the choice is restricted to the air/water heat pump alone, which is by far the most used and, in order to take into account also the age of the machine, the performance is expressed as

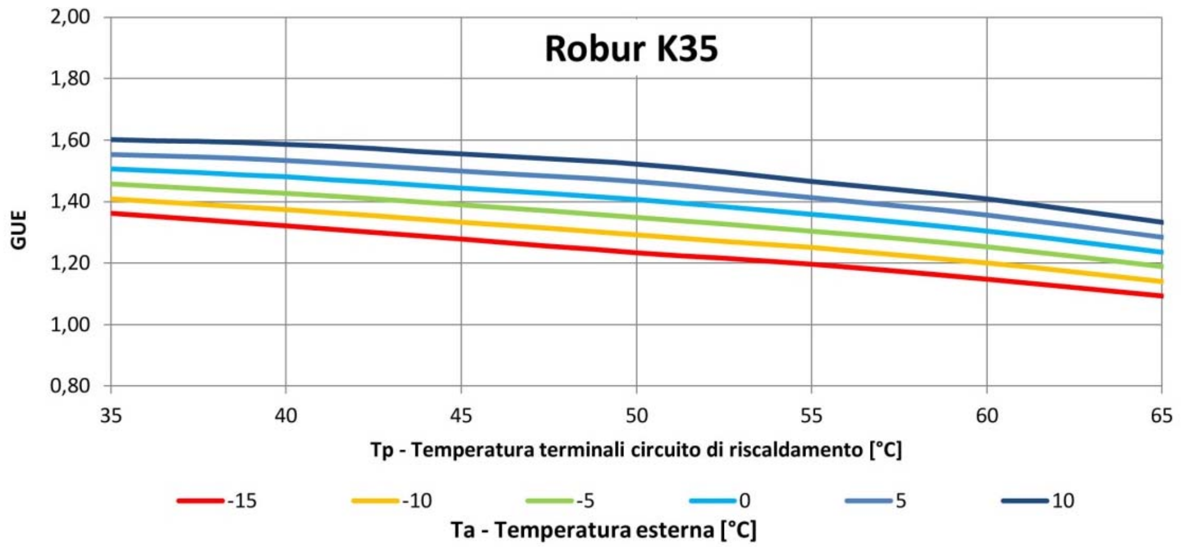
$$\eta_{gn} = eta\ \times \text{GUE}(T_a, T_p)$$

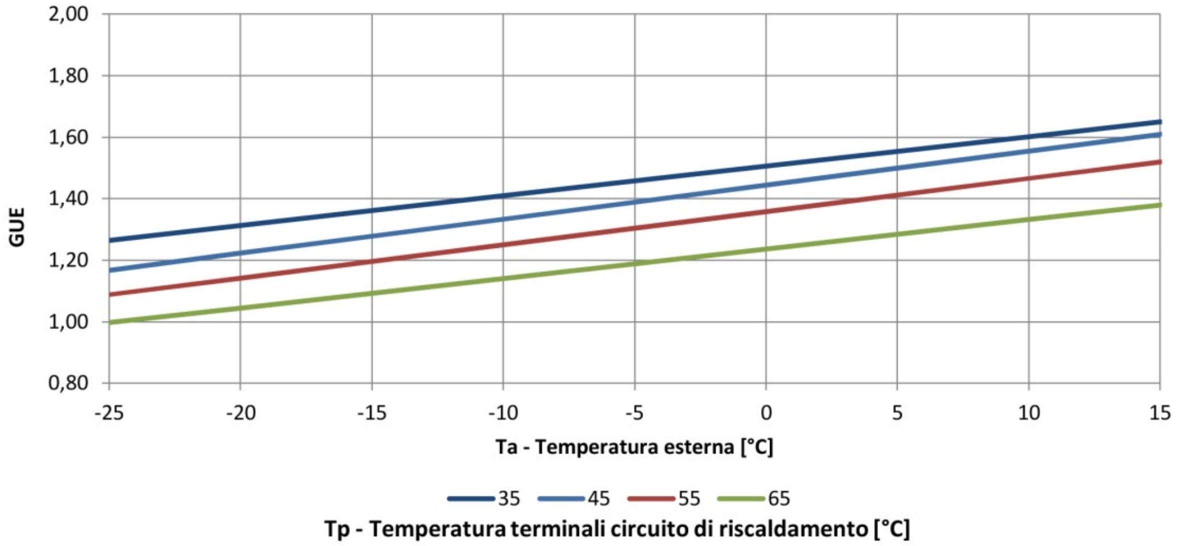
where

- $eta\ = \begin{cases} 1.00; & \text{from 0 to 5 years} \\ 0.92; & \text{from 5 to 10 years} \\ 0.85; & \text{from 10 to 20 years} \end{cases}$
- GUE = is the performance function of that particular heat pump given by the manufacturer

A an example, Table13-5 reports the experimental data of a gas heat pump produced by ROBUR, industry leader in the sector, that are used in RRE to evaluate GUE for that particular generator. In case the manufacturer data are not available, as in the case of an old plant, RRE simply assume that $\text{GUE} = 1.3$.

Table13-5: *GUE* Robur gas heat pump





		T_p [°C]						
		35	**40**	**45**	**50**	**55**	**60**	**65**
T_a [°C]	**-25**	1.27	1.21	1.17	1.12	1.09	1.04	1.00
	-20	1.31	1.27	1.22	1.18	1.14	1.10	1.04
	-15	1.36	1.32	1.28	1.23	1.20	1.15	1.09
	-10	1.41	1.37	1.33	1.29	1.25	1.20	1.14
	-5	1.46	1.43	1.39	1.35	1.30	1.25	1.19
	0	1.51	1.48	1.44	1.41	1.36	1.30	1.24
	5	1.55	1.53	1.50	1.46	1.41	1.36	1.28
	10	1.60	1.59	1.55	1.52	1.47	1.41	1.33
	15	1.65	1.64	1.61	1.58	1.52	1.46	1.38

Source: courtesy of ROBUR 2018 - Original figure

13.4 Electric (compression) Heat Pump efficiency evaluation

The Electric heat pumps efficiency is defined as the ratio

$$\eta_{pdc\_elet} = \frac{P_{Gn,Out}}{P_{Gn,In}} \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right]$$

where

- $P_{Gn,In}$ =Electrical power absorbed by the Heat Pump in $[\mathrm{kW_{electric}}]$
- $P_{Gn,Out}$ =Thermal power produced by the PdC in $[\mathrm{kW_{thermic}}]$

In particular, the efficiency of the heat pump takes on a particular name depending on the operating mode

$$\eta_{pdc\_elet} = \begin{cases} COP & \text{Coefficient of Performance} & \text{heating} \\ EER & \text{Energy Efficiency Ratio} & \text{cooling} \end{cases}$$

To compare the efficiency of an electric with that of a gas heat pump we have to refer to

$$\eta_{pdc\_elet\_primary} = \frac{P_{Gn,Out}}{P_{Gn,In,primary}} = K_{elet\_primary} \times \eta_{pdc\_elet}\ ; \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right]$$

being

$$K_{elet\_primary} = 0.46 \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right] = \frac{1}{2.17 \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right]}$$

therefore to equal the efficiency of a gas heat pump with a $\mathrm{GUE} = 1.3$ it is necessary that the electric one has

$$\mathrm{GUE} = K_{elet\_primary} \times \mathrm{COP} = GUE/K_{elet\_primary} = 2.81$$

the conversion factor, established by law, which makes it possible to assess the thermal energy that is necessary to consume in the power plants of the national electricity system to produce the electricity consumed locally, also taking into account the losses sustained along the transmission lines of the electricity network national.

In RRE simulator, similarly to the gas heat pump case, the choice is limited to the air/water heat pumps and their performance is expressed as

$$\eta_{gn} = eta \times \eta_{pdc\_elet}$$

where

- $eta = \begin{cases} 1.00; & \text{from 0 to 5 years} \\ 0.92; & \text{from 5 to 10 years} \\ 0.85; & \text{from 10 to 20 years} \end{cases}$

13.4.1 The Electric Heat Pumps performances in Heating

For the heating mode, the Coefficient of Performance of heat pumps takes the form

$$\eta_{pdc\_elet} \therefore COP = \frac{P_{Gn,Out}}{P_{Gn,In}} \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right]$$

where

- $P_{Gn,In}$ =Electrical power absorbed by the Heat Pump $[\mathrm{kW_{electric}}]$
- $P_{Gn,Out}$ =Thermal power produced by the heat pump $[\mathrm{kW_{thermic}}]$

Theoretically, the maximum COP (Coefficient Of Performance) is calculated with the formula:

$$COP_{max} = \frac{T_p + 273.15}{T_p - T_a}$$

where in an air-water hydronic heat pump

- T_p =Temperature of the produced hot water, also called "*hot source*";
- T_a = Temperature of the external air, also called "*cold source*".

For Electric heat pumps, according to of DLGS 296/2006 (as revised by Annex I of DM 06/09/2009), the performance values cannot be less than the limit values reported in the following Table 13-6.

Table 13-6: Minimum performance coefficient values (COP) for electric heat pumps

Type of heat pump	External Environment [C]	Internal Environment [-C]	COP
air/air	Dry bulb at the entrance : 7 Wet bulb at the entrance: 6	Dry bulb at the entrance: 20 Wet bulb at the entrance: 15	3.9
air/water With useful thermal power < 35 kW	Dry bulb at the entrance : 7 Wet bulb at the entrance: 6	Entry temperature: 30 Output temperature: 35	4.1
air/water With useful thermal power > 35 kW	Dry bulb at the entrance : 7 Wet bulb at the entrance: 6	Entry temperature: 30 Output temperature: 35	3.8
brine/air	Input temperature: 0	Dry bulb at the entrance: 20 Wet bulb at the entrance: 15	4.3
brine/water	Input temperature: 0	Entry temperature: 30 Output temperature: 35	4.3
water/air	Entry temperature: 10 Output temperature: 7	Dry bulb at the entrance: 20 Inbound wet bulb: 15	4.7
water/water	Entry temperature: 10	Entry temperature: 30 Output temperature: 35	5.1
Source: Annex I of DM 06/09/2009			

For calculating COP, UNITS 11300-4 assumes the existence of the following 2 types of experimental data provided by the manufacturer

1. Full-load performance data.

$$P_{max} = P_{max}(T_p, T_a)$$

$$COP_{max} = COP_{max}(T_p, T_a)$$

experimental relationships provided by the manufacturer of the type reported in Table 13-7 where

- the values on a grey background are the reference climatic conditions imposed by UNITS 11300-4;
- the values on a white background show the real performance data of a Heat Pump produced by a well-known manufacturer and are shown here only as an example;
- P_{max} = maximum thermal power produced by the Heat Pump to the corresponding T_p and T_a;

In case the project temperature values T_p do not match those of the (T_p, T_a) experimental data, the values of P_{max} and COP_{max} should be calculated by linear interpolation from the available one.

2. Partial-load performance data

$$f_{cop} = f_{cop}(CR)$$

where

$$CR = \frac{P_{Gn,Out}}{P_{max}}\bigg|_{T_p,T_a}$$

- f_{cop} = COP corrective factor at partial load
- CR = load factor

If the experimental data for f_{cop} are not available, you can use the following default function

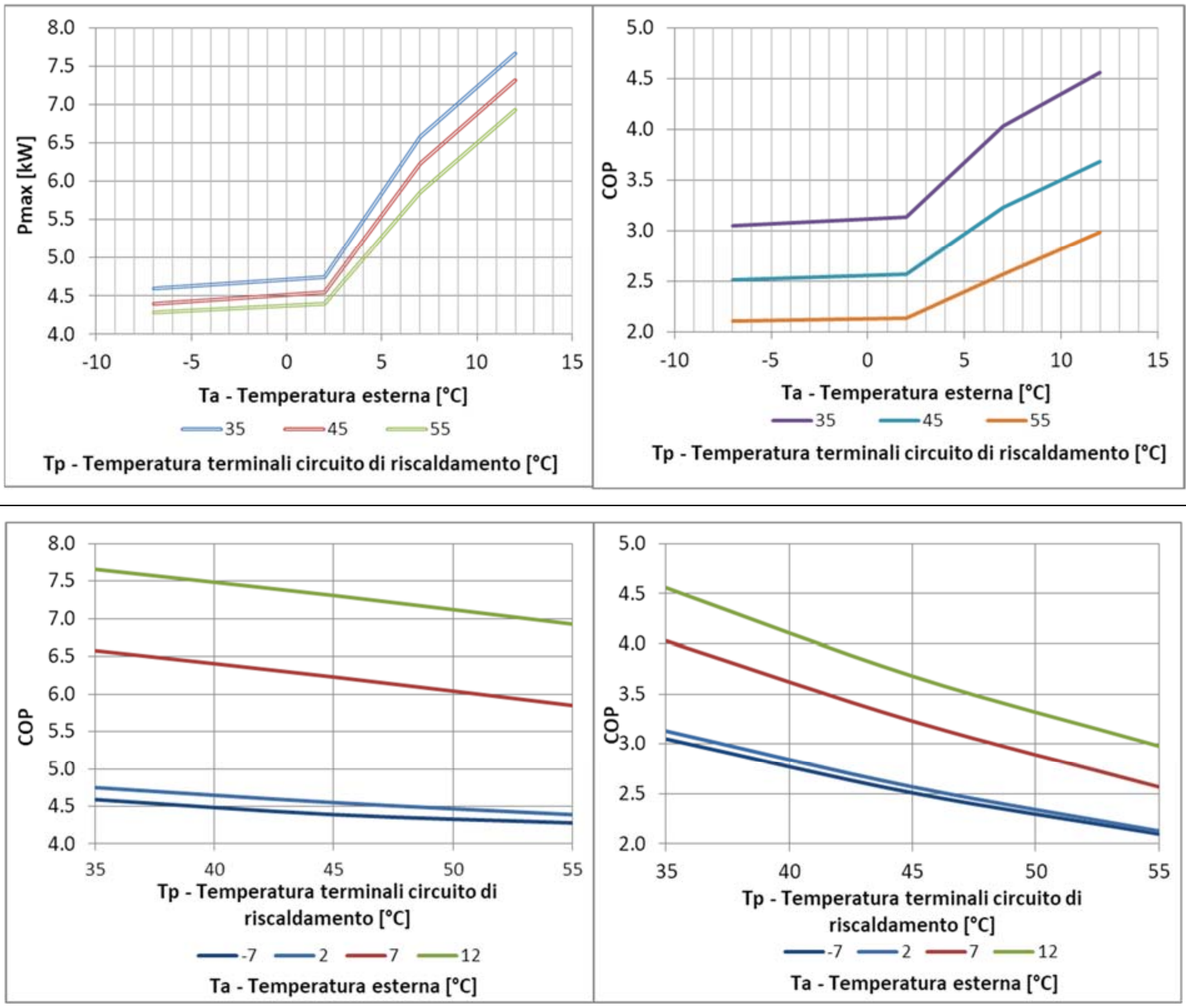
$$f_{cop} = \frac{CR}{[C_c x\ CR + (1 - C_c)]}$$

where C_c is an experimental data, in the absence of which, you assume $C_c = 0.9$.

Table 13-7: heat pump full load performance data - Original Figures

T_p [°C]	35		45		55	
T_a	P_{max}	COP_{max}	P_{max}	COP_{max}	P_{max}	COP_{max}
[°C]	[kW]		[kW]		[kW]	
-7	4.59	3.05	4.39	2.51	4.28	2.1
2	4.75	3.13	4.55	2.57	4.39	2.13
7	6.58	4.03	6.23	3.23	5.85	2.57
12	7.66	4.56	7.31	3.68	6.93	2.98

Source: UNITS 11300-4



In practice, the electrical power $P_{Gn,In}$ [kW$_{electric}$] absorbed by the heat pump to meet the thermal power required $P_{Gn,Out}$ [kW$_{thermal}$] to produce hot water at the temperature T_p [°C], being the external temperature equal to T_a [°C], is calculable as

$$P_{Gn,In} = \frac{P_{Gn,Out}}{COP} \; [kW_{electric}]$$

where

$$COP = f_{cop}(CR) \times COP_{max}$$

and

- CR =load factor as defined above
- f_{cop} ="*corrective factor*" of the partial load COP as defined above
- P_{max} and COP_{max} are derived from the full load performance data provided by the manufacturer corresponding to the values T_p and T_a through, where necessary, linear interpolation of the available data.

In case the manufacturer data are not available, as in the case of an old plant, RRE simply assume that $COP = 2.8$.

13.4.2 The Electric Heat Pumps performances in cooling

Similarly to the heating case described in the previous Section, also in the cooling case the Energy Efficiency Ratio is defined as

$$\eta_{pdc\_elet} \therefore EER = \frac{P_{Gn,Out}}{P_{Gn,In}} \left[\frac{\mathrm{kW_{thermic}}}{\mathrm{kW_{electric}}}\right]$$

where

- $P_{Gn,In}$ = Electrical power absorbed by the Heat Pump in $[\mathrm{kW_{electric}}]$
- $P_{Gn,Out}$ = Thermal power produced by the Heat Pump in $[\mathrm{kW_{thermal}}]$

As with COP, the value of Energy Efficiency Ratio also varies depending on the operating status of the generator

$$EER = EER(CR, T_p, T_a)$$

where

$$CR = \left.\frac{P_{Gn,Out}}{P_{max}}\right|_{T_p,T_a}$$

- T_p =Temperature of the water produced;
- T_a =Outdoor air temperature;
- CR = load factor
- P_{max} =maximum thermal power produced by the Heat Pump to the corresponding T_p and T_a;

For the calculation of the EER, UNI TS 11300-3

a. assumes that each generator has a reference value provided by the manufacturer

$$\overline{EER} = EER(CR = 100, T_p = 7°C, T_a = 35°C)$$

b. provides 4 different correction factor tables of the type reported in Table 13-8, each of them referred to a different load factor: $\mathrm{CR} = [100\%,\ 75\%,\ 50\%,\ 25\%]$.

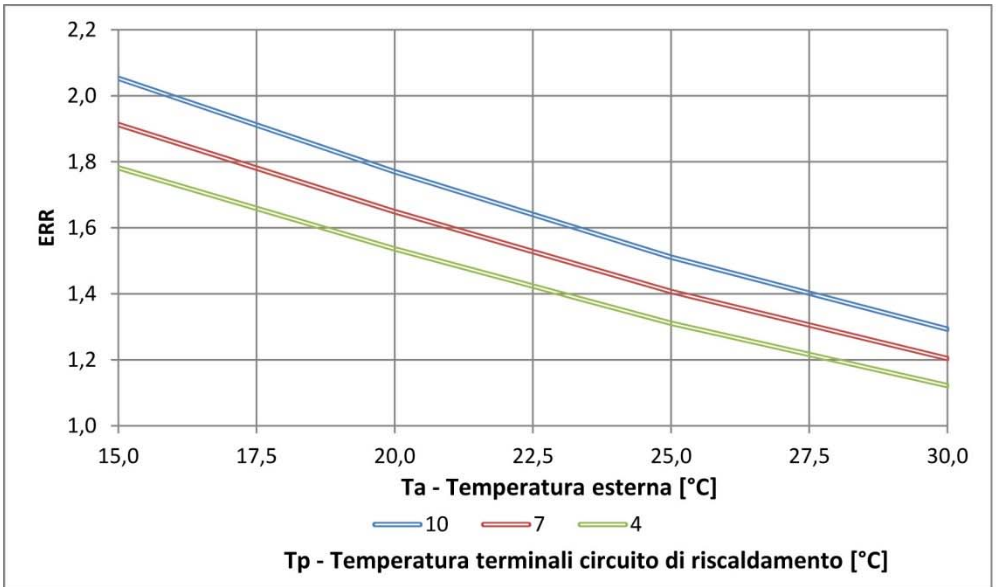
Based on that, the EER can be calculated as a

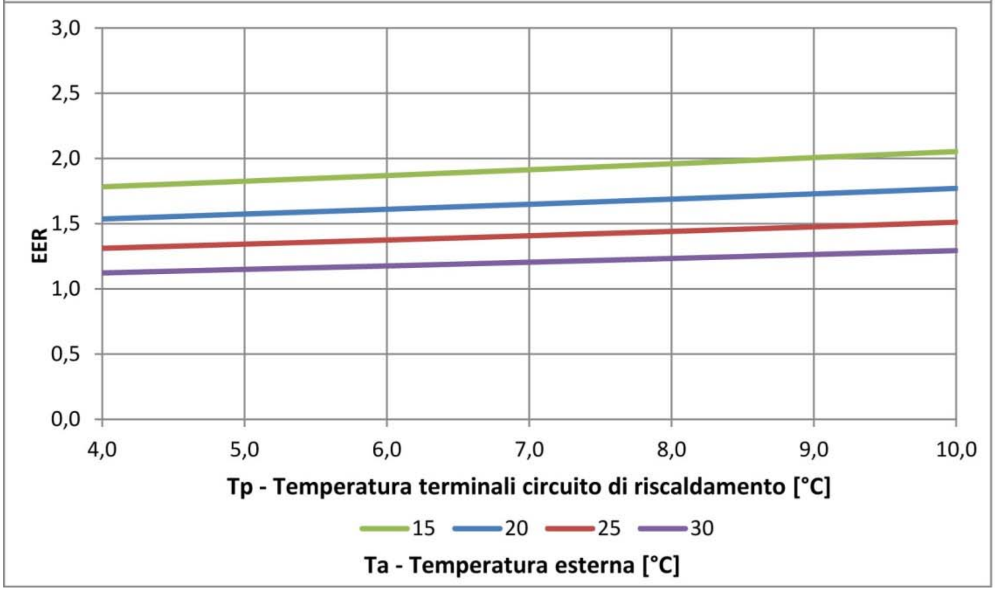
$$EER(CR, T_p, T_a) = f_{p,a}(CR, T_p, T_a) \times \overline{EER}$$

where $f_{p,a}(CR, T_p, T_a)$ is the correction factor found on the table corresponding to CR at the intersection of the columns relative to (T_p, T_a);

For project data (CR, T_p, T_a) different than those provided in the tables, the corresponding EERvalues are calculated by linear interpolation of the available data.

Table 13-8: Corrective air/water heat pump coefficient for CR = 100%





CR = 100%									
		Outdoor air dry bulb temperature T_a							
	100%	15°C	20°C	25°C	30°C	35°C	40°C	45°C	50°C
Water output temperature T_p	10°C	2.053	1.77	1.511	1.293	1.073	0.925	0.797	0.687
	9°C	2.006	1.728	1.475	1.263	1.048	0.903	0.779	0.671
	8°C	1.959	1.688	1.441	1.233	1.024	0.882	0.76	0.655
	7°C	1.913	1.649	1.407	1.204	1	0.862	0.743	0.64
	6°C	1.869	1.61	1.375	1.176	0.977	0.842	0.725	0.625
	5°C	1.825	1.573	1.343	1.149	0.954	0.822	0.709	0.611
	4°C	1.782	1.536	1.311	1.122	0.932	0.803	0.692	0.596

Source: UNITS 11300-3 - Original Figures

13.5 The Bin Hourly Method

The "*bin method*" refers to a procedure where monthly weather data is sorted into discrete groups (bins) of weather conditions. Each bin contains the number of average hours of occurrence during a month or year of a particular range of weather condition.

Let us consider *j*-th month of a climatic period (winter or summer) and define

- $\bar{T}_j$ = Average external temperature of *the month* according to UNI 10349;
- $\hat{T}_k$ = Bin Temperature with

$$\hat{T}_k \in [\hat{T}_1, \hat{T}_2, \cdots, \hat{T}_{\hat{n}}]$$

$$\Delta\hat{T} = \hat{T}_k - \hat{T}_{k-1} = 1\,°C$$

Particularly in the DSS-RRE model, we assume

$\hat{T}_k \in [-16, -15, \cdots, +35]$ for which $\hat{n} = 51$

which covers all the average Italian climatic temperature range.

The Bin Method allows to estimate the number of hours $\hat{h}_{k,j}$ of the month in which the external temperature T is kept at the same temperature $\hat{T}_k$ as

$$\hat{h}_{j,k} = \hat{F}_{j,k} \times h \times g_j$$

where

- $\hat{F}_{j,k}$ = density factor relative to the *j*-th month and function of $\hat{\theta}_k$;
- h = number of hours of air conditioning allowed per day;
- g_j = number of days in *j*-th month

The density factor is defined by the following normal distribution (or Gaussian)

$$\hat{F}_{j,k} = \frac{1}{\sigma_j * \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\hat{T}_k - \bar{T}_j}{\sigma_j}\right)^2} \times \Delta\hat{T}$$

where

$$\sigma_j = 1.8 + 0.16 \times H_j + \Delta\sigma_j$$

$$\Delta\sigma_j = \Delta\sigma_{max} \times k_{corr,j}$$

$$\Delta\sigma_{max} = -0.502 - 0.15825 \times (\bar{T}_1 - \bar{T}_{des}) + 0.06375 \times (\bar{T}_1 - \bar{T}_{des})^2 - 0.16 \times H_1$$

$$k_{corr,j} = \begin{cases} 1.0; & \text{for january} \\ 0.5; & \text{for february and december}, \\ 0 & for\ all\ the\ other\ months \end{cases}$$

as defined in the UNI TS 11300-4 G.1 prospect, and

- T_{des} =Outdoor winter design temperature according to UNI EN 12831
- H_j =Sum of the average monthly daily irradiation on the diffuse and direct horizontal plane, UNI 10349, expressed in MJ/mq.

In which the values $\bar{\bar{T}}_1$ and H_1 are those related to the month of January, assumed as the coldest month of the year. Figure 13-2 reports the mathematical properties of the Gaussian function.

Since the normal theoretical distribution extends to infinity, for practical purposes it is truncated by zeroing the bin durations $\hat{h}_{k,j}$of less than 1.5% of the duration of the month and redistributing the hours remaining over the duration of the month, i.e.

$$\tilde{F}_{j,k} = \begin{cases} \hat{F}(\hat{T}_k, \bar{T}_j, \sigma_j); & j = 1,2,\cdots,s\,; & \text{per } \hat{F}_{k,j} \geq 0{,}015 \\ 0; & j = s+1, s+2, \cdots, 12\,; & \text{per } \hat{F}_{k,j} < 0{,}015 \end{cases}$$

and, subsequently, the value is rescaled as

$$\hat{F}_{j,k} = \frac{\tilde{F}_{j,k}}{\sum_{i=1}^{s} \tilde{F}_{j,k}} \; ; \; j = 1,2,\cdots,s$$

so that the properties of the Gaussian function can also be preserved in the discreet and limited form

$$\sum_{k=1}^{\hat{n}} \hat{F}_{j,k} \cong \int_{-\infty}^{+\infty} f(\hat{T})\, d\hat{T} = 1$$

$$\sum_{k=1}^{\hat{n}} (\hat{T}_k \times \hat{F}_{j,k}) \cong \int_{-\infty}^{+\infty} \hat{T} \times f(\hat{T}) d\hat{T} = \bar{T}_j$$

where

$$f(\hat{T}) = \frac{1}{\sigma_j * \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\hat{T} \; - \bar{T}_j}{\sigma_j}\right)^2}$$

It follows that

$$\sum_{k=1}^{\hat{n}} \hat{h}_{j,k} = \sum_{k=1}^{\hat{n}} (\hat{F}_{j,k} \times h \times g_j) = h \times g_j \times \sum_{k=1}^{\hat{n}} (\hat{F}_{j,k}) =$$
$$= h \times g_j$$

13.6 The definition of Degree-Hours

Similar to the Degree-Days GG_j defined in Section 12.3.3, the degree-hours are defined below $\widehat{GG}_{k,j}$ as

- Winter

$$\widehat{GH}_{j,k} = \begin{cases} (T_{int,des} - \hat{T}_k) \times \hat{h}_{j,k}; & \forall\, \hat{T}_k < T_{int,des} \\ 0; & \end{cases}$$

- Summer

$$\widehat{GH}_{j,k} = \begin{cases} (\hat{T}_k - T_{int,des}) \times \hat{h}_{j,k}; & \forall\, \hat{T}_k > T_{int,des} \\ 0; & \end{cases}$$

where (Section 13.5):

$$T_{int,des} = \begin{cases} 20°C; & \text{in winter} \\ 26°C; & \text{in summer} \end{cases}$$

$\hat{T}_k$ = the Bin Temperature

$\hat{h}_{k,j}$ = the number of hours of the *j*-th month where external temperature remain constant at $\hat{T}_k$

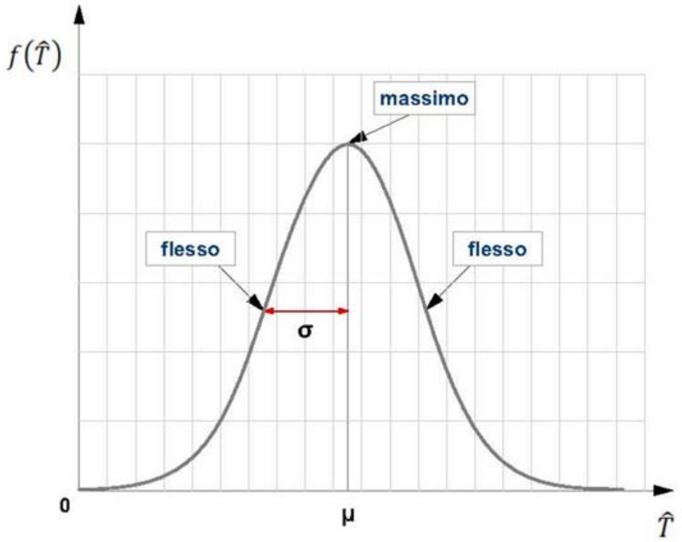
It is of interest to note that

$$\sum_{k=1}^{\hat{n}} \widehat{GH}_{j,k} = GG_j$$

from which

$$\sum_{k=1}^{\hat{n}} Q_{Gn,Out,j,k} = Q_{Gn,Out,j}$$

Figure 13-2: The normal distribution of Gauss – Original Figures



Property

$$f(\hat{T}) = \frac{1}{\sigma \times \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\hat{T}-\bar{T}}{\sigma}\right)^2}$$

$$\int_{-\infty}^{+\infty} f(\hat{T}) d\hat{T} = 1$$

$$\int_{-\infty}^{+\infty} [\hat{T} \times f(\hat{T})] d\hat{T} = \bar{T}$$

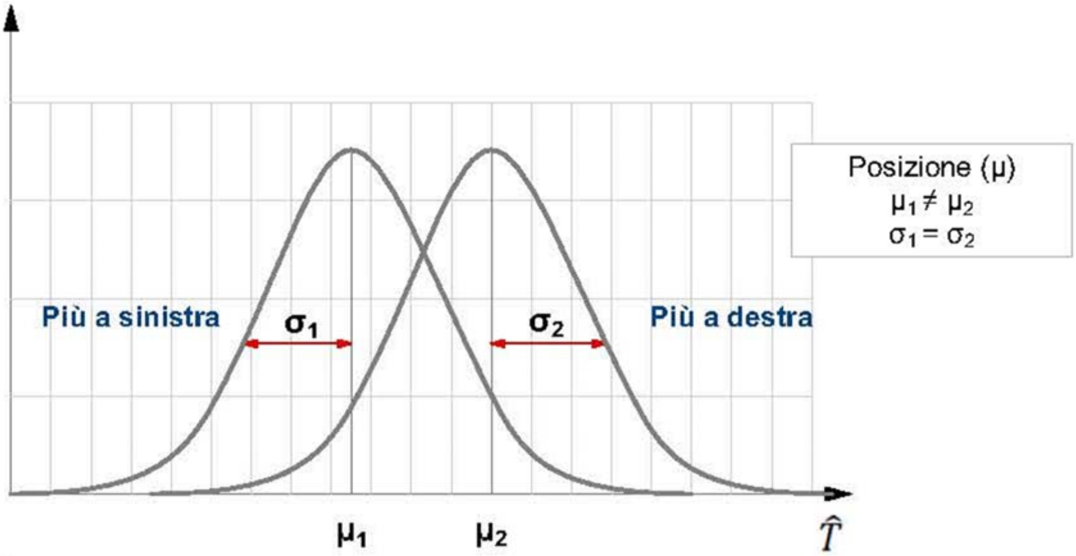
$$\int_{-\infty}^{+\infty} \left[(\hat{T} - \bar{T})^2 \times f(\hat{T})\right] d\hat{T} = \sigma^2$$

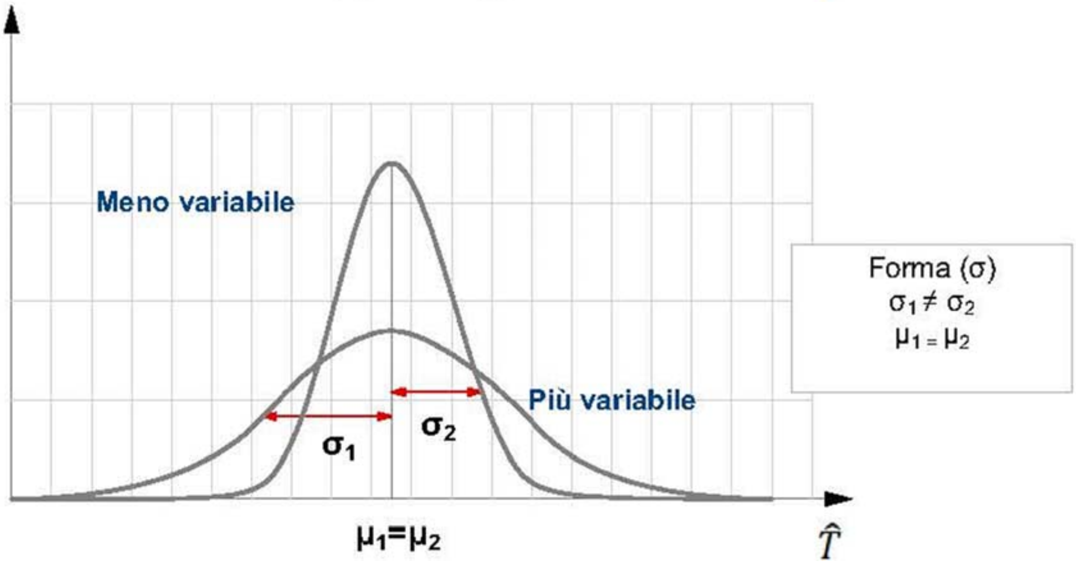
$f(\hat{T} = \bar{T}) = \frac{1}{\sigma \times \sqrt{2\pi}}$ Maximum

symmetrical with respect to $\bar{T}$

$\bar{T}$ =mode, mean and median

σ =standard deviation





In fact

$$\sum_{k=1}^{\hat{n}} \widehat{GH}_{j,k} = \sum_{k=1}^{\hat{n}} (T_{int,des} - \hat{T}_k) \times \hat{h}_{j,k} = \sum_{k=1}^{\hat{n}} (T_{int,des} \times \hat{h}_{j,k}) - \sum_{k=1}^{\hat{n}} \hat{T}_k \times \hat{h}_{j,k} =$$

$$= T_{int,des} \times \sum_{k=1}^{\hat{n}} (\hat{h}_{j,k}) - \sum_{k=1}^{\hat{n}} (\hat{T}_k \times \hat{F}_{j,k} \times h \times g_j) =$$

$$= T_{int,des} \times h \times g_j - \left[\sum_{k=1}^{\hat{n}} (\hat{T}_k \times \hat{F}_{j,k})\right] \times h \times g_j =$$

$$= (T_{int,des} - \bar{T}_j) \times h \times g_j =$$

$$= GG_j$$

and

$$\sum_{k=1}^{\hat{n}} Q_{Gn,Out,j,k} = \sum_{k=1}^{\hat{n}} \left(\frac{\widehat{GH}_{j,k}}{GG} \times Q_{Gn,Out}\right) = \frac{GG_j}{GG} \times Q_{Gn,Out} = Q_{Gn,Out,j}$$

13.7 Energy Consumption according to the integration algorithm

In the introduction of this Chapter Section, three different ways of integrating the Energy demand were defined to determine energy consumption

A. Basic definition

$$Q_{Gn,In}^{(1)} = \frac{Q_{Gn,Out}}{\eta_{gn}}$$

B. Integration according to average monthly temperature $\bar{T}_j$

$$Q_{Gn,In}^{(2)} = \sum_{j=1}^{\bar{n}} \left(\frac{Q_{Gn,Out,j}}{\eta_{gn,j}}\right)$$

C. Integration based on Bin hourly temperature $\hat{T}_k$

$$Q_{Gn,In}^{(3)} = \sum_{j=1}^{\bar{n}} \sum_{k=1}^{\hat{n}} \left(\frac{Q_{Gn,Out,j,k}}{\eta_{gn,j,k}}\right)$$

Below we will demonstrate that, if the monthly energy demand is expressed as in Eq. B in Section 12.11, it follows

A. Equality of thermal demand

$$Q_{Gn,Out} = \sum_{j=1}^{\bar{n}} (Q_{Gn,Out,j})$$

$$Q_{Gn,Out,j} = \sum_{k=1}^{\hat{n}} (Q_{Gn,Out,j,k})$$

And therefore

$$Q_{Gn,Out} = \sum_{j=1}^{\bar{n}} (Q_{Gn,Out,j}) = \sum_{j=1}^{\bar{n}} \sum_{k=1}^{\hat{n}} (Q_{Gn,Out,j,k})$$

B. Energy Consumption's Inequality

$$Q_{Gn,In}^{(1)} \neq Q_{Gn,In}^{(2)} \neq Q_{Gn,In}^{(3)}$$

but in the event that

$\eta_{gn} = \eta_{gn,j} = \eta_{gn,j,k} \ \forall j \in [1,\bar{n}], k \in [1,\hat{n}]$

following equality is obtained

$Q_{Gn,In}^{(1)} = Q_{Gn,In}^{(2)} = Q_{Gn,In}^{(3)}$

In fact

$$Q_{Gn,In}^{(2)} = \sum_{j=1}^{\bar{n}} \left(\frac{Q_{Gn,Out,j}}{\eta_{gn,j}} \right) = \frac{1}{\eta_{gn}} \sum_{j=1}^{\bar{n}} \left(Q_{Gn,Out,j} \right) = \frac{1}{\eta_{gn}} \sum_{j=1}^{\bar{n}} \left(\frac{GG_j}{GG} \times Q_{Gn,Out} \right) = \frac{1}{\eta_{gn}} \sum_{j=1}^{\bar{n}} \left(\frac{GG_j}{GG} \times Q_{Gn,Out} \right) =$$

$$= \frac{1}{\eta_{gn}} \sum_{j=1}^{\bar{n}} \left(\frac{GG_j}{GG} \times Q_{Gn,Out} \right)$$

$$Q_{Gn,Out,j} = \frac{GG_j}{GG} \times Q_{Gn,Out} = \frac{\sum_{k=1}^{\hat{n}} \widehat{GH}_{j,k}}{GG} \times Q_{Gn,Out} = \sum_{k=1}^{\hat{n}} \left(\frac{\widehat{GH}_{j,k}}{GG} \times Q_{Gn,Out} \right) =$$

$$= \sum_{k=1}^{\hat{n}} Q_{Gn,Out,j,k}$$

13.8 Conclusion

Having taken note that

- UNITS 11300 computes the energy consumption $Q_{Gn,In}$ needed by the thermal generator to meet the demand of the building $Q_{Gn,Out}$ as

  $$Q_{Gn,In}^{(2)} = \sum_{j=1}^{\bar{n}} \left(\frac{Q_{Gn,Out,j}}{\eta_{gn,j}} \right)$$

  that is on the basis of the average monthly temperature $\bar{T}_j \in [\bar{T}_1, \bar{T}_2, \cdots, \bar{T}_{\bar{n}}]$ of the external air;

- while the efficiencies of the generator varies with the operating conditions

  $$\eta_{gn} = \eta_{gn}(P_n, T_a, T_p)$$

  where the external air T_a varies during that the energy consumption

we have introduced the "bin hourly method" that gives the possibility of considering the hourly temperature $\hat{T}_k \in [\hat{T}_1, \hat{T}_2, \cdots, \hat{T}_{\hat{n}}]$, so that the energy consumption can be calculated as

$$Q_{Gn,In}^{(3)} = \sum_{j=1}^{\bar{n}} \sum_{k=1}^{\hat{n}} \left(\frac{Q_{Gn,Out,j,k}}{\eta_{gn,j,k}} \right)$$

- In which $\eta_{gn,j,k}$ can be calculated on hourly base.

Then It has been proved that the "bin hourly method" can be seen as an extension of the standard UNI TS 11300 so that

A. Equality of Degrees Day and Degrees hour

$$\sum_{k=1}^{\hat{n}} \widehat{GH}_{j,k} = GG_j$$

B. Equality of thermal demand:

$$Q_{Gn,Out} = \sum_{j=1}^{\bar{n}} \left(Q_{Gn,Out,j} \right) = \sum_{j=1}^{\bar{n}} \sum_{k=1}^{\hat{n}} \left(Q_{Gn,Out,j,k} \right)$$

C. Inequality of energy consumptions

$$Q_{Gn,In}^{(1)} \neq Q_{Gn,In}^{(2)} \neq Q_{Gn,In}^{(3)}$$

but in the case that

$$\eta_{gn} = \eta_{gn,j} = \eta_{gn,j,k} \; \forall j \in [1, \bar{n}], k \in [1, \hat{n}]$$

it is obtained the following equality

$$Q^{(1)}_{Gn,In} = Q^{(2)}_{Gn,In} = Q^{(3)}_{Gn,In}$$

Therefore, all three methods take into account the correct Thermal Demand $Q_{Gn,Out}$. However, if η_{gn} is not a constant value, they lead to a different assessment of the energy consumption needed to meet the demand $Q_{Gn,In}$,.

We notice that, since the BIN Method operates an hourly basis $\hat{T}_k$, at each time step *k* the thermal Power required by the building is known being simply

$$P_{n,k} = Q_{Gn,Out,j,k}.$$

Thus, operating with the BIN method, necessarily the calculation of the Energy Consumption it results more accurate, since it is possible to evaluate the performance function at each time integration step as

$$\eta_{gn,k} = \eta_{gn}\left(P_{n,k}, \hat{T}_k, T_p\right)$$

Moreover, the BIN hourly Method time method brings the following inherent benefits:

- it allows an hourly assessment of the power that the generator have to deliver;
- it determines the design power of the generator.

14 Towards the nZEB building

14.1 Introduction

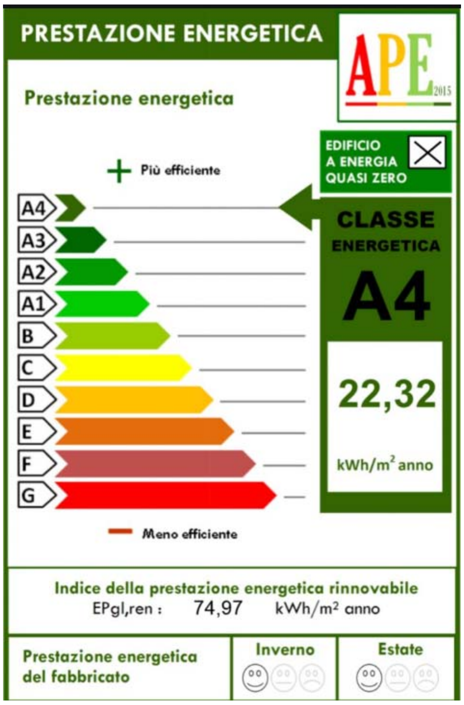
The Energy Classes has been created to classify the energy performance of buildings based on the calculated energy consumption. The calculation method is the quasi-steady one, described in previous Chapters 11.8 and 0, expressed in terms of non-renewable primary energy.

Starting in 2005, following D.Lgs. 192/05 and subsequent legislative interventions completed with DM 162/15, the evaluation of the Energy Class through the so-called “APE (Attestato di Prestazione Energetica)” - Certificate of Energy Performance –- has become mandatory by law.

The new APE, as determined in DM 26/06/2015, which came into force on 1 October 2015, defines 10 Energy Classes which are:

- based on the non-renewable global energy performance index $EP_{gl,nren}$ (Section 14.2)
- named based on alphabet letters - plus numbers - from class A4 - the best - to G - the worst - (Section 14.4)

Figure 14-1: Example of a label for an energy performance certificate



As already reported in Section 4.3, Class A1 is determined as the maximum non-renewable energy that the specific building can consume if all the components of the casing and the plants meet the minimum thermal performance requirements indicated by the regulation itself.

Indeed, therefore, all the ***buildings belonging to the classes A1 - A4*** have, according to the current legislation, an insulation and an efficiency of the heating systems that respect the best building practice - in other words they ***do not waste energy unnecessarily***.

However, for nZEB buildings this is not yet sufficient: a series of additional requirements must be met, including that of ensuring that ***the energy still required by the building is largely satisfied with renewable energy produced on site***, (Section 14.5).

According to the PNIEC submitted in December 2018 by the Italian government to the European Commission, **Section 3.3**, ***one of the most interesting solutions in the residential field is to combine a heat pump with a photovoltaic system.***

For this reason it was considered essential to equip the DSS-RRE model with an algorithm able to: 1) calculate the heat pump and the photovoltaic coupled system, 2) determine the achievable Energy Class, 3) compute the installation and, then, the operating costs.

For the DSS-RRE model purposes it has been necessary to develop a model that is simple and immediate to apply and which, moreover, requires a limited number of data that can be easily estimated by a non-expert operator. Despite these limitations, the model obtained, compared with the results obtained using commercially available professional calculation software, proved to be appropriately reliable, normally containing the error to a few percent, (Section 14.6).

Through this algorithm it is possible to (Section 14.6):

1) Take into account the different productivity of the photovoltaic system depending on the solar month;
2) Properly size the battery storage of photovoltaic system.
3) Estimate the direct contribution of the photovoltaic system during the hours of daytime production and the indirect one of the photovoltaic batteries at night.

14.2 Renewable and non-renewable primary energy

In its most general sense, quoting the definition given by Wikipedia, an energy source is defined as ***primary energy when it is present in nature and therefore it does not derive from the transformation of any other form of energy*.** This classification includes both renewable sources (such as solar, wind, hydroelectric, geothermal, biomass energy) and non-renewable sources, such as directly usable fuels (raw oil, natural gas, coal) or nuclear power.

***Secondary energy* sources**, instead, can only be used after a transformation (such as gasoline as a result of chemical refining, or electricity or hydrogen).

In the specialist "*thermo-technics*" context, primary energy is considered as a "primitive" measure that can be attributed to all different energy forms, allowing to:

1. Compare the efficiency of any thermo-technical plant regardless of the type of fuel used;
2. Assess the amount of renewable and non-renewable energy used.

With the approval of D.L. 96/2010, implementing the 2009/28/CE Directive, the assessment of primary energy, especially the non-renewable energy one, it has even become a legal norm. This is because, among other things, it is part of the international obligations of the EU countries in the context of environmental protection.

For this purpose, the legislation provides a precise definition of renewable and non-renewable energy sources (D.L. 28/2011 in Article 2, Section 1, letter a) and of the so-called *conversion factors in primary energy.* These coefficients allow to convert every form of energy consumed by a building into total primary energy, renewable and non-renewable.

In practice, primary energy is evaluated simply as

$\hat{Q}_{Gn,tot} = f_{p,tot} \times Q_{Gn,In};$ total primary energy [kWh]

$\hat{Q}_{Gn,nren} = f_{p,nren} \times Q_{Gn,In};$ non renewable primary energy [kWh]

$\hat{Q}_{Gn,ren} = f_{p,ren} \times Q_{Gn,In};$ renwable primary energy [kWh]

Where ""

- $Q_{Gn,In}$ = generator input energy.

and, Table 14-1,

- $f_{p,nren}$ = conversion factor for non-renewable primary energy,
- $f_{p,ren}$ = conversion factor for enewable primary energy,
- $f_{p,tot} = f_{p,nren} + f_{p,ren}$ = conversion factor for total primary energy,

Table 14-1: Primary energy conversion factors			
Energy vector	fP,nren	fP,ren	fP,tot
Natural GAS (1)	1,05	0	1,05
GPL	1,05	0	1,05
Oil and fuel oil	1,07	0	1,07
Coal	1,10	0	1,10
Solid Biomass (2)	0,20	0,80	1,00
Liquid and gas Biomass (2)	0,40	0,60	1,00
Electricity from the grid (3)	1,95	0,47	2,42
District heating (4)	1,5	0	1,5
Urban solid waste	0,2	0,2	0,4
District Cooling(4)	0,5	0	0,5
Thermal energy from solar panel (5)	0	1,00	1,00
Electricity produced by photovoltaic, mini-wind and mini-hydraulic (5)	0	1,00	1,00
Thermal energy from the external environment - free cooling (5)	0	1,00	1,00
Thermal energy from the external environment - heat pump (5)	0	1,00	1,00

(1) The values will be updated every two years based on the data provided by GSE.

(2) As defined in Annex X of the legislative decree 3 April 2006, n. 152.

(3) The values will be updated every two years based on the data provided by GSE.

(4) Factor assumed in the absence of values declared by the supplier and asseverated by a third party, in accordance with the provisions of Section 3.2.

(5) Conventional values functional to the calculation system.

Source: UNITS 11300-3

Table 14-2. Thermal end electric yearly demand for a building				
Energy service	Energy demand	Plant losses (net of recoveries)	Distribution demand (a) (generator output)	Electricity demand
Heating	$Q_{H,nd}$ UNI TS 11300-1:2008	$Q_{H,ls,ngn}$(b) UNI TS 11300·2:2008	$Q_{H,d,in}$ UNI TS 11300 2:2008	$Q_{H,aux,el,ngn}$ UNI TS 11300·2:2008
Cooling	$Q_{C,nd}$ UNI TS 11300·1:2008	$Q_{C,ls,ngn}$(c) UNI TS 11300 3:2010	$Q_{C,d,in}$(d) UNI TS 11300-3:2010	$Q_{C,aux,el\,ngn}$(e) UNI TS 11300·3:2010
DHW	$Q_{W,nd}$(f) UNI TS 11300·2:2008	$Q_{W,ls,ngn}$(g) UNI TS 11300 2:2008	$Q_{W,d,in}$ UNITS 11300·2:2008	$Q_{H,aux,el,ngn}$ UNI TS 11300·2:2008
Ventilation(h)	Annex B	-	-	$Q_{V,el}$ Annex B
Lighting(h)	$Q_{L,nd}$	-	-	$Q_{L,el}$

a) including any accumulation losses
b) UNI TS 11300.2: 2008 deals with hydronic systems. For 'all air' heating systems see Appendix B.
c) $Q_{C,ls,ngn}$ is obtained from the formula 3 of the UNITS 11300-3 excluding the term $Q_{C,nd,K}$
d) $Q_{C,d,in}$ equivalent to the term$Q_{Cr,k,x} + Q_{V,k,x}$ referred to the formula 1 of the UNITS 11300 - 3
e) $Q_{C,aux,el,ngn}$ equivalent to the formula 9 of the UNITS 11300 - 3 excluding the electrical auxiliaries of the generation
f) $Q_{CW,nd}$ equivalent to the term $Q_{H,W}$ used in the UNITS 11300 2
g) loss of supply, distribution and accumulation of the UNITS 11300 - 2
h) assessment not required by Ministerial Decree 5912009 and Legislative Decree 28/2011.

Source: UNITS 11300-3

14.3 The Reference Building

According to DM 26/06/2015, (Annex 1, Chapter 3 of the Minimum Requirements Decree of 26 June 2015), the energy class of a building is established by relating its energy consumption to the so-called ***reference building*** defined as:

1) identical to the analysed building in terms of geometry, orientation, territorial location, use and boundary situation;
2) having predetermined thermal characteristics and energy parameters (e.g. thermal transmittances, dynamic parameters, plant efficiencies) whose values are established by this law (Appendice A, (Allegato 1, Capitolo 3)) as function of the specific climatic zone.
3) equipped with the standard technologies listed in Table 14-3, in line with the current parameters for 2019/21:

Table 14-3: standard technologies of the *reference building*

Winter air conditioning	Gaseous fuel generator (natural gas) in compliance with the requirements of table 8 of the Appendix A to the Annex I of the DM minimum requirements and with relative efficiency of the utilization subsystems as per table 7 of the same Appendix.
Summer air conditioning	Electric motor steam compression refrigerating machine in compliance with the requirements of Table 8 of Appendix A to Annex I of the DM minimum requirements and with relative efficiency of the utilization subsystems referred to in table 7 of the same Appendix.
Ventilation	Simple flow mechanical ventilation for extraction in compliance with the requirements of table 9 of Appendix A to Annex I of the DM minimum requirements
DHW	Gaseous fuel (natural gas) generator in compliance with the requirements of table 8 of Appendix A to Annex I of the DM minimum requirements and with relative efficiency of the utilization subsystems as per table 7 of the same Appendix.
Lighting	Compliance with the requirements referred to in Section 1.2.2 of Appendix A. to Annex I of the Ministerial Decree minimum requirements.
Transport of people or things	Compliance with the requirements of the DM minimum requirements.

Source DM 26/06/2015

14.4 Definition of the Energy Class for Buildings

According to DM 26/06/2015, the Energy Class is determined through the non-renewable global energy performance index $EP_{gl,nren}$, defined as the sum of the individual energy services provided in the building and is expressed in [kWh/mq/year]:

$$EP_{gl,nren} = EP_{H,nren} + EP_{C,nren} + EP_{W,nren} + EP_{V,nren} + EP_{L,nren} + EP_{T,nren}$$

where

- $EP_{H,nren}$ and $EP_{C,nren}$ refer to the energy consumed for heating and cooling respectively;
- $EP_{W,nren}$, $EP_{V,nren}$and $EP_{L,nren}$ refer to the energy consumed for the production of hot Water health (DHW), Ventilation and artificial Lighting (to be considered only in the non-residential sector) respectively.
- $EP_{T,nren}$ refers to the energy consumed for transporting people or things.

For example, considering the case of winter heating,

$$EP_{H,nren} = \hat{Q}_{Gn,nren}/S\,; \quad \text{total primary energy [kWh/m}^2\text{]}$$

where

- $\hat{Q}_{Gn,nren}$ = primary energy as defined in the previous Section
- S = useful surface

The class division has been developed on the basis of the letters of the alphabet - in addition to numbers -, on a scale that classifies consumption in ascending order, starting from class A4, up to G, for a total of 10 classes. Performance ranges that identify the classes are derived through multiplication coefficients of value reduction/increase or the energy performance index $EP_{gl,nren,rif,standard\ (2019/21)}$ calculated for the ***reference building* defined** in the previous Section 14.3

Table 14-4; Energy Class for Buildings		
	Classe A4	$\leq 0.40\ EP_{gl,nren,rif,standard\ (2019/21)}$
$0.40\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe A3	$\leq 0.60\ EP_{gl,nren,rif,standard\ (2019/21)}$
$0.60\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe A2	$\leq 0.80\ EP_{gl,nren,rif,standard\ (2019/21)}$
$0.80\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe A1	$\leq 1.00\ EP_{gl,nren,rif,standard\ (2019/21)}$
$1.00\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe B	$\leq 1.20\ EP_{gl,nren,rif,standard\ (2019/21)}$
$1.20\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe C	$\leq 1.50\ EP_{gl,nren,rif,standard\ (2019/21)}$
$1.50\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe D	$\leq 2.00\ EP_{gl,nren,rif,standard\ (2019/21)}$
$2.00\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe E	$\leq 2.60\ EP_{gl,nren,rif,standard\ (2019/21)}$
$2.60\ EP_{gl,nren,rif,standard\ (2019/21)} <$	Classe F	$\leq 3.50\ EP_{gl,nren,rif,standard\ (2019/21)}$
	Classe G	$> 3.50\ EP_{gl,nren,rif,standard\ (2019/21)}$

14.5 Requirements for nZEB buildings

As already described in Section 4.4, with the DLGS of 4.06.2013, Italy has fully implemented the European Directive extending the application also to the restructuring of existing public and private buildings (Ministero Economia e Finanza, 2013).

The Ministerial Decree of 26 June 2015, subsequently specified that from a technical point of view, every building, whether new or existing is considered "***near zero energy building***", if it meets the following requirements:

1. All the following indices, calculated according to the values of the minimum requirements in force since 1 January 2019 for public buildings and from 1 January 2021 for all other buildings, are lower than the values of the corresponding indices calculated for the *reference building* (building virtual geometrically equivalent to that of the project but with the energy parameters and minimum thermal characteristics in force):
    a. the average global heat transfer coefficient per transmission per unit of dispersing surface (H'_T);
    b. summer equivalent solar area per usable area ($A_{sol,est}/S$)
    c. the energy performance index for winter air conditioning ($EP_{H,nd}$), the thermal performance index for summer air conditioning ($EP_{C,nd}$), including any humidity control,
    d. the global energy performance index, expressed in primary energy (EP_{gl}), both total and non-renewable;
    e. the performance of the winter air-conditioning system (η_H), summer air-conditioning (η_C) and domestic hot water production (η_W).
2. Thermal energy production plants must be designed and constructed so as to guarantee simultaneous compliance with the coverage, through the use of energy produced by plants powered by renewable sources, of 50% of the consumption of domestic hot water and the following percentages of the sum of consumptions of domestic hot water, heating and cooling:
    a. 20% when application for the building permit was submitted from 31 May 2012 to 31 December 2013;
    b. 35% when application for the building permit was submitted from 1 January 2014 to 31 December 2016;
    c. 50% when application for the building permit was submitted from 1 January 2017.

In the following, each of the previous points will be discussed.

14.5.1 The Average Global Thermal Exchange Coefficient

UNI-TS 11300-1 defines the average global thermal exchange coefficient of the *reference building* as

$$H'_T = \frac{H_{tr}}{\sum_{i=1}^{n-elem} S_i}\ [\mathrm{W/m^2K}]$$

where

- H_{tr} = the global thermal exchange coefficient for envelope transmission, as defined in Section 12.3;
- S_i = the surface of the *i-th* element in which the heat flow passes, as defined in Section 12.3; [m²]

According to the DGR Lombardy Region 2456/2017, following the DM 26 June 2015, for nZEB buildings it is required that:

$$H'_T < H'_{T,lim}$$

where

- $H'_{T,lim}$ = the limit value of the global average thermal exchange coefficient shown in the following Table 14-5, defined as function of the surface-to-volume ratio and of the climate zone of the building.

Table 14-5 Limit values of the global average thermal exchange $H'_{T,lim}$ coefficient

SHAPE RATIO (S/V)	Climate zone				
	A and B	C	D	e	F
S/V ≤ 0.7	0,58	0,55	0,53	0,50	0,48
0,7 > S/V >0,4	0,63	0,60	0,58	0,55	0,53
0.4 ≥ S/V	0,80	0,80	0,80	0,75	0,70

14.5.2 The summer equivalent solar area per unit of surface

Appendix A of DM 26 June 2015 defines the summer equivalent solar as:

$$A_{sol,est} = \sum_{i=1}^{n-elem} F_{sh,ob} \times g_{gl+sh} \times \left(1 - F_f\right) \times S_{w,i} \times F_{sol,est}$$

where

- $F_{sh,ob}$ = reduction factor for shading relative to external elements for the actual solar capture area of the *i-th* surface, as defined in Section 14.6;
- g_{gl+sh} = total solar power of the window calculated in July, when solar shielding is used, as shown in Table 12-7;
- F_f = fraction of the frame area: the ratio of the projected area of the frame and the total projected area of the windowed component, as defined in Section 12.8.1;
- $S_{w,i}$ = projected area of the glazed component (window space area), as defined in Section 12.8.1;
- $F_{sol,est}$ = Correction factor for accident radiation, derived as a ratio of the average irradiation in July, in the location and on the exhibition considered, and the average annual irradiation of Rome, on the horizontal level;

According to the DGR Lombardy Region 2456/2017, the ratio of the summer equivalent solar area and the useful area of the building must be less than the limit values shown in Table 14-6

Table 14-6: Limit values for the ratio between equivalent summer solar area and building useful area

#	Building Category	All climate zones
1	Category E.1 except for colleges, convents, penalty houses, barracks and category E.1(3)	< 0,030
2	All other buildings	< 0,040

For nZEB buildings, therefore, it is necessary that:

$$\begin{cases} A_{sol,est}/S < 0{,}030 & \text{for buildings belonging to E.1 classification;} \\ A_{sol,est}/S < 0{,}040 & \text{for all the other buildings;} \end{cases}$$

where

- $A_{sol,est}$ = the equivalent summer solar area;
- S = the total walkable surface of the building, as defined in Section 12.6;

14.5.3 The thermal performance indices for heating and cooling

The indexes of thermal performance useful heating $EP_{H,nd}$ and cooling $EP_{H,nd}$, express the needs for annual thermal energy in heating and cooling related to the unit of useful surface of the building considered, that is

$$\begin{cases} EP_{H,nd} = Q_{H,nd}/S \\ EP_{C,nd} = Q_{C,nd}/S \end{cases}$$

where

- $Q_{H,nd}$ = ideal thermal energy demand for heating, defined as in Section 12.3.1
- $Q_{C,nd}$ = ideal thermal energy demand for cooling, defined as in Section 12.3.2;
- S = useful area of the building, defined as in Section 12.4.1

According to the DGR Lombardy Region 2456/2017, the thermal performance index useful for heating must comply with the following requirements:

$$\begin{cases} EP_{H,nd} < EP_{H,nren,limite} \\ EP_{C,nd} < EP_{C,,nren,limite} \end{cases}$$

where

- $EP_{H,nren,limite}$ = limit value of the thermal performance index for heating calculated for the *reference building*;
- $EP_{C,nren,limite}$ = limit value of the thermal performance index useful for cooling calculated for the *reference building*;

14.5.4 Average seasonal plant efficiency

The average seasonal efficiency of heating, cooling and domestic hot water production systems is directly proportional to the regulation, distribution and emission efficiencies of the building. As indicated in Section 12.11, the overall performance of the plant subsystems is defined as:

$$\eta = \eta_e \times \eta_{rg} \times \eta_d$$

where

- η_i =performance of the *i-th* subset of the plant;

In accordance with the DM 26 June 2015, for buildings with almost zero energy it is required that:

$$\begin{cases} \eta_H > \eta_{H,limite} \\ \eta_W > \eta_{W,limite} \\ \eta_C > \eta_{C,limite} \end{cases}$$

where

- η_H = overall efficiency of the heating system subsystem;
- η_W = efficiency of the plant subsystem for the production of domestic hot water;
- η_C = efficiency of the cooling system subsystem;
- $\eta_{i,limite}$ = Average limit efficiency of the *i-th* subsystem of the *reference building* for heating, cooling and production of domestic hot water as reported in Table 14-7;

Table 14-7: Average efficiencies of the subsystems used by the *reference building* for services of H, C, W

Efficiency of use subsystems $\eta_{i,limite}$	H	C	W
Hydronic distribution	0.81	0.81	0.7
Aeraulic distribution	0.83	0.83	-
Mixed distribution	0.82	0.82	-

The rule also requires that

$$\eta_{gn,i} > \eta_{gn,i,limite}$$

where

- $\eta_{gn,i}$ = performance of the *i*-th generation subsystem;
- $\eta_{gn,i,limite}$ = limit performance of the *i-th* generation subsystem depending on the plant subsystem and the type of generator being considered, as reported in Table 14-8;

Table 14-8: Average efficiencies of the *reference building* thermal generation subsystems				
Generation subsystems:	**Thermal energy production**			**In situ electricity production**
	H - Heating	C - Cooling	W - Hot water	
Liquid fuel generator	0.82	-	0.80	-
Gas fuel generator	0.95	-	0.85	-
Solid fuel generator	0.72	-	0.70	-
Solid biomass generator	0.72	-	0.65	-
Liquid biomass generator	0.82	-	0.75	-
Steam compression heat pump with electric motor	3.00	(*)	2.50	-
Electric-powered steam compression cooler	-	2,50	-	-
Absorption heat pump	1.20	(*)	1.10	-
Indirect flame cold machine	-	0.60 x η_{gn} (**)	-	-
Direct flame-cold machine	-	0.60	-	-
Endothermic motor steam compression heat pump	1.15	1.00	1.05	-
Co-generator	0.55	-	0.55	0.25
Heating with electrical resistance	1.00	-	-	-
District heating	0.97	-	-	-
District cooling	-	0.97	-	-
Thermal solar	0.3	-	0.3	-
Solar photovoltaic	-	-	-	0.1
Mini wind and mini hydroelectric	-	-	-	(**)

NOTE: all data related to fuels refer to the lower calorific value
(*) For heat pumps that provide the cooling function, consider the same value as the refrigeration machines of the same type
(**) assumes the average efficiency of the system installed in the actual building

14.5.5 Building Global Energy Performance Index (EPgl,tot)

The building's global energy performance index $EP_{gl,tot}$ expresses the overall primary energy demand for useful surface unit, expressed in kWh/mq per year.

For nZEB buildings, the value must be less than the limit value of the global energy performance index calculated for the *reference building*, i.e. $EP_{gl,tot}$

- $EP_{gl,\text{nren}} < EP_{gl,nren,rif,standard\ (2019/21)}$
- $EP_{gl,nren,rif,standard\ (2019/21)}$ = limit value of the calculated global energy performance index for the *reference building*;

14.5.6 The use of the renewable energy produced in situ

In the case of new buildings or buildings subjected to major renovations, the consumptions for heating, cooling and DHW must be met for 50% of energy from renewable sources. According to the current legislation (Annex 3, Article 11 Section 1 of the Legislative Decree n ° 29 March 3, 2011) the renewable quota for the $Q_{HCW}FR$ building subsystems must be equal to

$$\begin{cases} Q_{HCW}FR > 50\% & \text{for residenzial buldings;} \\ Q_{HCW}FR > 55\% & \text{for public buildings;} \end{cases}$$

where

$$Q_{HCW}FR = EP_{gl,ren}/EP_{gl,tot}$$

$$EP_{gl,tot} = EP_{gl,ren} + EP_{gl,nren}$$

with

- $EP_{gl,ren}$ = Renewable global energy performance index;
- $EP_{gl,nren}$ = Non-renewable global energy performance index, as defined in 0;

In the case of historic buildings, the coverage percentages may vary depending on the intended use.

$$\begin{cases} Q_{HCW}FR > 25\% & \text{for residential buildings located in historic center;} \\ Q_{HCW}FR > 27.5\% & \text{for public buildings located in historic center;} \end{cases}$$

14.5.7 The Average Heating Plant Global Efficiency

In case of the new installation, renovation or replacement of heating thermal systems in existing buildings, the DGR Lombardy Region 2456 /2017, in Chapter 8.6 Section a, requires the calculation of average seasonal overall efficiency of the heating system and verify that it is higher than the limit value calculated using the efficiencies values provided in Exhibit B for the *reference building*.

Based on the clarifications in the MISE FAQ August 2016 No. 2.28 and 2.71, the Average Global Efficiency of the Heating Plant is defined as

$$\eta_{Gh} = Qh/QP_H$$

where

- Qh = useful thermal energy demand for heating;
- QP_H = primary energy demand for heating;

Table 14-9:indexes to describe energy efficiency performance according to nZEB requirements		
H'_t	$\frac{W}{m^2 \times K}$	average global thermal exchange coefficient per transmission per unit of disperdent surface
$\frac{A_{sol,est}}{A_{sup\,utile}}$	$[-]$	summer equivalent solar area per useful surface unit;
$EP_{H,nd}$	$\frac{kWh}{m^2}$	heating
η_h	[]	seasonal average efficiency of the winter air conditioning system;
$EP_{W,nd}$	$\frac{kWh}{m^2}$	heating performance index. It is expressed in non-renewable primary energy (index "nren") or total (index "tot") ;
EP_H	$\frac{kWh}{m^2}$	thermal performance index for the production of sanitary hot water;
η_W	$[-]$	seasonal average efficiency of the health hot water production plant;
EP_W	$\frac{kWh}{m^2}$	energy performance index for the production of sanitary hot water. It is expressed in non-renewable primary energy (index "nren") or total (index "tot");
EP_V	$\frac{kWh}{m^2}$	energy performance index for ventilation. It is expressed in non-renewable primary energy (index "nren") or total (index "tot");
$EP_{C,nd}$	$\frac{kWh}{m^2}$	thermal performance index for cooling;
η_c	[]	seasonal average efficiency of the cooling system (including possible humidity control);
EP_C	$\frac{kWh}{m^2}$	summer air conditioning performance index (including possible humidity control). It is expressed in non-renewable primary energy (index "nren") or total (index "tot");
EP_L	$\frac{kWh}{m^2}$	energy performance index for artificial lighting. This index is not calculated for category E.1, except for colleges, convents, penalty houses, barracks and category E.1(3). It is expressed in non-renewable primary energy (index "nren") or total (index "tot");
EP_T	$\frac{kWh}{m^2}$	energy performance index of the service for the transport of people and things (lifts, sidewalks and escalators). This index is not calculated for category E.1, except for colleges, convents, penalty houses, barracks and category E.1(3);
$EP_{W,nd} = = EP_H + EP_W + + EP_V + EP_C + + EP_L + EP_T$	$\frac{kWh}{m^2}$	building's overall energy performance index. It is expressed in non-renewable primary energy (index "nren") or total (index "tot").

14.6 A model for calculating renewable energy production from a photovoltaic plant

The mathematical models commercially available for the design of a photovoltaic system have now reached high levels of sophistication and accuracy. However, precisely because of this, they are characterized by a high complexity of the mathematical formulation which makes them not easy to understand and use.

The difficulty is linked to the need to take into account the geometric factors that determine the amount of solar radiation that ultimately affects the photovoltaic panel such as the location of the installation site, orientation and tilt of the panel itself as well as the shading caused by nearby obstacles. Moreover, the difficulty is inherent in calculating the amount of electricity that the technology with which the specific panel is made is able to produce by transforming the accident solar radiance.

For DSS-RRE model purposes, it was then considered necessary to develop a model that was simple to use and required a limited number of data that could be easily fulfilled by a non-expert operator. Despite these limitations, the model obtained, compared with the results calculated using commercially available professional computing software, proved sufficiently reliable, usually limiting the error at a few percent.

The energy produced by a photovoltaic system $Q_{fv,j}$ at the *j-th* month is estimated here according to the following mathematical model

$$Q_{fv,j} = R_{module} \times S_{fv} \times H_j^{(u)}; \text{[kWh]}$$

where

- R_{module} = the efficiency with which pv-module converts incident energy into electricity.
- S_{fv} = total area of photovoltaic modules $[m^2]$
- $H_j^{(u)}$ = useful irradiation on the panel floor, (net of plant losses $[\text{kWh/m}^2]$

14.6.1 The useful irradiance

The useful irradiation is the solar energy that can be used by the photovoltaic module to produce electricity. It is estimable as

$$H_j^{(u)} = R_{BOS} \times H_j^{(d)} \text{ ; [kWh/m}^2\text{]}$$

Where

- R_{bos} =efficiency that takes into account factors such as the losses of the system that converts the continuous energy DC output from the modules into AC output from the inverter, the thermal stresses of the modules, the dust on the surface of the modules, the differences in performance between the modules.
- $H_j^{(d)}$ = Irradiance available on the panel surface,$[\text{kWh/m}^2]$

Finally

$$H_j^{(d)} = K_{ombre} \times F_{\propto} \times H_j^{(o)} \text{ ; [kWh/m}^2\text{]}$$

- $\text{K}_{\text{ombre}} \in [0,1]$, factor of reduction in radiation caused by location shading
- $F_{\propto}$ = exposure factor of the photovoltaic module surface.
- $H_j^{(o)}$ = average daily solar radiation of the *j-th* month on horizontal surface, depending on its installation site;$[\text{kWh/m}^2]$

The technical standard for calculating solar radiation is the UNI 11328, which replaced (and substantially resumed) by UNI 8477. In Italy, the average solar radiation value is publicly available through the site of the Italian Solar Radiation Atlas, created as part of the sitological analysis of the Thermodynamic Solar Project, currently merged into the Renewable Energy Technical Unit of ENEA.

In the DSS-RRE model we use the normalized values 1994-1999 as

$$H_j^{(o)} = c \times n_j \times \overline{H}_j^{(o)}$$

where

$$c = \frac{\overline{H}_{anno}^{(o)}}{\sum_{j=1}^{12} \left(n_j \times \overline{H}_j^{(o)} \right)}$$

- n_j =number of days in j-th month;
- c =correction factor to make monthly values consistent with the annual value;
- $\overline{H}_j^{(o)}$ =average hourly solar irradiance at j-th month;
- $\overline{H}_{anno}^{(o)}$ =average annual solar irradiance.

14.6.2 The exposure factor

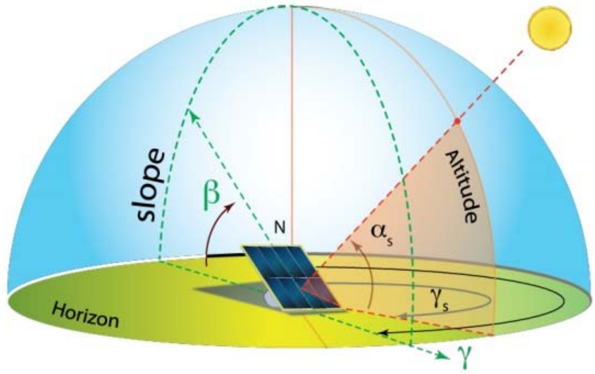
The Exposure Factor $F_{\propto}$ allows to calculate the irradiance available to the solar panel starting from the irradiance value measured on the horizontal plane.

$$F_{\propto} = F_{\propto}(\lambda, \beta, \gamma)$$

where

- λ =longitude of the site;
- β =tilt angle of the pv module surface;
- γ =azimut of the pv module surface.

Figure 14-2: representation of exposure factors



Noting on the one hand the difficulty of calculating the parameters and, on the other hand, the not excessive variability with regard to the practical applications in the Italian territory, in the DSS-RRE model the following Tabulated values of $F_{\propto}$ have been implemented for three values that are representatives of the interval of variation of longitude on Italian territory: Longitude = [36 (Ragusa), 42 (Rome), 46 (Pordenone)]

Table 14-10: implemented $F_{\propto}$ values

Azimuth	0	45	90	135	180
Orientation	**S**	**SE/SW**	**E/W**	**NE/NW**	**n**
Tilt Roof					
Plan (0th)	1.00	1.00	1.00	1.00	1.00
Little (15o)	1.09	1.06	0.98	0.90	0.86
Medium (30o)	1.12	1.08	0.94	0.78	0.70
Very (45th)	1.10	1.05	0.88	0.66	0.56
Very much (60degrees)	1.03	0.98	0.81	0.56	0.43
Almost vertical (75th)	0.91	0.87	0.71	0.49	0.34
Vertical Wall (90th)	0.74	0.73	0.61	0.42	0.31
Source: Italian Atlas of Solar Radiation managed by Enea					

14.6.3 Calculation parameter values

The efficiency with which the photovoltaic module converts incident energy into electricity can be calculated as

$$R_{modulo} = \frac{W_p}{1000 \times S_{fv,k}}$$

where

- W_p =Peak power of the module in [W]
- 1000[W/mq] is the irradiance in STC (standard Test Condition).
- $S_{fv,k}$ =the area of the single k-th photovoltaic module for which

  $S_{fv} = \sum_{k=1}^{n-pannelli} S_{fv,k}$; [mq]

In the DSS-RRE model, the efficiency that affects the available irradiance in the useful one was set equal to

$$R_{bos} = 0.70$$

That can be considered a standard value as it takes into account:

- Power loss due to deviation of real operating conditions compared to STCs. We fix this loss equal to a value of about 8 %, both in the case of a stand-alone system and in the case of a grid-connected system;
- Losses due to reflection generated by the light radiation reflected by the glass protecting the cell (therefore not absorbed) (3%);
- Losses due to mismatching or decrease in overall efficiency caused by connecting several photovoltaic modules in series with characteristics that are not perfectly identical. In this case, the MPPT maximum power point tracking circuit, not finding the optimal operating curve, positions itself on the worst module curve, penalizing the performance of the entire string (5%);
- Losses along the DC sections caused by the resistance offered by the electric cables, by the losses due to voltage drops on the blocking diodes and by the contact resistances on the circuit-breakers. These losses can be set around a value of around 1% if a correct section of the cables has been estimated in the design phase.
- Losses on the storage system (for stand-alone systems) depending on the performance of the storage and can be quantified around 10-12% (in the case of an open vessel lead-acid accumulator);
- Losses in the static conversion group varying from 4-10% in the case of grid-connected inverters and between 4-20% in the case of inverters for stand-alone applications. The greatest losses in the inverters for stand-alone applications are mostly due to the presence of the filters necessary to “round up” the waveform to the load by reducing the high harmonics. These losses also include those caused by LV transformers (if present) and LV / MV transformers in the case of plants connected to the MV network. In general, it is preferable to refer to the value of the European efficiency declared by the manufacturers, which takes into account the efficiency by carrying out a weighted average in different load conditions depending on the degree of generic use of the plant
- Losses due to dirt, debris and dust, depending on the site of installation, weather conditions and the inclination of the modules themselves. If scheduled, timely cleaning can reduce the loss within 1% point during the year;
- Annual efficiency losses caused by the deterioration of the system components estimated at around an average value of 1.5% of linear reduction per year

14.7 Energy consumption computing algorithm of a heat pump powered by photovoltaic plant

As already pointed out in Section 4.3.1, according to the PNIEC, heat pumps combined with photovoltaic plants appears to be the most compatible configuration with the distributed generation paradigm, necessary for the future development of so-called "smart-cities". Moreover it appears one of the most cost effective choice to achieve the nZEB level.

For these reasons a calculation procedure has been developed in this research thesis that allows to:

1) Take into account the different productivity of the photovoltaic system depending on the solar month.
2) Properly size the battery storage of photovoltaic production.
3) Estimate the direct contribution of the photovoltaic system to meet the demand for electricity in the hours of daytime production and the indirect one of the photovoltaic batteries at night.

With these features, the DSS-RRE simulator is able to calculate

a) the energy needs of the building and, consequently, the amount of electricity needed by the heat pump to satisfy it,
b) the energy that at the same time the photovoltaic plant produces and which by definition is renewable.

Thus, the subtraction a) from b) determines the non-renewable energy consumed by the building.

Finally, knowing the amount of total energy, and its renewable and non-renewable components, it is possible to calculate the Energy Class of the building and the eventual possibility of defining it *nZEB* .

14.7.1 The time gap between the energy production and demand

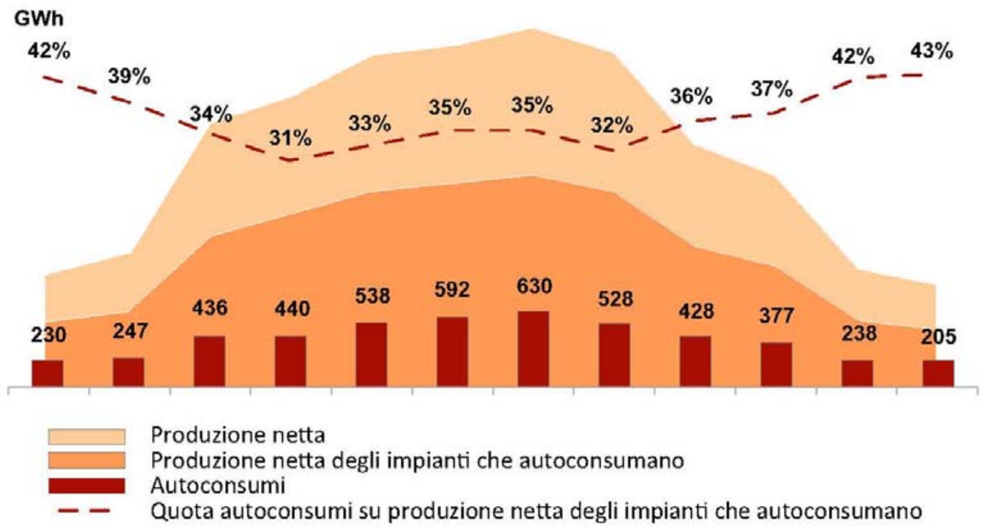
Depending on the quantity of solar irradiance, PV production obviously varies throughout the year and, even, during the course of the day, ending at night. Statistical studies (Figure 14-3 and Figure 14-4) point out that only some of the energy produced is self-consumed because of the non-contemporary demand and production; the surplus is fed into the public grid from which it is then purchased to cover night-time demand. This mechanism, referred to as "*scambio sul posto*", is in Italy managed by the GSE – Electrical Services Manager, a company owned by the Ministry of Economy and Finance. Specifically, in the residential sector, the percentage of self-consumed energy is estimated at an average of 35%.

One possibility to increase the share of self-consumption is to use batteries (the most recommended are lithium batteries) that have the function of accumulating in the daytime the energy produced in excess by photovoltaics for then return it at night.

Alternatively, you can use thermal generators that can use the instantaneous production of photovoltaic energy such as electric heat pumps, as described in Section 13.4. In this case you can cover the demand for day time air conditioning up to 70%. With the heat pumps there is the additional advantage of saving the additional cost for the purchase of batteries and their disposal at the end of their life.

This type of indication also emerges from the numerous indications given by the European directives issued from 2012 to date.

Figure 14-3: Self-consumption in Italy in 2017

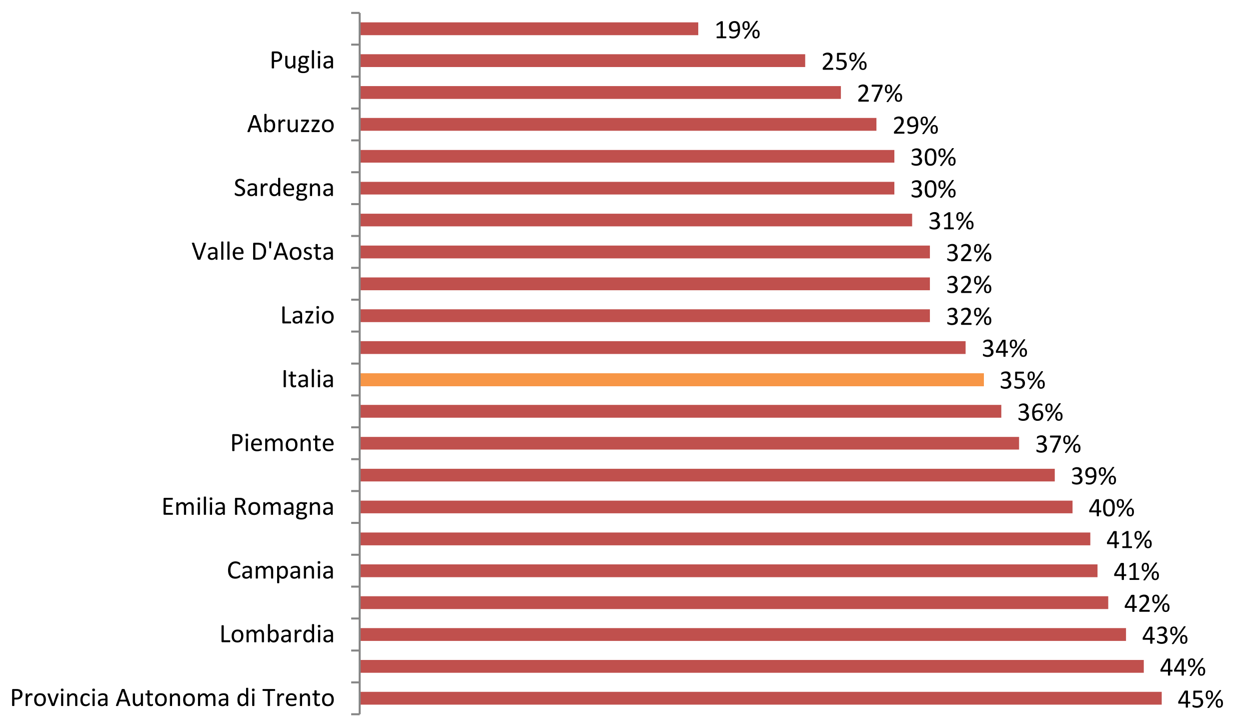


Source: Photovoltaic solar statistical report 2017, GSE – Original Figure

Power class in withdrawal	Medium plant size	Average withdrawal power	Self-consumption quota on production	Self-consumption quota on consumption
Fino a 3 kW	4.2	2.8	24%	21%
Da 3 a 20 kW	5.2	5.2	30%	33%
Da 20 a 100 kW	32	46.4	48%	25%
Da 100 a 200 kW	83.1	146.5	60%	21%
Da 200 a 950 kW	122.8	393.4	73%	12%
Maggiore di 950 kW	131.6	1969.1	87%	30%
Total	**8.5**	**13.1**	**42%**	**19%**

Sector	Medium plant size	Average withdrawal power	Self-consumption quota on production	Self-consumption quota on consumption
Agriculture	33.5	38.7	41%	24%
Residential	4.6	4.9	31%	32%
Industry	61.6	144	59%	13%
Tertiary	25.1	50.5	51%	16%
Total	**8.5**	**13.1**	**42%**	**19%**

Figure 14-4: Annual self-consumption by Italian region in 2017



Sorce: Photovoltaic solar statistical report 2017, GSE – Original Figure

14.7.2 Defining data

For the purpose, the production of the E_Generate photovoltaic system is divided as

```
E_Generata = AutoConsumo + E_Immessa
```

where

- AutoConsumo is the amount of energy generated and consumed on site
- E_Immessa is the remaining quantity not used and which is then fed into the national electricity grid.

In general

```
AutoConsumo = AutoConsumo_Diretto + AutoConsumo_InDiretto
```

where

- AutoConsumo_Diretto is the energy supplied directly from the photovoltaic system.
- Richiesta_Notturna it is the supplied energy, where available, from an accumulation battery of the energy produced and not used directly.

On the other hand, the demand for electricity from the building is satisfied as

```
Richiesta = AutoConsumo + E_Prelelevata
```

where

- E_ Prelelevata is the amount of energy that cannot be satisfied by the energy produced by the photovoltaic system (AutoConsumo) and it must be bought from the national electricity grid.

Consistent with the above, it follows that

```
E_Eccedente = MASSIMO(0,E_Immessa – E_Prelevata)

E_Scambiata = MINIMO(E_Prelevata, E_Immessa)
```

In fact, the energy required covers the whole day and therefore

```
Richiesta = Richiesta_Diurna + Richiesta_Notturna
```

where

- Richiesta_Diurna is the energy that can be directly met by the photovoltaic system.
- Richiesta_Notturna it is the remaining energy that can be satisfied, where available, by a storage battery where energy produced and not used directly has been accumulated.

In a residential building equipped with Heat Pump it is considered reasonable to suppose that the percentage of daytime energy compared to the total can be considered equal to

```
%_Richiesta_Diurna_PdC = 70%

%_Richiesta_Diurna_Altro = 50%
```

Just as it appears reasonable to suppose that there is no perfect correspondence between the energy generated and that required during the daytime period for which

```
AutoConsumo_Diretto = %AutoConsumo_Diurno x MINIMO(Richiesta_Diurna, E_Generata)
```

with

```
%AutoConsumo_Diurno = 70%
```

It follows that, in the absence of a heat pump

```
AutoConsumo_Diretto ≤ 35% E_Generata
```

while in the case the consumption was entirely attributable to the heat pump

```
AutoConsumo_Diretto ≤ 49% E_Generata
```

which are percentage values in line with statistical observations.

14.7.3 Calculation model

Based on the above definitions, the procedure for calculating the relative values starting from the following data

```
E_Generata, Richiesta_Totale_PdC, Richiesta_Totale_Altro, Capacita_Batteria
```

is structured as follows

```
Richiesta_Totale = Richiesta_Totale_PdC + Richiesta_Totale_Altro
Richiesta_Diurna = %_Richiesta_Diurna_PdC x Richiesta_Totale_PdC
 + %_Richiesta_Diurna_Altro x Richiesta_Totale_Altro
Richiesta_Notturna = Richiesta_Totale - Richiesta_Diurna
Richiesta_Diretto = %AutoConsumo x MINIMO(Richiesta_Diurna, E_Generata)
E_Inutilizzata = E_Generata - AutoConsumo_Diretto
```

- System equipped with a storage battery

```
E_Immagazzinata = MINIMO(Capacita_Batteria, E_Inutilizzata)
```

- System not equipped with a storage battery

```
E_Immagazzinata = 0
```

```
E_Inutilizzata = E_Inutilizzata - E_Immagazzinata
Richiesta_Insoddisfatta = (Richiesta_Diurna - Autoconsumo_Diretto) + Richiesta_Notturna
AutoConsumo_InDiretto = MINIMO(E_Immagazzinata, Richiesta_Insoddisfatta)
AutoConsumo = AutoConsumo_Diretto + AutoConsumo_InDiretto
E_Immessa = E_Generata – AutoConsumo
E_Prelevata = MASSIMO(0, Richiesta – AutoConsumo)
E_Eccedente = MASSIMO(0,E_Immessa – E_Prelevata)
E_Scambiata = MINIMO(E_Prelevata, E_Immessa)
```

15 The validation of the DSS-RRE model

15.1 Introduction

The goal of this Chapter is to demonstrate the reliability in the calculations and usefulness of the DSS-RRE model. To do this, Sections 15.2 ÷ 15.3 analyze a simple reference case study to assess the accuracy of the method. Then, Section 15.4 ÷ 15.6 examine the very complex case of the historic building in Figure 15-1, already considered in Section 5.4 with the aim of highlighting the practical usefulness of the analysis produced by the DSS-RRE platform that has been developed.

The DSS-RRE model contains 2 types of approximation: a) the geometric representation of the building; b) the calculation of the heat demand/energy consumption. In order to verify the reliability of the calculations, the results of the DSS-RRE model have been compared with those produced by the commercial software TerMus V. 52 (updated 2019), which has the ministry certification to correctly calculate the thermal needs of buildings according to the UNI ISO 11300 standard as implemented by Italian law.

It is important to highlight that TerMus software implements the standard UNI TS 11300 calculation procedure based on a monthly time discretization, thus being able to take into account only the average monthly temperature. The DSS-RRE model adopts the same UNI TS 11300 analytic formulation but with the following differences:

1. the Thermal Energy Demand of the building is calculated with the simplifications summarized in Section 12.13;
2. the Energy Consumption of the climate generator is calculated using the BIN hourly method describe in Chapter 0.

Thus the verification work start in Section 15.2 with the description of the hypotheses and the mathematical relationships on which the geometric model is based and, subsequently, Section 15.3 shows that, in the reference case, the error committed on the annual values is contained at 1%, all due to the simplifications made in calculating the Thermal Energy Demand. This demonstrates first of all that the DSS-RRE correctly implements the UNI ISO 11300 and the Bin Hourly Method in the terms reported in the previous Chapters 12 and 0.

It has been mentioned several times that one of the advantages of the DSS-RRE model is that it requires very little data to describe even complex projects. As an example, Figure 15-2 shows the input screenshot of the all the data necessary to describe the "*as- is*" state of the historical building shown in Figure 15-1.

The comparative analysis with TerMus, reported in Section 15.4, shows that the difference in the annual Thermal Energy Demand calculated values between the two software is always contained within 7% and the difference is for the most part due to the particular geometric complexity of the building.

It is believed that this s completely acceptable for the purposes of the DSS, especially considering that to obtain the correct results with TerMus it took about 5 work-days of a specialized technician while those with the DSS-RRE simulator a few minutes of a person without any particular knowledge of civil engineering. Furthermore, as illustrated in Section 15.5, the results provided by the DSS-RRE simulator are not limited to those strictly technical engineering, but they deliver also an analysis of the costs and the profitability of the investment.

To demonstrate this remarkable opportunity 3 distinct analyzes are herein presented:

1) Sections 15.4 and 15.5, examine the case of a renovation intervention aimed at reaching the same standard as the so-called *Reference building* (see Section 14.3).
2) Section 15.6 extends the renovation intervention to reach the nZEB qualification using 2 alternative financial strategy:
    a) Financial aid limited to the Ecobonus incentive
    b) In addition to the Ecobonus incentive, recourse to Tax credit transfer, ten-year loan to finance the residual cost with the activation of the Sabatini law to reduce the cost of bank interest.

It should be noted that this later analysis is made possible by the algorithm presented in Sections 14.6 and 14.7, which allows to evaluate the Energy Consumption required by an Electric Heat Pump taking into account the energy produced by a photovoltaic system.

Figure 15-1: The reference case for RRE real application: the Town-Hall

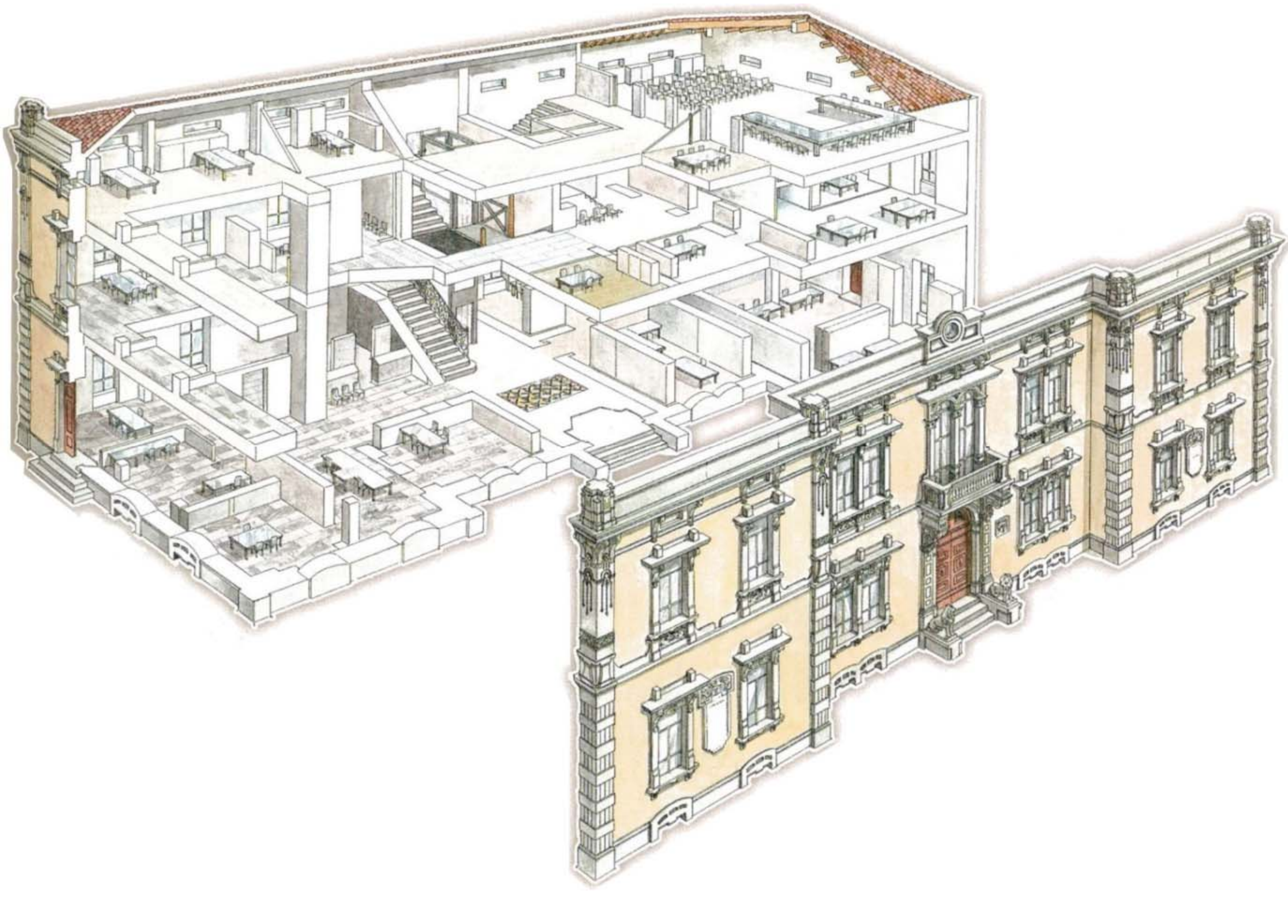
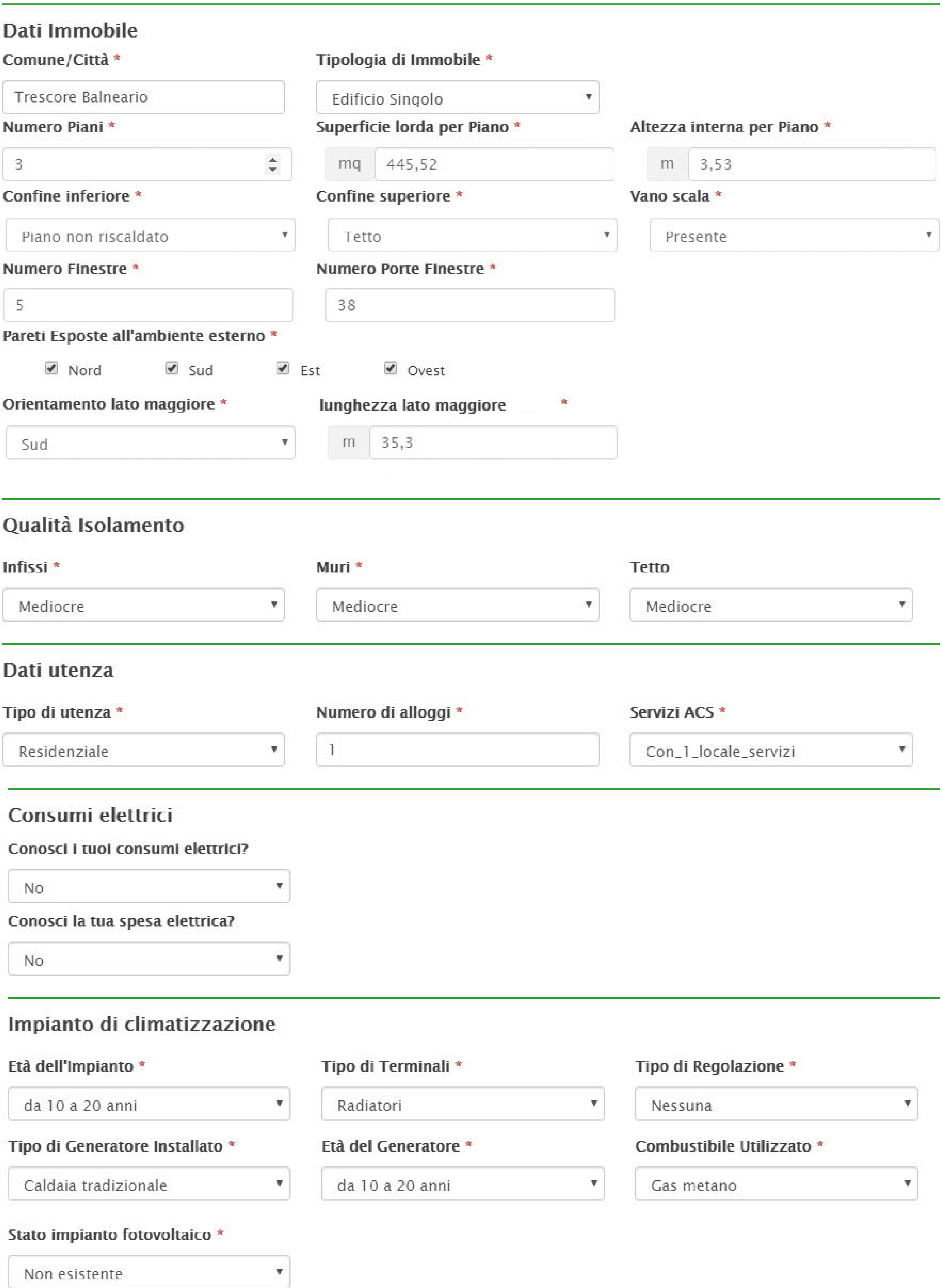


Figure 15-2. Screenshot of RRE input data # 1 – geometric data: Town-Hall case



Dati Immobile

Comune/Città * : Trescore Balneario

Tipologia di Immobile * : Edificio Singolo

Numero Piani * : 3

Superficie lorda per Piano * : mq 445,52

Altezza interna per Piano * : m 3,53

Confine inferiore * : Piano non riscaldato

Confine superiore * : Tetto

Vano scala * : Presente

Numero Finestre * : 5

Numero Porte Finestre * : 38

Pareti Esposte all'ambiente esterno *

- [x] Nord
- [x] Sud
- [x] Est
- [x] Ovest

Orientamento lato maggiore * : Sud

lunghezza lato maggiore * : m 35,3

Qualità Isolamento

Infissi * : Mediocre

Muri * : Mediocre

Tetto : Mediocre

Dati utenza

Tipo di utenza * : Residenziale

Numero di alloggi * : 1

Servizi ACS * : Con_1_locale_servizi

Consumi elettrici

Conosci i tuoi consumi elettrici? : No

Conosci la tua spesa elettrica? : No

Impianto di climatizzazione

Età dell'Impianto * : da 10 a 20 anni

Tipo di Terminali * : Radiatori

Tipo di Regolazione * : Nessuna

Tipo di Generatore Installato * : Caldaia tradizionale

Età del Generatore * : da 10 a 20 anni

Combustibile Utilizzato * : Gas metano

Stato impianto fotovoltaico * : Non esistente

Table 15-1 Alternative selections for RRE input data # 1					
Tipologia di immobile	**Impianto di climatizzazione**				**Tipo di utenza**
	Età impianto	**Tipo di generatore**	**Tipo di emissione**	**Tipo di regolazione**	
Edificio singolo	da 0 a 5 anni			Ambiente	Residenziale
Appartamento Piano Terra	da 5 a 10 anni			Zona	Palestre, Caserme
Appartamento intermedio	da 10 a 20 anni				Alberghi, uffici
Attico					Cliniche, Ospedali
Qualità isolamento	**Fascia climatica:**	**Muro [W/mq*K]**	**Solaio [W/mq*K]**	**Tetto [W/mq*K]**	**Finestra [W/mq*K]**
Mediocre		0.925	1.427	1.46	5.8
Standard		0.671	0.854	0.89	3.7
Ottimale	A	0.4	0.42	0.32	3
	B	0.4	0.42	0.32	3
	C	0.36	0.38	0.32	2
	D	0.32	0.32	0.26	1.8
	E	0.26	0.26	0.22	1.4
	F	0.24	0.24	0.2	1
I valori numerici utilizzati nei calcoli conseguenti alle diverse scelte sopra elencate sono riportate nei Capitoli 11 e 12					

15.2 Geometric model data

The DSS-RRE model is interested in determining the Energy Demand of the whole building and not of the individual spaces that make up it. Therefore, the geometric description is limited only to the **building envelope** that is perimeter surfaces that define the heated environment pf the building. We recall that by definition the building envelope is the physical separator between the conditioned and unconditioned environment of a building including the resistance to air, water, heat, light, and noise transfer. Therefore, the building envelope is all of the elements of the outer shell that maintain a dry, heated, or cooled indoor environment and facilitate its climate control.

To simplify as much as possible the geometry input data, DSS-RRE model refers to straight rectangular prism of the type shown in Figure 15-3. In the more general case, the DSS-RRE simulator can analyze a Single Building consisting of n_{floors} floors, with the first floor against the ground, and the upper one having the ceiling directly to the outside. It follows, as special case, the possibility of narrowing the analysis to one of the floors that make up the building or even to one of the real estate units in which the floor is divided.

The screenshot of the RRE input data shown in Figure 15-4 highlights that the geometric data needed to describe the building to be analyzed is limited to:

1. Number of floors.
2. Gross area by floor.
3. Height per floor.
4. Number of windows and door-windows.
5. Walls exposed to the outdoor environment.
6. Orientation and length longer side.

The gross area $S_{piano,lordo}$ of the single floor is the total surface of floor, including the perimeter wall. The living space, net of the thickness of the walls and unused spaces (and therefore not heated), comes as

$$S_{piano,netto} = S_{piano,lordo} \times 0.8$$

Then, by knowing the dimension of the longer side of the building floor l_{max}, the shorter one l_{min} can be calculated as

$$l_{min} = S_{piano,lordo}/l_{max}$$

The building can contain an arbitrary number of glazed fixtures, distinct in windows and door-windows, which are distributed on the external walls proportionally to the length of the walls. Moreover the building may contain a stairwell, that is a square unheated space located inside the building floor, as shown in Table 15-2.

The model is supplemented with the following assumptions:

- All the elements of the same type (walls, glasses, floors and roof) that make up the outer envelope have the same thermo-technical properties.
- There are no thermal losses to properties and/or unheated environments.
- Windows have a standard size $\hat{S}_{finestre} = 0.9 \times 1.5 = 1.35\, m^2$
- Door-Windows are standard in size $\hat{S}_{porte} = 1.5 \times 2.1 = 3.15\, m^2$
- Length of stairwell walls $l_{scala} = 4.5\, m$

Thus, all other geometric measures necessary for calculations can be obtained as follows:

15.3 The accuracy of the DSS-RRE model

Table 15-3 and in Figure 15-6 report the result of the study carried out to verify the accuracy of the DSS-RRE model in the calculation of the Annual Energy Demand. For this purpose, the example shown Figure 15-3 was tested comparing the results obtained by RRE against those obtained by the certified software TerMus V.52.

This result show that in case the shape of the building can be approximated to a straight rectangular prism, REE is able to evaluate the Energy Demand according to UNI TS 13100 with high accuracy.

As for the extra thermal flow for infrared radiation to the celestial vault, the error is due to the approximation in Sections 12.6 and 12.6.1 so because

$$T_{sky} = 18.0 - 51.6 \times e^{-p_{v,e}/1000} \cong 11. [°K]$$

$$\tilde{h}_i = \varepsilon\sigma \frac{(T_{air}+273)^4 - (T_{sky}+273)^4}{(T_{air} - T_{sky})} = \begin{cases} 4.5; & \text{for opaque materials} \\ 4.185; & \text{for glasses} \end{cases} \quad ; \left[\frac{\mathrm{W}}{\mathrm{m^2\ °K}}\right]$$

which avoids the laborious calculation of T_{sky} due to the presence of the term $p_{v,e}$. However the error in the extra thermal flow is completely insignificant in the overall calculation of total heat loss.

The small error on the heat demand only depends on the Utilization Factor that in DS-RRE is assumed, according to Annex 2 of DM 26-09-2009, equal to the constant value, Section 12.10,

$$\eta_{H,gn} = 0.95$$

whereas the monthly values calculated by TerMus give a seasonal value of 0.96.

Figure 15-5 reports the monthly distribution of the Energy Demand which shows, as expected, that the values calculated by DSS-REE differ from that calculated by TerMus, although the annual values (i.e. the sum of all monthly values) are nearly equal. Consequently the Energy Consumption of the Generator calculated from DSS-RRE will differ from that of the UNI TS 11300 for 2 distinct reasons:

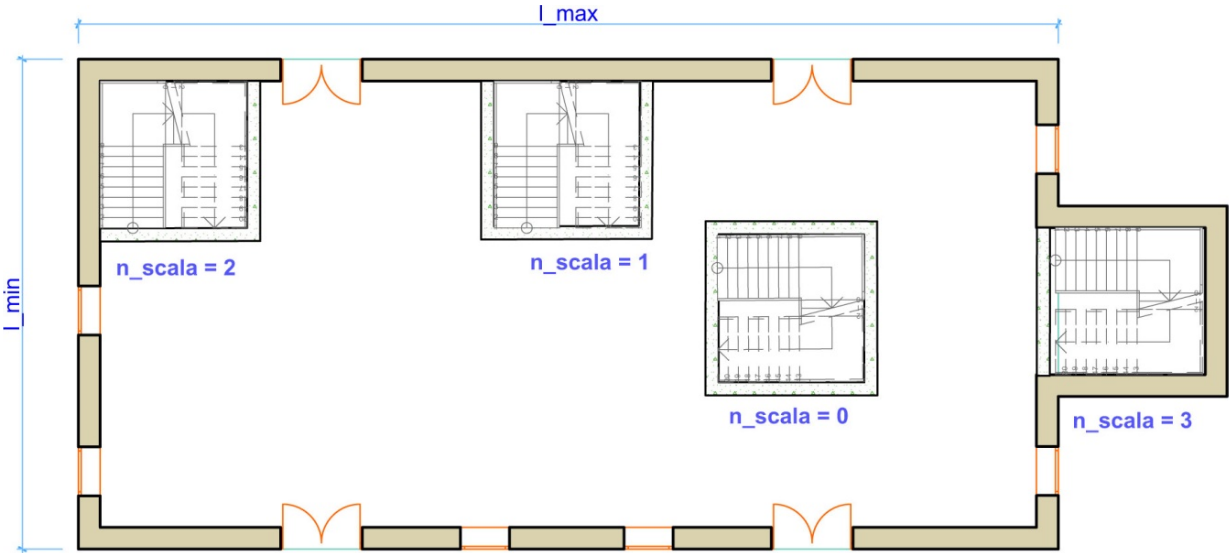
- The different evaluation of the monthly energy demand reported in Section 12.11.
- The UNI TS formulation of the energy demand which, being based on the monthly average outdoor temperature $\overline{T}_{a,j}$, is unable to integrate the efficiency factor η_{gn} of the generator which, having a mathematical formulation of the type, Section 13.1,

  $$\eta_{gn} = \eta_{gn}(P_n, T_a, T_p)$$

  strongly depend on the instant temperature T_a

In this regard, we mention that an analytical formulation of Energy Demand has been developed which allows to evaluate the same monthly values of UNI TS 13100 keeping intact the hourly bin method presented in Chapter 0. At present, however, the numerical implementation in the DSS-RRE is not yet complete.

Table 15-2: Geometric relationships in the RRE geometrical building model



INPUT	CALCULATED	
$S_{piano,lordo}$	$S_{finestre} = n_{finestre} \times \hat{S}_{finestre}$	$l_{min} = S_{floor.gross}/l_{max}$
l_{max}	$S_{porte} = n_{porte} \times \hat{S}_{porte}$	$S_{edif,max} = l_{max} \times h_{edif}$
n_{piani}	$S_{pavim,scala} = l_{scala} \times l_{scala}$	$S_{edif,min} = l_{min} \times h_{edif}$
h_{piano}	$S_{piano,netto} = S_{piano,lordo} \times 0.8 - S_{pavim,scala}$	$S_{edif} = n_{pareti,max} \times S_{edif,max}$
$n_{finestre}$	$S_{pavim.netto} = n_{piani} \times S_{piano.netto}$	$+ n_{pareti,min} \times S_{edif,min}$
n_{porte}	$h_{piano.tot} = h_{piano} + 0.3$	$S_{muri} = S_{edif} - S_{finestre} - S_{porte}$
$n_{pareti,min} \leq 2$	$h_{edif} = n_{piani} \times h_{piano.tot} + 0.3$	$S_{muro.lato} = S_{muri}/n_{pareti}$
$n_{pareti,max} \leq 2$	$S_{muri,scala} = n_{scala} \times l_{scala} \times n_{piani} \times h_{piano.tot}$	$V_{edif} = S_{pavim.lorda} \times h_{edif}$
$n_{scala} \leq 3$		

Figure 15-3: Geometry of the Test Building

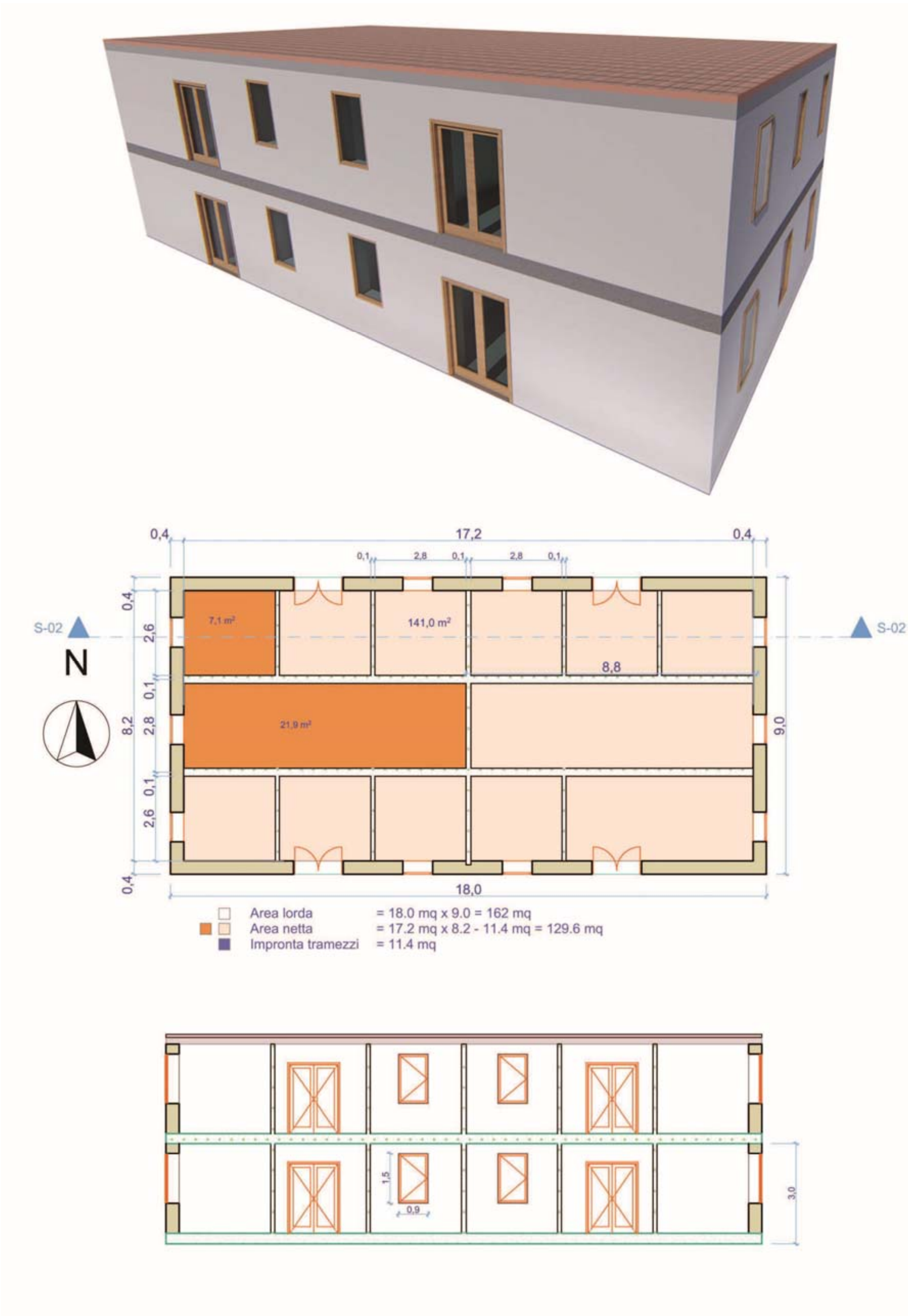
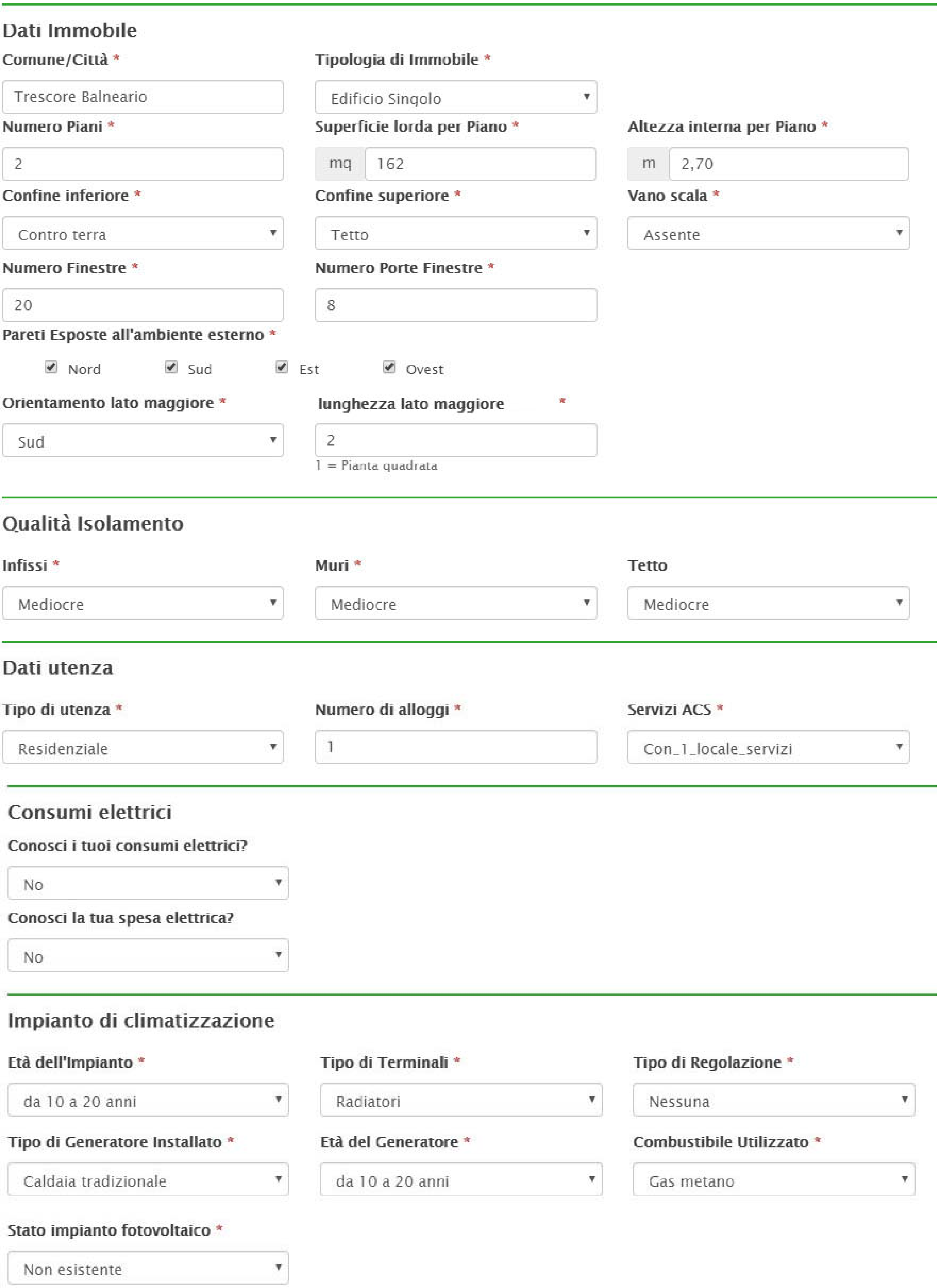


Figure 15-4. Screenshot of the RRE of the Test Building input data



Dati Immobile

Comune/Città * : Trescore Balneario

Tipologia di Immobile * : Edificio Singolo

Numero Piani * : 2

Superficie lorda per Piano * : mq 162

Altezza interna per Piano * : m 2,70

Confine inferiore * : Contro terra

Confine superiore * : Tetto

Vano scala * : Assente

Numero Finestre * : 20

Numero Porte Finestre * : 8

Pareti Esposte all'ambiente esterno *

☑ Nord ☑ Sud ☑ Est ☑ Ovest

Orientamento lato maggiore * : Sud

lunghezza lato maggiore * : 2

1 = Pianta quadrata

Qualità Isolamento

Infissi * : Mediocre

Muri * : Mediocre

Tetto : Mediocre

Dati utenza

Tipo di utenza * : Residenziale

Numero di alloggi * : 1

Servizi ACS * : Con_1_locale_servizi

Consumi elettrici

Conosci i tuoi consumi elettrici? : No

Conosci la tua spesa elettrica? : No

Impianto di climatizzazione

Età dell'Impianto * : da 10 a 20 anni

Tipo di Terminali * : Radiatori

Tipo di Regolazione * : Nessuna

Tipo di Generatore Installato * : Caldaia tradizionale

Età del Generatore * : da 10 a 20 anni

Combustibile Utilizzato * : Gas metano

Stato impianto fotovoltaico * : Non esistente

Table 15-3: DSS-RRE model Accuracy Assessment: Test Building - Numeric values

		UM	TerMus		DSS-RRE		
			Value	% Total	Value	Relative error	Absolute error
			Val_1	I_1	Val_2	Err_1	Err_2
A= A1 + ... + A4	Transmission heat loss	kWh	55'089	93%	55'066	0%	0%
A1	*Fixtures*	*kWh*	*18'325*	*31%*	*18'327*	*0%*	*0%*
A2	*Floor against the ground*	*kWh*	*6'297*	*11%*	*6'297*	*0%*	*0%*
A3	*Roof*	*kWh*	*14'328*	*24%*	*14'317*	*0%*	*0%*
A4	*Walls*	*kWh*	*16'138*	*27%*	*16'125*	*0%*	*0%*
B	Ventilation heat loss	kWh	4'236	7%	4'236	0%	0%
C = *C1 + ... + C3*	Extra-flow Celestial Vault	kWh	4'200	7%	4'439	6%	0%
C1	*Fixtures*	*kWh*	*1'158*	*2%*	*1'158*	*0%*	*0%*
C2	*Roof*	*kWh*	*1'946*	*3%*	*2'055*	*6%*	*0%*
C3	*Walls*	*kWh*	*1'096*	*2%*	*1'221*	*11%*	*0%*
D = D1 + D2	Solar heat gain opaque surfaces	kWh	4'067	7%	4'132	2%	0%
D1	*Roof*	*kWh*	*2'124*	*4%*	*2'176*	*2%*	*0%*
D2	*Walls*	*kWh*	*1'942*	*3%*	*1'956*	*1%*	*0%*
E = A + B + C -D	**Total loss**	**kWh**	**59'458**	**100%**	**59'609**	**0%**	**0%**
F	Internal gains	kWh	1'976	16%	1'976	0%	0%
G	Solar heat gain glazed surfaces	kWh	10'195	84%	10'237	0%	0%
H = F + G	**Total gains**	**kWh**	**12'171**	**100%**	**12'213**	**0%**	**0%**
I	**Thermal demand**	**kWh**	**47470.1**	**100%**	**48'005**	**1%**	**1%**
L = (E - I) / H			0.98		0.95		0%
Total loss rate		I_1 = A / E; B / E; C / E; D / E; E / E;					
Total gain rate		I_1 = F / H; G / H; H / H;					
Error on the single term value		Err_1 = (Val_1 - Val_2) / Val_1					
Error on the total value		Err_2 = I_1 x Err_1					

Figure 15-5: DSS-RRE model Accuracy Assessment: Test Building – monthly values

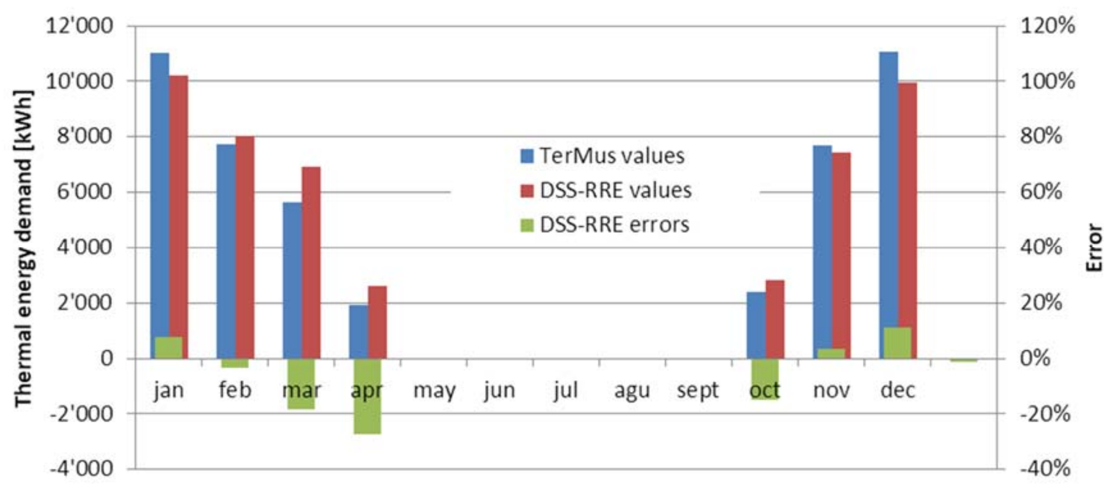
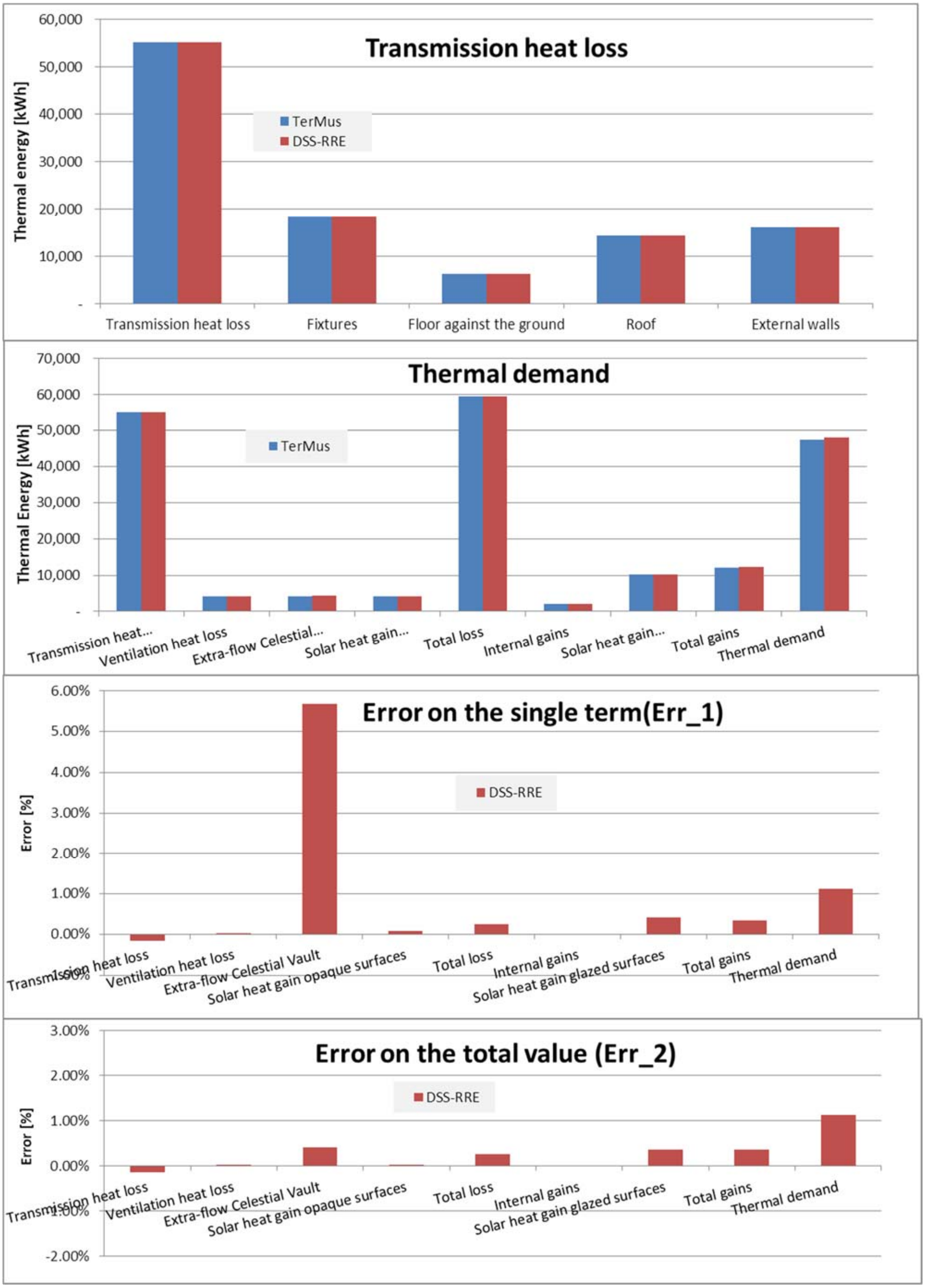


Figure 15-6: DSS-RRE model Accuracy Assessment: Test Building – Annual values



15.4 Applying the DSS-RRE model to a complex case

Figure 15-7 shows the 3D CAD representation of the historic building in Figure 15-1, which we will refer as Town-Hall, on which it is intended to demonstrate the usefulness of the DSS-RRE model even in complex cases.

From the plan and section shown in Figure 15-7 we note that the most complex elements for the DSS-RRE model are obviously:

- The irregular layout.
- The presence of vast unheated spaces such as the stairwell and the cellar floor.
- The pitched roof.
- Variable floor height.
- Large window frames.

The study has contemplated 2 distinct analyzes:

A. The thermal demand calculation through the TerMus code of the Real Building.

B. The thermal demand calculation using the DSS-RRE model where the few input data are shown in the screenshot shown in Figure 15-2, Figure 15-9 and Figure 15-10.

It is necessary to point out that in order to perform the calculation correctly with TerMus it was necessary first of all to build the CAD model of the entire building on the basis of which it was possible to create the geometric data in the form and completeness required by the successive numerical analyses. In particular, for each of the elements of the building envelope, it was necessary to define, with the required precision, the thicknesses and the thermo-technical characteristics of the layers composing it.

Then the geometric data has been exported in IFC format through the BIN platform to TerMus. Finally it was necessary to select, among the many model options present in the software (in the order of hundreds as envisaged by current regulation), those that best represent the building and the type of use that is made.

Despite the remarkable level of the graphic interface provided by TerMus, the complete analysis (including the computation of the investment and the operational costs) took about 5 workdays of a specialized technician. It goes without saying that to provide the data required by the DSS-RRE model and illustrated in Figure 15-2 it only took a few minutes of a person without any particular knowledge of civil engineering.

The interesting thing is that the time taken to obtain a correct analysis from TerMus can been considerably reduced using the results of the DSS-RRE simulator as a guide line. In fact, the simplicity of the RRE data structure almost eliminates the possibility of error while the complexity of the procedure involved in the BIN analysis inevitably leads to errors in the input data whose identification is not always fast or even obvious.

Going into the merits of the results, Table 15-4 reports the numerical values calculated while Figure 15-8 shows their graphical representation. Firstly, these results confirm the small errors in evaluating the “Extra thermal flow for infrared radiation to the celestial vault” and on the “Utilization Factor” already discussed in Section 15.3. This is due to the simplifications made in the analytical relationships of the complete quasi-stationary model which, however, are totally negligible in the global term.

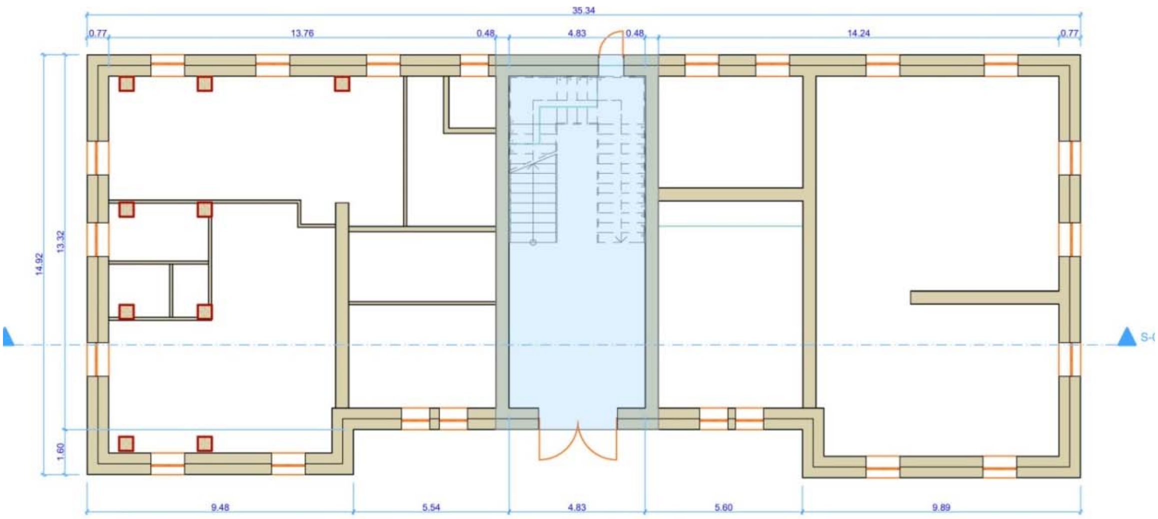
In this case, however, an additional error is noted regarding the evaluation of the “Transmission heat loss” deriving, above all, from an underestimation of the terms "Floor against the ground" and "External walls". Both are easily explained by the architectural peculiarities present in the building that the geometric model implemented in DSS-REE cannot fully grasp.

In fact, as regards the "Floor against the ground" term, in the real building the ground floor partly borders on the cellar and partly on the crawl cavity. The DSS-RRE model does not provide this double option; thus it has been assumed that the whole floor confined with an unheated space (the cellar) which, having a lower thermal differential than that of the crawl cavity, the heat flow results lower.

As for the "External walls" term, we have to pointed out that, actually, this term is made by the sum of two distinct contribution: heat transmission through the external wall of the build and that internal of the stairwell. In this example, the real building has a stairwell dimension much more important than the one implemented in RRE which instead has a conventional dimensions. Consequently, RRE calculates a wall area of the stairwell smaller than the real one and, therefore, also the heat transmission through these walls is less than that calculated by TerMus.

However, despite the complexity of the building, the overall error is still limited to around 7%.

Figure 15-7 Town-Hall: CAD representation used in the BIN analysis



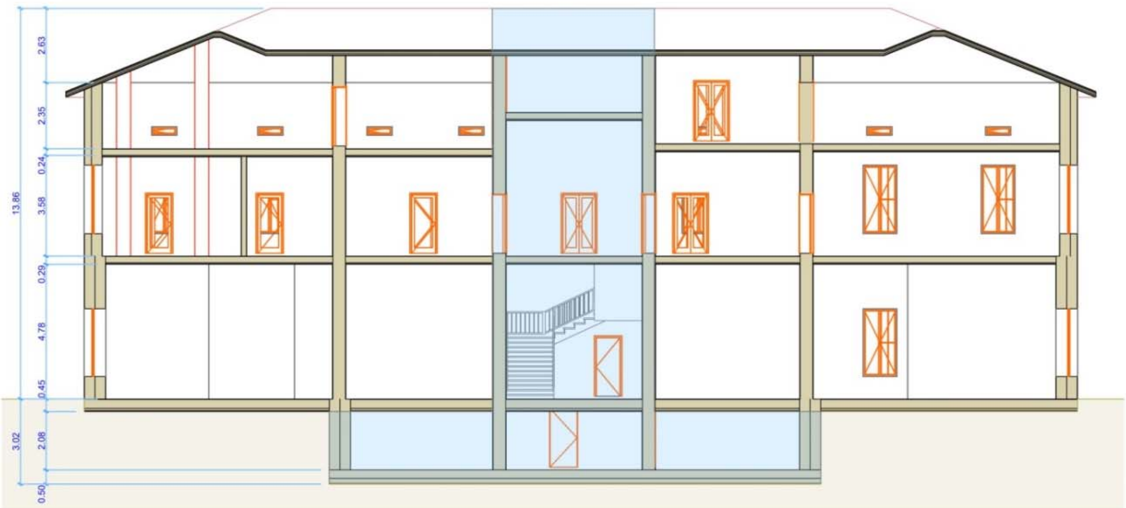
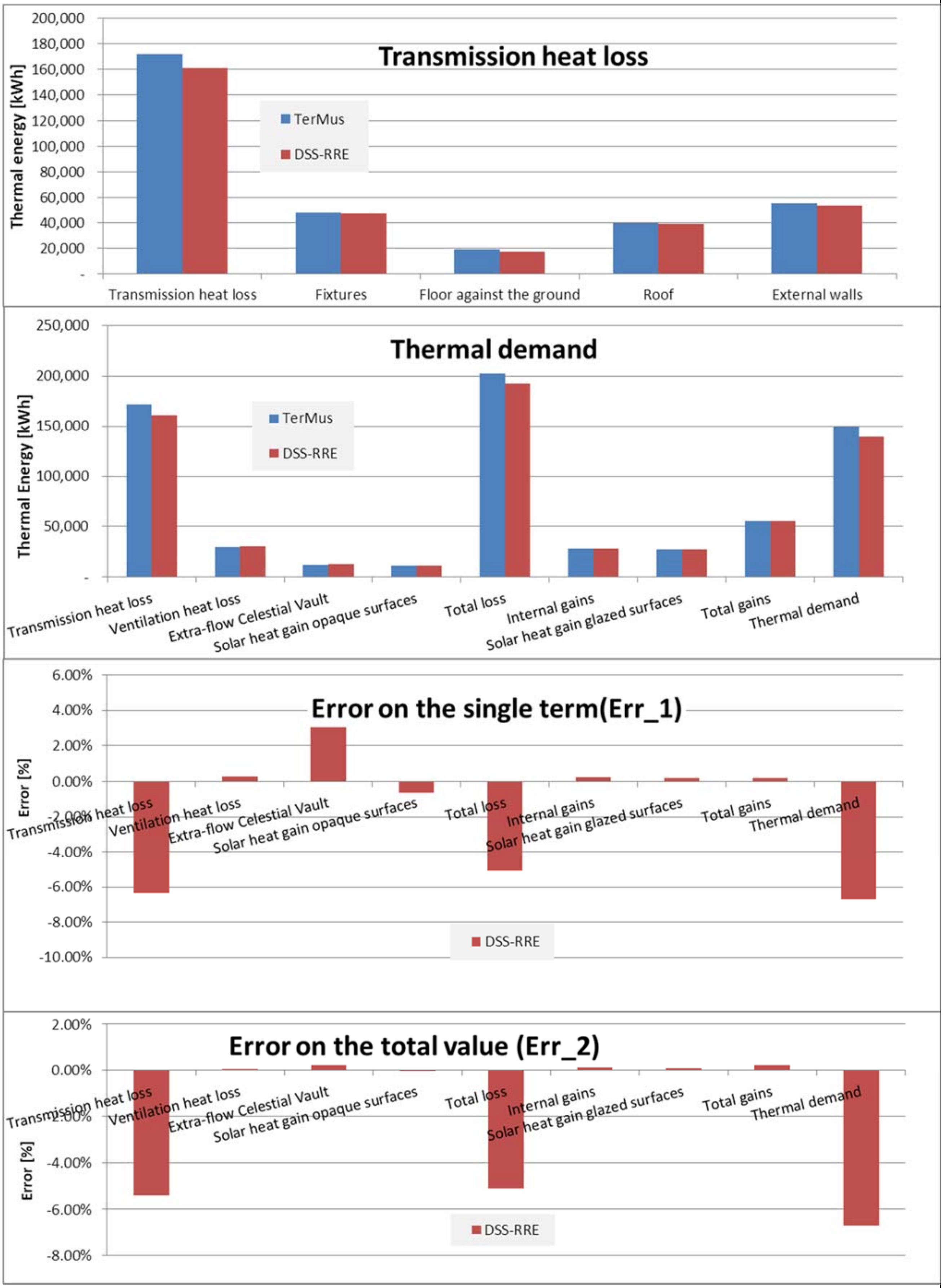


Table 15-4 Town-Hall: Heat demand – Numeric results

		UM	TerMus		DSS-RRE		
			Values	% Total	Values	Relative error	Absolute error
			Val_1	I_1	Val_2	Err_1	Err_2
A= A1 + … + A5	Transmission heat loss	kWh	171'940	85%	161'022	-6%	-5%
A1	*Fixtures*	*kWh*	*47'973*	*24%*	*47'712*	*-1%*	*0%*
A2	*Floor against the ground*	*kWh*	*19'279*	*10%*	*17'297*	*-10%*	*-1%*
A3	*Roof*	*kWh*	*39'867*	*20%*	*39'327*	*-1%*	*0%*
A4	*External walls*	*kWh*	*55'231*	*27%*	*53'516*	*-3%*	*-1%*
A5	*Internal stair walls*		*9'589*	*5%*	*3'169*	*0%*	*0%*
B	Ventilation heat loss	kWh	30'338	15%	30'428	0%	0%
C	Extra-flow Celestial Vault	kWh	12'252	6%	12'681	4%	0%
D = D1 + D2	Solar heat gain opaque surfaces	kWh	11'689	6%	11'613	-1%	0%
D1	*Roof*	*kWh*	*5'837*	*3%*	*5'846*	*0%*	*0%*
D2	*Walls*	*kWh*	*5'851*	*3%*	*5'767*	*-1%*	*0%*
E = A + B + C -D	**Total loss**	**kWh**	**202'842**	**100%**	**192'518**	**-5%**	**-5%**
F	Internal gains	kWh	28'081	50%	28'144	0%	0%
G	Solar heat gain glazed surfaces	kWh	27'560	50%	27'618	0%	0%
H = F + G	**Total gains**	**kWh**	**55'641**	**100%**	**55'762**	**0%**	**0%**
I	**Thermal demand**	**kWh**	**149'542**	**100%**	**139'500**	**-7%**	**-7%**
L = (E - I) / H			0.96		0.95	-1%	0%
Total loss rate		I_1 = A / E; B / E; C / E; D / E; E / E;					
Total gain rate		I_1 = F / H; G / H; H / H;					
Error on the single term value		Err_1 = (Val_1 - Val_2) / Val_1					
Error on the total value		Err_2 = I_1 x Err_1					

Figure 15-8: Town-Hall: Heat demand – graphs



15.5 The DSS-RRE tools to asses renovation interventions

For a complete analysis of a renovation intervention, the DSS-RRE simulator requires the compilation of 3 distinct data sheets. With reference to the case here analyzed of the Town Hall, they are represented as follows:

1. Geometric data sheet in Figure 15-2, widely described in the previous Sections.
2. Data sheet for improvements in Figure 15-9.
3. Economic-financial data sheet in Figure 15-10.

With reference to Figure 15-9, the selection of a type of intervention means that the DSS-RRE simulator redefines the thermo-technical characteristics of the selected element bringing them to the required quality for the so-called *Reference building*, see Section 14.3.

It follows that by performing the selection indicated in Figure 15-9- A, the quality of the entire building is increased to that of the *Reference building* and, therefore, brought to Class A1. A higher class can be obtained by selecting, as shown in Figure 15-10- B, the electric heat pump and placing it side by side with a suitable photovoltaic system.

Once the calculation of the heat demand and the relative energy consumption has been completed, the simulator determines the cost of the intervention on the low of the quantities calculated for each type of intervention multiplied by the unit cost, as provided for by the D.M. 16 February 2016 as regards the so-called "Thermal Account".

Finally, based on the requests made in the 3rd sheet, the simulator completes its work by performing economic financial analyzes of interest.

Once the calculation is completed, the simulator produces on the video a summary report of the analysis carried out consisting of the following 3 sections:

- Figure 15-11. Building data
- Figure 15-12. Cost and profitability
- Figure 15-13. Comparison between energy consumptions and operating costs.

From this summary it is possible to access the detailed results shown in Figure 15-14 ÷ Figure 15-19, which allow to view and compare all relevant technical and economic data in the status ex-ante (as-is) against ex-post (after the renovation work). In particular, the aforesaid figures report:

- Figure 15-14. Results in detail: Status quo
- Figure 15-15. Results in detail: The benefits of the energy efficiency intervention
- Figure 15-16. Results in detail: Climate system operating data
- Figure 15-17. Results in detail: Heating data analysis
- Figure 15-18. Results in detail: Cooling data analysis
- Figure 15-19. Results in detail: Finance

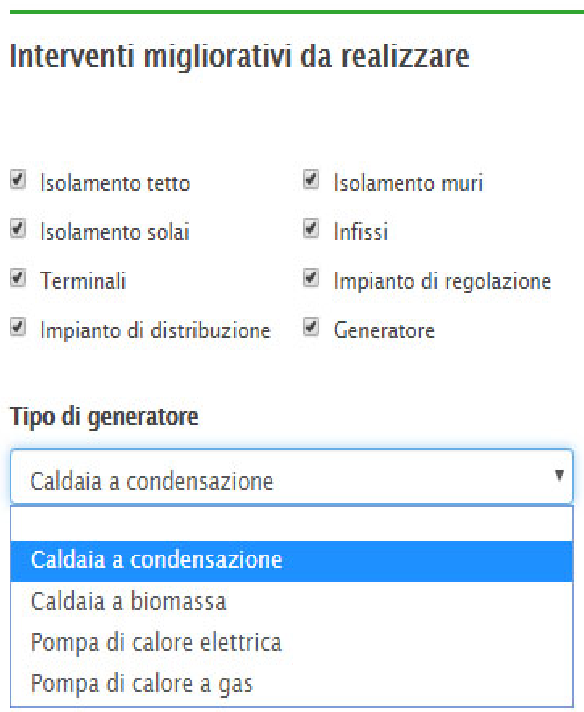
The relative simplicity of the IT structure, with the possibility of easy interfacing with the Database, offers the possibility of implementing analysis procedures, even original ones, without any particular problems, which may help the full understanding of the problem examined. For example, Figure 15-15 shows:

a. The composition of the individual cost items that contribute to determining the final cost of the energy such as the new cost in the bill, the tax deductions and the fee of the loan taken to finance the energy upgrading.
b. The cash flow generated by the redevelopment taking into account the savings in the cost of the operation, the tax deduction and the fee of the loan taken to finance the investment. This view also includes identifying the return time of the investment.

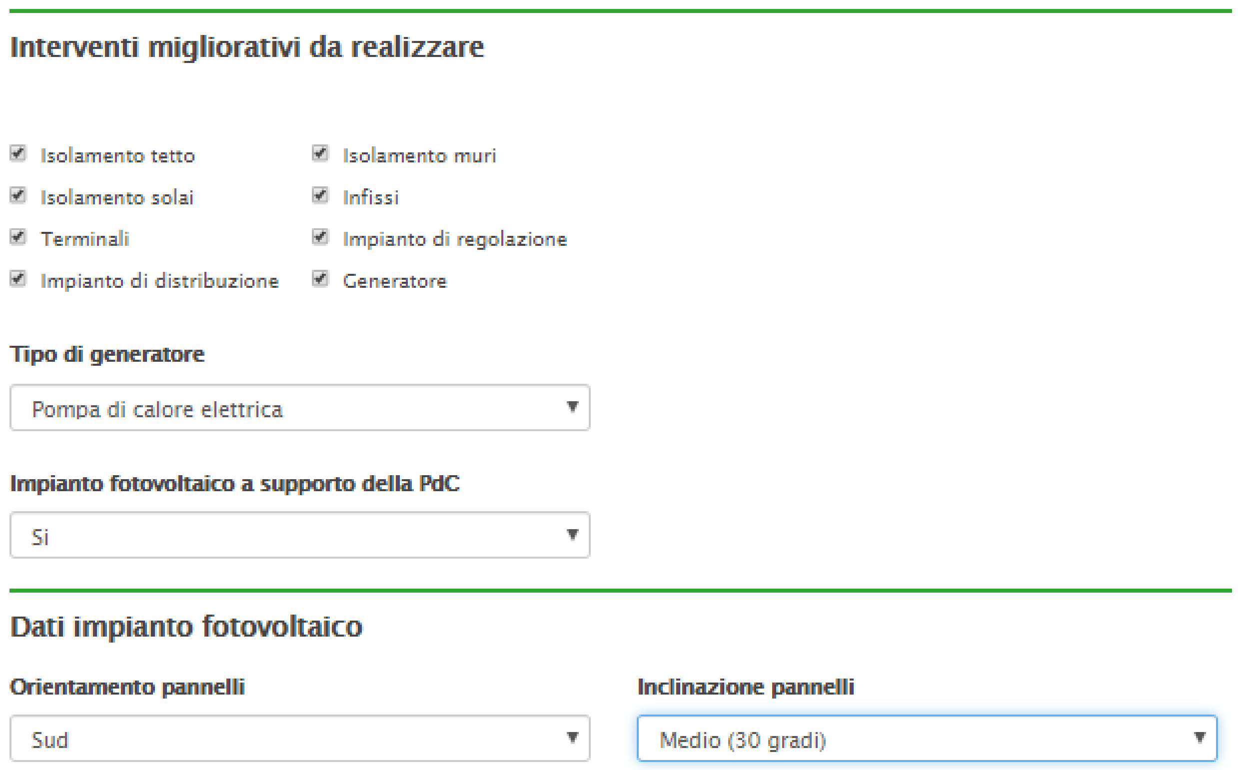
Figure 15-15 shows the dispersion and the thermal contributions in the single structural elements to the state of fact and to the state of design. This view allows you to compare and, therefore, evaluate the priority to be assigned in the redevelopment to the various elements of the building.

On request it is possible to obtain a report in pdf format containing all the above results in an articulated form, as reported in appendix 15.A.

Figure 15-9. Screenshot of RRE input data # 2 – requalification work: Town-Hall case



A. Redevelopment works that allow to reach Class A1



B. Redevelopment works that allow to reach Class A4 - nZEB

Figure 15-10. Screenshot of RRE input data # 3 - economic-financial data: City-Hall case

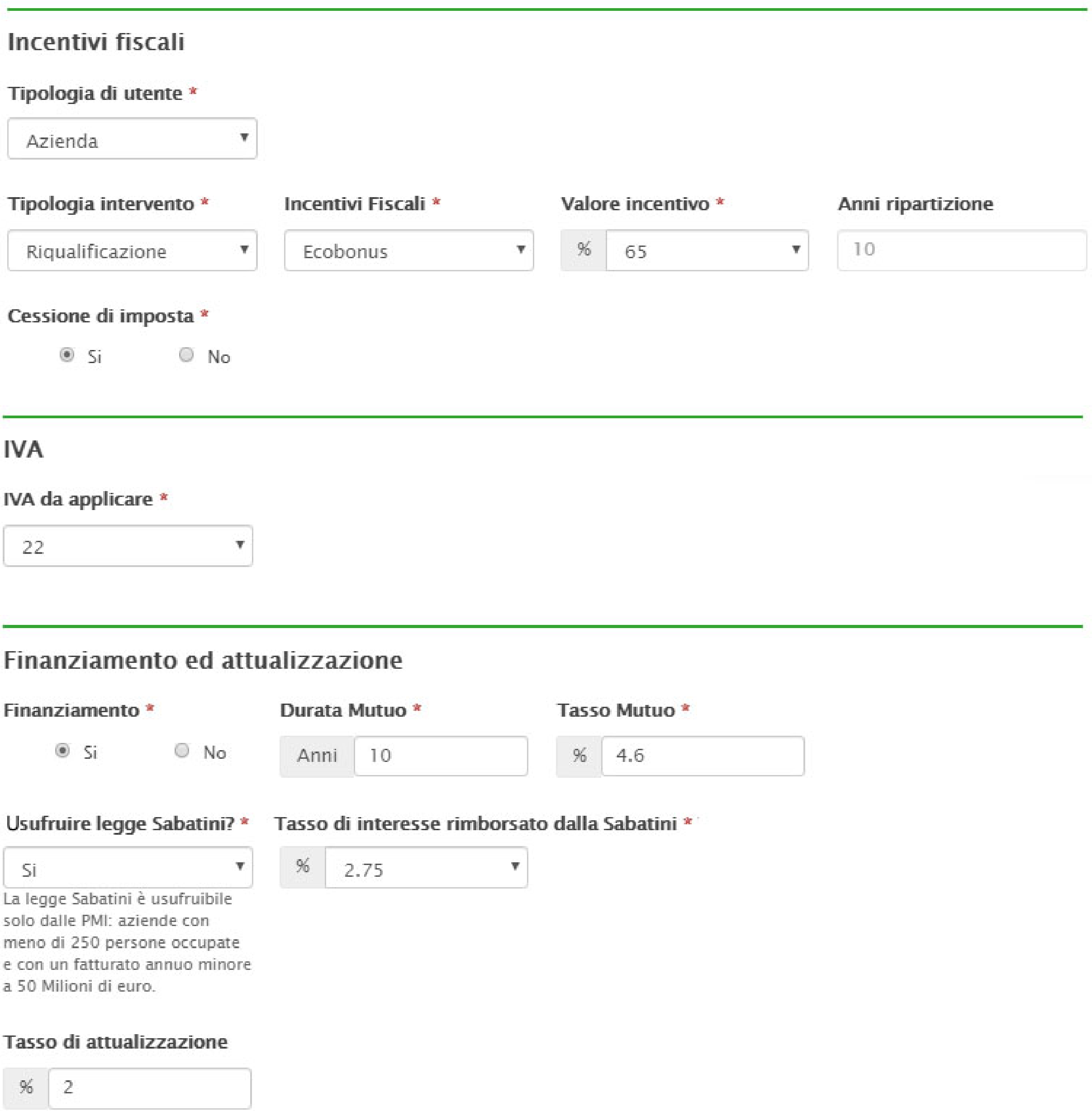


Figure 15-11. Building data

CONFRONTO CLASSE ENERGETICA

Edificio esistente

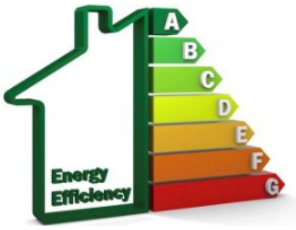
Classe energetica

G

EPh,nren: 216.35 kWh/mq

EPh,tot: 216.35 kWh/mq

Quota Rinnovabile: 0.00 %



Edificio Ristrutturato

Classe energetica

A4

EPh,nren: 12.50 kWh/mq

EPh,tot: 33.95 kWh/mq

Quota Rinnovabile: 63.19 %

DATI DELL'IMMOBILE

Voce	U.M.	Valore
Comune:		Trescore Balneario
Regione:		LOMBARDIA
Zona climatica:		E
Gradi giorno invernali:	Gradi	2,454.00
Tipologia immobile:		Edificio Singolo
Superficie utile riscaldata:	mq	1,069.25
Volume Lordo riscaldato:	mc	3,774.45
Numero piani:	n	3.00
Altezza per piano:	m	3.53
EPH,nren di riferimento - Riscaldamento	kWh/m2	33.34
EPC,nren di riferimento - Raffrescamento	kWh/m2	

Figure 15-12. Cost and profitability

PREVENTIVO DI SPESA E CONVENIENZA ECONOMICA e FINANZIARIA

Nota	Voce	U.M.	Valore
	INTERVENTI PREVISTI		INVOLUCRO ESTERNO
Si	Isolamento tetto	Euro	53,462.40
Si	Isolamento solai	Euro	35,641.60
Si	Isolamento muri	Euro	150,528.95
Si	Sostituzione infissi	Euro	67,018.50
	Totale INVOLUCRO ESTERNO - IVA esclusa	Euro	306,651.45

Nota	Voce	U.M.	Valore
	INTERVENTI PREVISTI		IMPIANTI
Si	Sostituzione generatore	Euro	10,302.40
Si	Rifacimento impianti	Euro	32,077.44
Si	Sostituzione terminali	Euro	53,462.40
Si	Building_automation	Euro	26,731.20
Si	Impianto fotovoltaico	Euro	10,295.30
	Totale IMPIANTI - IVA esclusa	Euro	132,868.74

Nota	Voce	U.M.	Valore
	PREZZO OPERA CHIAVI IN MANO		
A = A1 + A2	Totale IVA inclusa	Euro	483,472.20
A1	- Imponibile	Euro	439,520.18
A2	- IVA	Euro	43,952.02
	INCENTIVO		Ecobonus
	Cessione credito d imposta		Si
B	PREZZO AL NETTO DELL INCENTIVO	Euro	247,779.50
	IPOTESI DI FINANZIAMENTO		
	Capitale proprio	Euro	0.00
	Mutuo bancario	Euro	247,779.50
	- Tasso d interesse	%	4.50
	- Durata	Euro	10.00
C1	Rata annua mutuo	Euro/Anno	31,314.08
C2	Contributo legge Sabatini, durata 5 anni	Euro/Anno	Non richiesto/Non Applicabile
C = C1 - C2	Rata annua mutuo netta	Euro/Anno	31,314.08
	VARIAZIONE DEL COSTO ENERGETICO		
D = D1 - D2	Risparmio annuo	Euro	20,166.88
D1	- Costo attuale	Euro	20,982.51
D2	- Nuovo costo a seguito realizzazione impianto	Euro	815.63
D / D1	Risparmio annuo	%	96.11

Nota	Voce	U.M.	Valore
	COSTO NETTO DELL INVESTIMENTO		
	Capitale proprio	Euro	0.00
E = E1 - E2 - E3	Costi annuali	Euro	11,147.20
E1	- Rata mutuo annua	Euro	31,314.08
E2	- Rimborso detrazione d imposta	Euro	0.00
E3	- Risparmio costi energetici	Euro	20,166.88
E / N. alloggi	Costo mensile per alloggio	Euro	928.93
E / mq	Costo mensile per mq superficie netta	Euro	0.87
	INDICI DI PROFITTABILITÀ		
	Vita impianto	Euro	30.00
	Tasso di attualizzazione	%	2.00
	Tempo di ritorno investimento	Euro	12.36
F	VAN - Valore investimento Attualizzato Netto	Euro	578,313.44
F / B	IP - Indice di Profitto (VAN/Prezzo netto)		2.33
	TIR - Rendimento dell investimento	%	19.07

Figure 15-13. Comparison between energy consumptions and operating costs

CONFRONTO CONSUMI ENERGETICI E COSTI DI ESERCIZIO

EDIFICIO ESISTENTE

RISCALDAMENTO

Voce	U.M.	Valore
RISCALDAMENTO		
Fabbisogno termico annuo	kWh	192,221.76
Potenza termica	kW	133.05
Tipo di combustibile		Gas metano
Consumo combustibile	m3	23,313.91
Tonnellate equivalenti di petrolio	TEP	19.12
Produzione Anidride Carbonica	ton CO2	45,958.24
Costo in bolletta	Euro	20,982.51

RAFFRESCAMENTO

Voce	U.M.	Valore
RAFFRESCAMENTO		
Fabbisogno termico annuo	kWh	0.00
Potenza termica	kW	0.00

EDIFICIO RISTRUTTURATO

RISCALDAMENTO

Voce	U.M.	Valore
RISCALDAMENTO		
Fabbisogno termico annuo	kWh	27,061.75
Potenza termica	kW	18.73
Tipo di combustibile		Elettricita
Consumo combustibile	kWh	6,852.43
Tonnellate equivalenti di petrolio	TEP	1.28
Produzione Anidride Carbonica	ton CO2	3,152.25
Costo in bolletta	Euro	1,671.99

RAFFRESCAMENTO

Voce	U.M.	Valore
RAFFRESCAMENTO		
Fabbisogno termico annuo	kWh	0.00
Potenza termica	kW	0.00

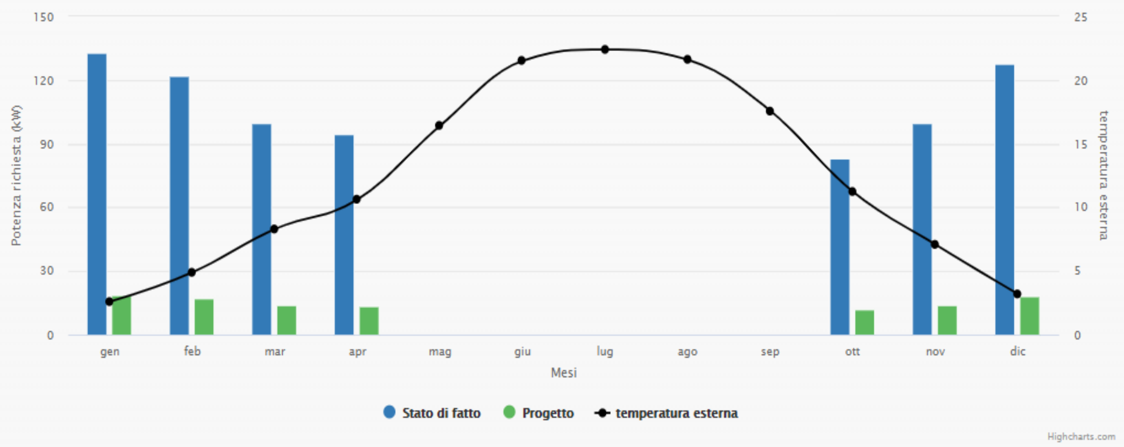
Figure 15-14. Results in detail: Status quo

1. Stato di fatto

+ **Dati edificio**

− **Potenza termica richiesta dall'edificio**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati



+ **Fabbisogno energia termica richiesta dall'edificio**

+ **Consumo energetico edificio attuale**

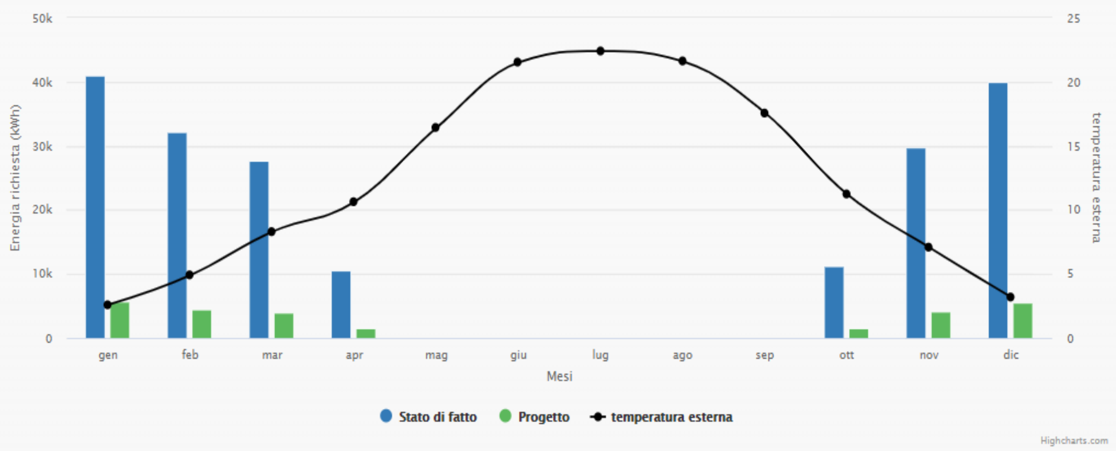
1. Stato di fatto

+ **Dati edificio**

+ **Potenza termica richiesta dall'edificio**

− **Fabbisogno energia termica richiesta dall'edificio**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati

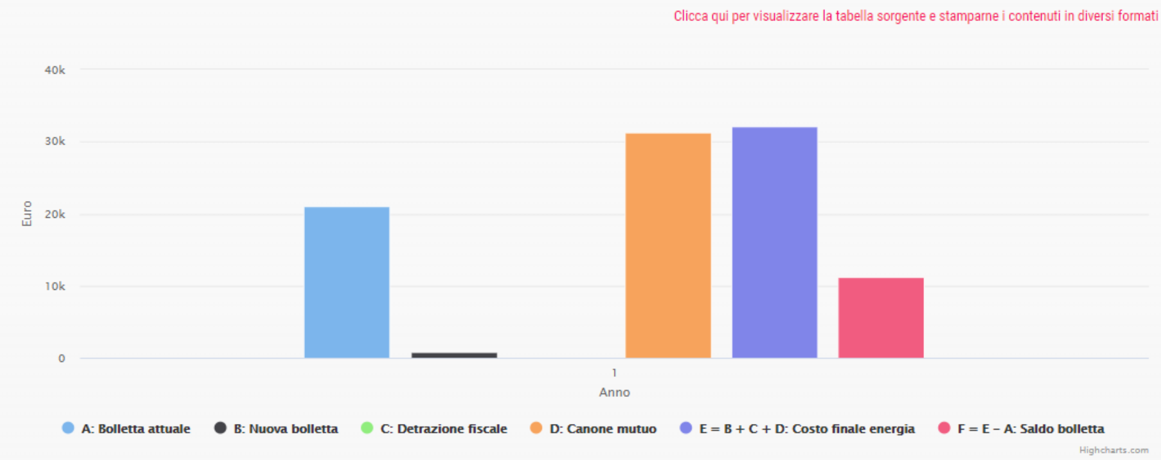


+ **Consumo energetico edificio attuale**

Figure 15-15. Results in detail: The benefits of the energy efficiency intervention

2. Benefici

— **Nuova bolletta primo anno**



+ **Nuova bolletta negli anni**

+ **Costo intervento**

+ **Flussi di cassa**

+ **Consumo energetico edificio ristrutturato**

+ **Risparmio conseguito**

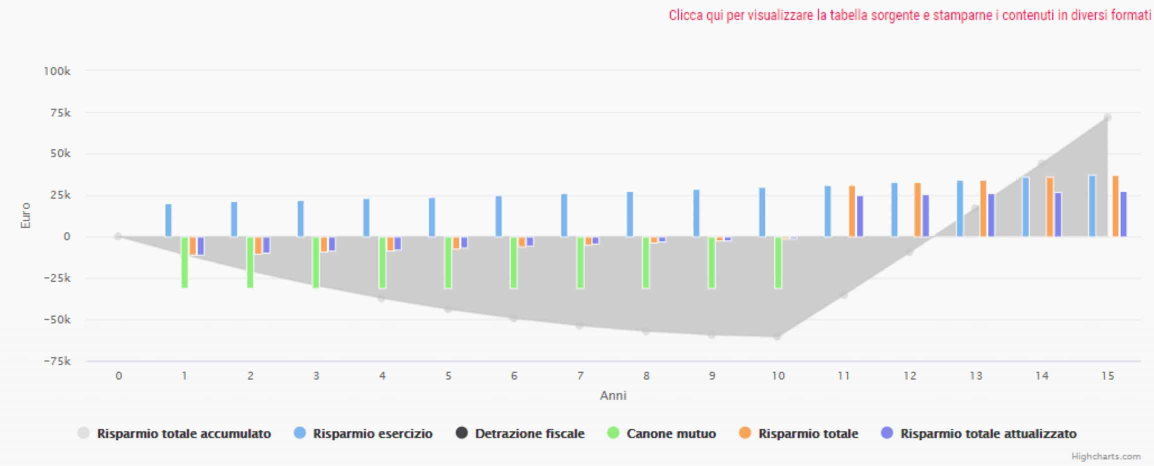
2. Benefici

+ **Nuova bolletta primo anno**

+ **Nuova bolletta negli anni**

+ **Costo intervento**

— **Flussi di cassa**



+ **Consumo energetico edificio ristrutturato**

+ **Risparmio conseguito**

Figure 15-16. Results in detail: Climate system operating data

3. Dati di funzionamento impianto climatico

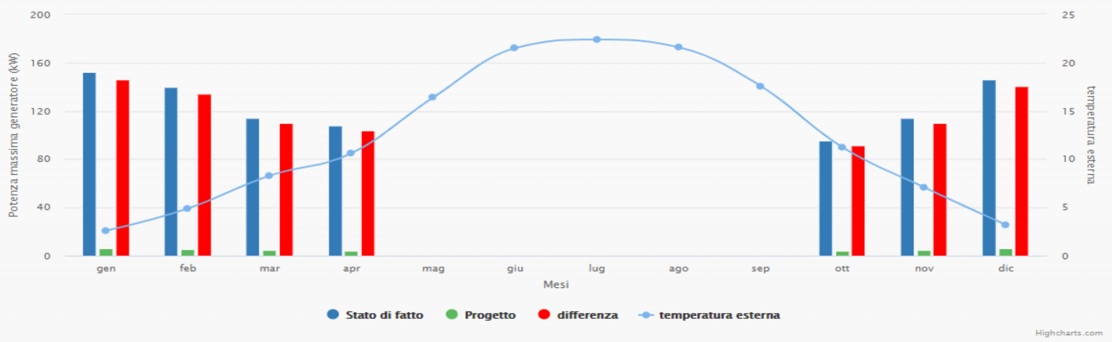
+ **Periodo di accensione impianto**

+ **Rendimento generatore**

+ **Energia consumata generatore**

− **Potenza max generatore**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati



+ **Costo combustibile**

+ **Energia primaria totale**

+ **Energia primaria rinnovabile**

+ **Energia primaria non rinnovabile**

+ **Anidride carbonica**

4. Analisi dei dati riscaldamento

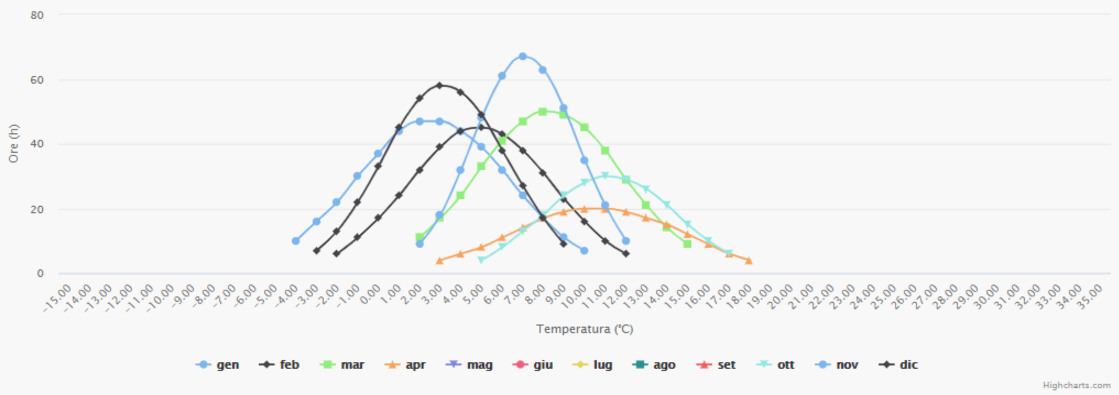
+ **Fabbisogno invernale**

+ **Dispersione ed apporti: valori numerici**

+ **Dispersione ed apporti: valori percentuali**

− **Frequenza oraria delle temperature esterne**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati



+ **Fabbisogno termico edificio vs Temperatura esterna**

+ **Potenza termica edificio vs Temperatura esterna**

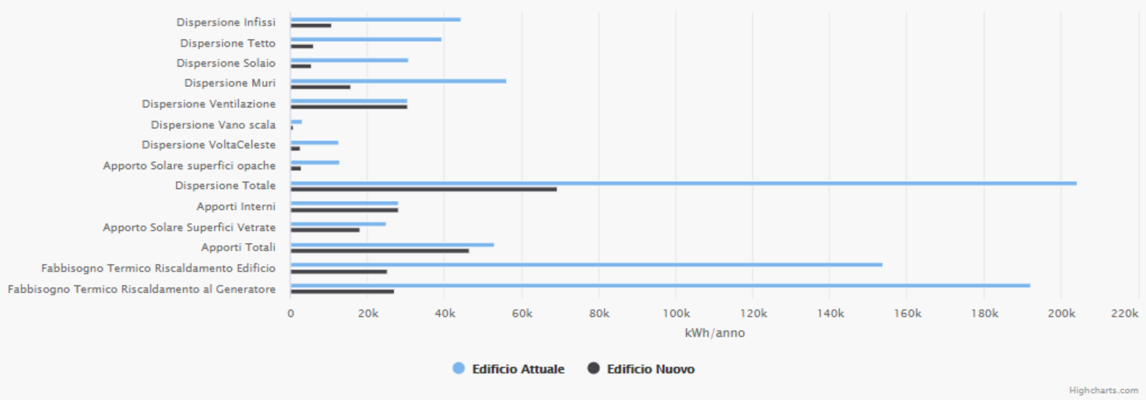
Figure 15-17. Results in detail: Heating data analysis

4. Analisi dei dati riscaldamento

+ **Fabbisogno invernale**

– **Dispersione ed apporti: valori numerici**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati



+ **Dispersione ed apporti: valori percentuali**

+ **Frequenza oraria delle temperature esterne**

+ **Fabbisogno termico edificio vs Temperatura esterna**

+ **Potenza termica edificio vs Temperatura esterna**

4. Analisi dei dati riscaldamento

+ **Fabbisogno invernale**

+ **Dispersione ed apporti: valori numerici**

+ **Dispersione ed apporti: valori percentuali**

+ **Frequenza oraria delle temperature esterne**

+ **Fabbisogno termico edificio vs Temperatura esterna**

– **Potenza termica edificio vs Temperatura esterna**

Clicca qui per visualizzare la tabella sorgente e stamparne i contenuti in diversi formati

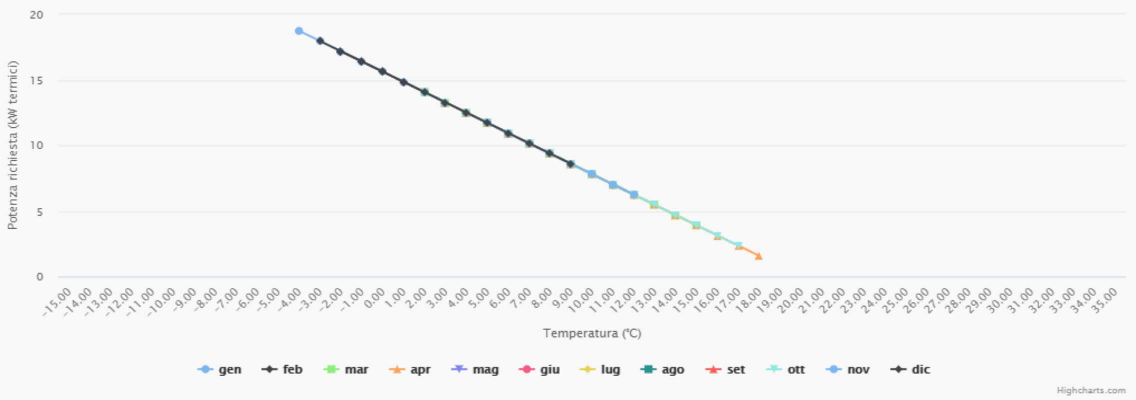


Figure 15-18. Results in detail: Cooling data analysis

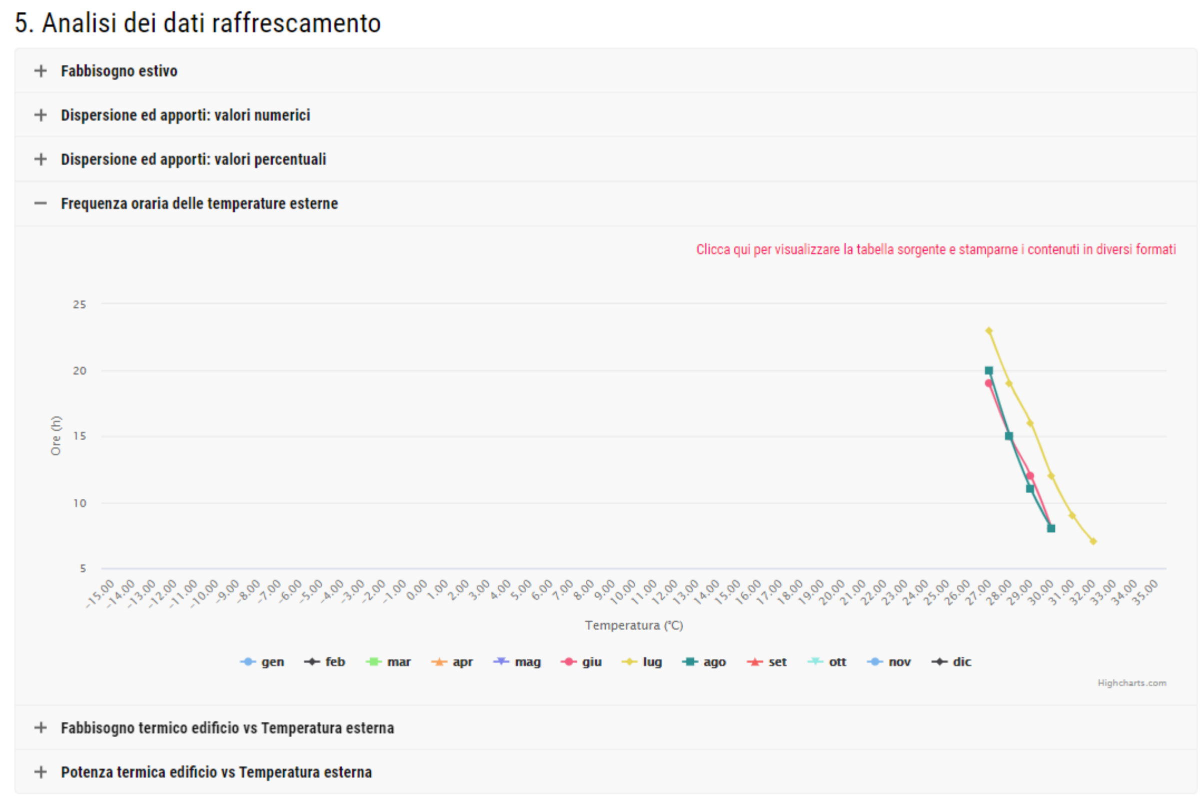


Figure 15-19. Results in detail: Finance

6. Finanza

— **Preventivo impianto**

Print Excel CSV Copy

Nota	Voce	UM	Prezzo
A = A_1 + ... + A_9	Totale fornitura	Euro	439,520.18
A_1	- Isolamento tetto	Euro	53,462.40
A_2	- Isolamento solai	Euro	35,641.60
A_3	- Isolamento muri	Euro	150,528.95
A_4	- Sostituzione infissi	Euro	67,018.50
A_5	- Sostituzione generatore	Euro	10,302.40
A_6	- Rifacimento impianti	Euro	32,077.44
A_7	- Sostituzione terminali	Euro	53,462.40
A_8	- Building_automation	Euro	26,731.20
A_9	- Impianto fotovoltaico	Euro	10,295.30
B = B_1 * B_2	Costo trasferta	Euro	0.00
B_1	- Distanza kilometrica	Km	0.00
B_2	- Costo kilometrico	Euro	0.65
C = A + B	Totale Imponibile	Euro	439,520.18
D = C * 10.0 %	IVA	Euro	43,952.02
R = C + O	Totale fattura	Euro	483,472.20

\+ **Finanza**

\+ **Cessione del credito**

6. Finanza

\+ **Preventivo impianto**

\+ **Finanza**

— **Cessione del credito**

Print Excel CSV Copy

Nota	Voce	U.M.	Senza cessione	Con cessione
A	Prezzo impianto eleggibile su cui calcolare la detrazione fiscale	Euro	483,472	483,472
%B	Percentuale detrazione fiscale	%	65	65
C = A x %B	Importo totale della Detrazione fiscale	Euro	31,425,693	31,425,693
D	Numero di rate annuale in cui viene suddivisa la detrazione fiscale	Anni	10	10
E	Quota parte ceduta della detrazione fiscale	Euro		31,425,693
G = E x %F	Incasso derivante dalla cessione	Euro		235,692
H = A - G	Prezzo impianto al netto della cessione del credito d imposta	Euro	483,472	247,779
I	Importo finanziato con il mutuo	Euro	483,472	247,779
L1	Tasso mutuo	%	4	4
L2	Durata mutuo	Anni	10	10
M = f(I, L1, L2)	Rata mutuo da pagare da 1 - 10 anni	Euro	61,100	31,314
N = M1 - M	Differenza rata mutuo annua	Euro		-29,786
O	Detrazione fiscale annua da richiedere da 1 - 10 anni	Euro	-31,425	0
P = O1 - O	Differenza Detrazione fiscale annua	Euro		31,425
Q = M - O	Rata netta annua da 1 - 10 anni	Euro	29,674	31,314
R = Q1 - Q	Differenza Rata netta annua	Euro		1,639
R	Tasso d attualizzazione	%	2	2
S = f (%R, P, Q)	Costo totale attualizzato	Euro	266,557	281,281
T = S_1 - S	Differenza Costo totale attualizzato	Euro		14,723
T% = (S_1 - S) / S		%		0

15.6 Bringing the Town-Hall into NZEB

Table 15-6 reports a summary of the results obtained with the DSS_RRE considering 3 distinct hypotheses of intervention for the redevelopment of the Town-Hall:

1) Renovation intervention with the aim of reaching **Class A1**, i.e. the same as the *Reference building*. This requires to renew all the structural elements of the external casing and of the technological systems for air conditioning with the replacement of the existing generator with a new generation condensing boiler. In DSS-REE this is obtained with the input data reported in Figure 15-9 A.
2) Renovation intervention with the aim of reaching the **nZEB level**. This is achieved with the same type of intervention as in the previous point 1 with the only difference that an electric heat pump combined with a photovoltaic plant is used as a generator as shown in Figure 15-9 B.
3) Renovation intervention, completely identical to the one of the previous point 2 as regards the technical aspects, but carried out with a completely **different financial strategy**: Tax credit transfer (Section 3.4), ten-year loan to finance the residual cost with the activation of the Sabatini law (Section 3.3) to reduce the cost of bank interest. In DSS-REE this is obtained keeping the same input data reported in Figure 15-9 B as far for the technical intervention, and specifying the financial strategy as shown Figure 15-10.

First of all, this example gives the possibility to confirm that, as indicated by the national energy plan adopted by Italy, PNIEC 2019 - Section 4.5.1, to reach the nZEB level it is necessary, not only to improve the thermal insulation of the building, but also replace the use of the boiler with other technologies such as, for example, the electric heat pump powered by a photovoltaic system built on site.

In fact the possibility of reaching a higher class can be obtained either by raising the degree of thermal insulation of the building envelope and/or the quality level of the technological systems. But increasing the degree of insulation reduces only the heat demand while by intervening on the technological systems it is possible to increase the percentage of renewable energy used as required by the nZEB level.

This example also gives the possibility to appreciate that a renovation intervention to class A1 reduces by at least 8 times the environmental impact of the air conditioning plant, both in terms of primary non-renewable energy and in terms of CO2 emission. Furthermore the nZEB hypothesis with the heat pump combined with a photovoltaic plant further halves the environmental impact.

Table 15-5. APE building class in the redevelopment works for the Town-Hall

Case	APE building class	HVAC plant	$EP_{gl,tot}$ kWh/mq	$EP_{gl,ren}$ kWh/mq	$EP_{gl,nren}$ kWh/mq	$\frac{EP_{gl,ren}}{EP_{gl,tot}}$ %
Status quo	G		216.4		216.4	0.0
1	A1	Condensing Boiler	28.7	0	28.7	0.0
2 & 3	A4 - nZEB	Electric Heat Pump with photovoltaic system	34.0	12.5	11.5	63.3

Although the 1st hypothesis with the boiler as thermal generator has an intervention cost lower than the 2nd one, the latter, having a greater saving on operating costs, it becomes even more financially convenient as shown by the NPV and the IRR. Moreover the 2nd hypothesis allows to increase the comfort giving the possibility to cool the building in the summer season.

The 3rd hypothesis overcomes the possible obstacle of unavailability of own capital by resorting to the Transfer of the credit and, for the remaining part, to a bank loan with the cost of the interest reduced through the Sabatini law. The result obtained shows that this strategy can even lead to halving the current operating costs. Obviously these excellent results could depend on an overly optimistic estimate of the renewal costs and the price paid by the buyer of the tax credit. Obviously in a practical case it is also necessary to identify the real data to be used for that specific project.

Table 15-6 Synthesis of the alternative redevelopment works for the Town-Hall							
		Case	UM	**Status quo**	**1**	**2**	**3**
		Climate generation type			**Boiler**	**Heat pump**	**Heat pump**
		Photovoltaic plant				Yes	Yes
		Energy Class		G	A1	A4	A4
		nZEB		No	No	Yes	Yes
		Thermal Energy demand	kWh	192'221	26'782	27'061	27'061
		Total primary energy	kWh/m2	216.4	28.7	34.0	34.0
		Non-renewable primary energy	kWh/m3	216.4	28.7	12.5	13.0
		Renewable primary energy rate	%	0%	0%	63%	63%
		CO2 production	Ton CO2	45'958	6'103	3'152	3'152
		Annual bill	€	20'982	2'786	815	815
		Tax Deduction			No	SI	SI
		Mortage Payment			No	No	Si
		Sabatini mortage incentive			No	No	Si
		Credit assignment			No	No	Si
A		**Total intervention cost**	€		464'078	483'472	483'472
B		**Total tax deduction**	€		301'651	314'257	314'257
C		**% recognized by credit transfer**	%				75%
D	= B x C	**Income from the assignment of credit**	€				235'693
E	= A - D	**Initial cost**			464'078	483'472	247'780
F		**Own capital**			464'078	483'472	
G	= E - F	**Funded capital**	€				247'780
H		**Interest Rate**	%				4.5%
I		**Mortgage Duration**	Year				10
L	= f(G,H,I)	**Mortgage payment**	€				31'314
M		**Bills saving**	€		18'196	20'167	20'167
N	= B / 10	**Annual tax deduction**	€		30'165	31'426	
O	= L - M - N	**Annual cost**	€		-48'361	-51'592	11'147
P		**n. real estate unit**	N		1	1	1
Q	= A / P	**Initial cost per condominium**	€		464'078	483'472	
R		**Amount financed by the loan**	€				247'780
S	= M / P	**Annual cost per condominium**	€		-48'361	-51'592	11'147
		Annual methane cost increase	%		4.8%	4.8%	4.8%
		Discount rate	%		2.0%	2.0%	2.0%
		Useful life of the project	Year		30.0	30.0	30
T		**NPV - Net present Value**	€		583'980	658'406	578'313
U		**Payback time**	Year		9.9	9.9	12.4
V		**IRR (Internal rate of return)**	%		9.8	9.9	16.4
Z	= T / E	**IP (NPV / Investment)**			1.3	1.4	2.3

15.7 Conclusions

Compared against the certified results of the commercial software TerMus, those obtained by the DSS_RRE appears to be adequately reliable even in complex case like the Town-Hall. The speed of use and the completeness of the results of the DSS_RRE appear extremely useful especially in the decision-making processes where it is necessary to evaluate different alternatives from which, finally, select the type of intervention that best suits the different needs of the project such as, for example: comfort standards to be assured (for example only heating or even cooling), financial resources, financial strategies etc.

The example shown in this Chapter allows us to appreciate the fact that even for complex cases, the input data are extremely limited. In fact, the geometric data are limited to those shown in the Figure 15-2 The type of works to be carried out for the renovation can be quickly specified through the simple form shown in the Figure 15-9. Finally, complex financial strategies can be developed with simple variations of the options shown in the Figure 15-10.

The Figure 15-11 ÷ Figure 15-19 provide an example of the quantity and quality of technical and economic information, including detailed information, that the DSS-RRE is currently able to provide. In addition to displaying on the PC screen, DSS-RRE provides the ability to print a report that organically exposes the results of the analysis.

Despite the qualities listed above, it should not be forgotten that DSS-REE is still a tool limited to a rough estimate and cannot be understood as a design tool where instead it is necessary to use the appropriate specialist tools, let alone leave aside the professionalism of a technician designer.

For this purpose, it is of interest to compare the results obtained here with those of the study reported in Chapter 5. In fact, the building is the same, however the analysis reported in Chapter 5 was carried out with the care due in an executive project.

		Chapter 5			**Chapter 15**		
Thermal energy demand	kWh	Table 5-3	TerMus	264,270	Table 15-4	TerMus	202'842
	kWh	Table 5-3	EnergyPlus	214,963	Table 15-4	DSS-RRE	192'221
Energy retrofit works	€	Table 5-6	Computed cost	753,800			
Energy retrofit works	€	Table 5-6	Eligible cost	452’983	Table 15-6	DSS-RRE	464'078
			Total	*494’143*			
			Replac. of lighting …	*-41’160*			

First of all, it should be remembered that, the technical parameters and the restructuring costs implemented in the DSS-REE refer to conventional buildings and standard renovations, while the accounts reported in Chapter 5 were obtained with specialized software able to take into consideration all those peculiar aspects present in the real structure.

In fact, the difference in the calculated values of the energy requirement is primarily due to the fact that, for the calculation of the trasmission heat loss, the DSS-REE allows defining the transmittance value only through three alternative possibilities (mediocre, standard, excellent). For solar gains the DSS-REE does not allow adjustments having fixed all the parameters that control the resulting value such as:

- Colour on the opaque surfaces, fixed at medium, $\alpha_{sol,i} = 0.6$
- Exposure factor $F_{w,i,j} = 0.9$, constant on time
- No shading on the whole building, $F_{hor,i,j} = F_{ov,i,j} = F_{fin,i,j} = 1;\ \forall i,j$
- No shielding of the glass surfaces, $F_{sh,gl} = 1$

Another source of difference are the operating parameters of the plants which in DSS-REE are also set at a single value while the specialized software allows a wide choice. For example in DSS-REE, the ventilation factor is fixed to that for residential buildings: it follows that DSS-REE performs its own calculations assuming the number of air changes equal to 0.3 times / hour instead of the 0.5 times / hours required by the law for public buildings.

Likewise, the restructuring cost calculated by the DSS-REE does not take into account, for example, the peculiarity of the historic fixtures whose replacement required a cost 3 times greater than the conventional one as verified by comparing the “Replacement of transparent closure …” costs shown in Table 15-4 at the "Computed cost" and "Eligible cost" columns. We remind you that these "Eligible costs" are obtained by using the intervention cost that the Thermal Account believes to be the market one. Therefore the correct comparison with the costs calculated with DSS-REE (€ 464'078) must be made with this "Eligible cost" with the further limitation that in DSS-REE there is no provision for the replacement of the electrical system (€ 452'983).

16 Conclusions and future developments

Certainly zeroing the energy consumption of the air conditioning plant of the buildings for civil use can provide a significant contribution to the mitigation of global warming. Indeed:

- buildings for civilian use represent 40% of total CO2 emissions;
- unlike industrial ones, the energy consumption do not serve to generate wealth;
- the engineering analyzes reported in this thesis confirm that the energy consumption can be (almost) zeroed thanks to already mature and consolidated technologies.

To obtain this result it is necessary to operate through so-called deep-renovation interventions, i.e. by acting both on the building envelope and on the climate plants. Indeed, only well-insulated buildings allow a capillary diffusion of technologies such as electric heat pumps which, combined with photovoltaic energy, would make it possible to permanently abandon natural gas for heating and DHW.

With the enactment of the European Directive 31/2010/EC, the European Union strategy to drastically reduce the excessive production of CO2 now appears clear:

A. on the one hand through the nZEB regulation imposes the obligation on new buildings or buildings subject to major restructuring to act both on the coat and on the plants, imposing that more than half of the energy consumed is produced locally by renewable sources.

B. On the other hand, it requires the various governments of individual states to make available important incentives to facilitate this transition.

To this purpose, in December 2018, Italy sent to the European Commission the first Proposal of the Integrated Energy and Climate National Plan (PNIEC), currently in public consultation, with which, the Italian Government commits itself to confirm and strengthen all the incentives currently in force (Ministero dello Sviluppo Economico, 2018).

The following Table shows the summary of the study presented in Chapter 2 on the consistency and state of greeting of Italian real estate assets and their energy consumption.

	Civil				Industrial		Total
	Residential		Non-residential				
	Housing Units <= 4	Condominium	Tertiary	PA	Industry	Other	
Buildings	10'756'679	1'431'019	545'000	115'802	287'000	1'496'097	14'631'597
Real estate units	17'651'428	17'112'935	3'783'521	115'802	1'209'946		39'873'631
Buildings ante 1976							
- in %	64%				NA	NA	
- number	6'884'275	915'852	348'800	74'113	NA	NA	8'223'040
Consumptions							
- in %	29%		14%		21%	36%	100%
- in %	43%				57		
- MToes	34,0		17,0		25,5	42,35	118,9

Considering that:

- about 64% of the buildings was built before the year 1976, the year in which the 1st law on the energy containment of buildings was issued;
- only 1% of the buildings is in energy class A, i.e. respects the maximum limit of energy consumption by the new European legislation;
- The number of heat pumps installed per year is today almost 7 times less than that of boilers.

it can be deduced that, while limiting attention to the civil sector alone, the work required to bring the italian buildings stock up to new EU standards is enormous.

In view of this, the PNIEC proposes a series of incentive measures to favor building owners in the implementation of energy redevelopment works. From the study reported in Chapter 3 it appears that the most interesting measures are the Thermal Account for the building of the PA and the Ecobonus for private civil construction.

On the other hand, the study reported in Chapter 4 shows that these actions have already been active for years, although with different implementation methods and amounts, but the results have been very limited indeed, especially regarding deep renovation of buildings.

To understand the reasons for this lack of success, the study reported in Chapter 5 and 6 concerning the total redevelopment (envelope and plants) of two real cases was carried out:

1. A 19th century public building using the New Thermal Account 2.0;
2. A typical 80s apartment building using the Ecobonus with and without the new mechanism called "Transfer of Credit".

This made it possible to verify that in both cases:

- Redevelopment reduces energy consumption by up to 90%.
- Tax incentives are able to reduce the cost of the deep renovation from 50% up to 70%.
- However, the economic savings obtained in the bill allow a Pay Back Time not less than 10 up to 15 years.

From this we should conclude that in practice restructuring operations are hardly carried out in buildings that have the external envelope and/or technological systems in good condition. If, on the other hand, it is necessary to restore some elements of the building, the existing incentives provide an indisputable economic motivation to extend the intervention to the achievement of the high energy standards advocated by the recent legislation, as this effectively reduces the actual costs incurred.

For example, the simple renovation of the facades in a building, which in any case need to be carried out at least every 25 years, requires the realization of the scaffold, restore the plaster and the paint of it. The application of a thermal coat requires the same identical work plus the application of the thermal coat itself. Thus the addition of the thermal coat can be treated as a differential cost (typically + 20%) compared to a cost that must be addressed anyway.

But since the since the application of a thermal coat is incentivized up to 55% in condominiums (i.e. the Ecobonus with Tax Credit Transfer), the resulting cost is lower than that of the simple renovation of the façade, as the following Table 16-1 summarized.

Table 16-1: Simple renovation of the facade vs. renovation of the facade with a thermal coat

	Facade reconstruction	With thermal coat
Cost	80%	100%
Energy Saving	no	yes
Increase in energy class	no	yes
Tax deduction with transfer of credit	no	55%
Net cost	80%	45%

As for the public buildings, the new Thermal Account 2 undoubtedly removed many of the obstacles that led to the failure of its previous version. However, the difficulty of public administrations to cover the remaining costs of the investment still persist. From the analysis conducted in Chapter 5, it emerged that the *EPC - shared savings contract tool* proposed by the Thermal Account can hardly find application. This is because the return on investment time required to the ESCO is incompatible with what its financial capability. EPC "guaranteed saving" formula appears much more practicable, since the ESCO does not participate in the investment but is only responsible for the effectiveness of the intervention through forms of penalty on the annual fees due for the supply of the energy service. However, this formula does not solve the financial problem that hinders the renovation of public buildings.

The analysis carried out in Chapter 6 for the private sector has shown that the Eco-bonus, in its latest version with the possibility of credit transfer, makes the intervention to a large section of the population really economically feasible. The resistance that is still observed derives, above all, from the lack of knowledge of the financial instrument available due to insufficient information, made more complicated by the continuous change of rules and by the persistent difficulty of their univocal interpretation.

The new construction sector does not currently enjoy any type of incentive or subsidy from the government. However, the study reported in Chapter 0 showed that the construction of nZEB buildings can certainly be economically convenient, provided the existence an integrated high-level (architectural, energy and structural) design, done with innovative digital techniques such as the BIM, and the building is equipped with Building Automation

Systems. In this sector, the real obstacle to the diffusion of nZEB is above all of a cultural type, so technicians are not prepared to use the new technologies necessary to design and build this type of building at reasonable costs.

Therefore, the three case studies mentioned above have shown that the combined use of the incentives currently available (although sometimes difficult to apply) and the adoption of innovative design methods are able to considerably reduce costs and make at least acceptable the profitability in the renovation of old buildings but also that in the construction of new ones. At the same time, despite the considerable efforts made by EU member countries to support the energy efficiency market, the results achieved so far are far below expectations.

To understand the reasons for the limited success of these incentives, the study reported in Chapter 0 was then carried out to identify where the decision-making process on the opportunity to perform an intervention of redevelopment stops. As a result, the factor that most prevents redevelopment is the lack of qualified and complete information on which to draw conclusions.

At the base there is the problem that a redevelopment intervention requires specific technical skills that are not yet widespread. Added to this is the need for legal competences, in order to extricate oneself from overly complicated regulations, and from economic-financial competences, to evaluate the convenience of a possible intervention. Then there is the need for a channel of great communication capable of establishing a relationship with users and finally gaining their trust.

Hence the study reported in Chapters 9 ÷ 0 allowed us to identify:

1) **Internet as the most effective communication channel.**
2) **The need to adopt a communication policy based on the new inbounding techniques, which seek to acquire the interest and trust of the user with a progressively more specific relationship, following the type of interest and the level of deepening expressed by the user.**
3) **The need to support this communication with tools that are able to provide an analytical assessment of the cost of the intervention, net of existing tax incentives, and the consequent savings.**

As a matter of fact, in the last 2 years the large utilities operating on the Italian market have published platforms that suggest energy efficiency interventions (for example Eni - Genius, Eon, AbbassaLeBollette, wikiwi, etc.). Most of these, however, have a purely commercial purpose and they lack a rigorous calculation procedures for sizing the systems.

Furthermore, the survey reported in Chapter 0 showed that there are no DSS available that are rigorous in calculations but easy to use even for non-thermotechnical experts. What is currently available are design support tools, perhaps of excellent quality, whose use however is limited to the technicians.

This lack motivated the implementation of the platform described in Chapter 11 able to provide a decision support for energy renovation interventions to both end users and technicians. At present the portal has three main functions:

1) Carry out an information and training function that is able to spread awareness of the opportunities for energy upgrading of buildings, highlighting both their economic and environmental benefits.
2) Provide analysis tools able to support, from the early stages of the decision-making process, the main technical, economic and financial issues.
3) Technical and economic dimensioning of energy efficiency interventions by providing a turnkey cost for the supply and installation taking into account the tax incentives.

Chapters 12 ÷ 14 show the theoretical development that allowed us to overcome the major obstacle of this research work, that is the simplification of the data to be supplied to the calculation so that even a non-expert user can use the DSS and still obtain a correct result.

Finally, Chapter 15 reports the application of the DSS to a theoretical case, to demonstrate analytically the correctness of the energy analysis, and to a real case, to demonstrate the usefulness of the tool.

Currently the platform is working on internet and contains about 30 different applications, from the energy diagnosis to the design of an electric heat pump powered by a photovoltaic system. All the applications are accompanied by explanatory videos, by economic-financial analysis tools, by the plant design and by the list of the costs of all its components dimensioned for the purpose (such as in a climate system: expansion vessel, tank inertial and DHW storage, etc.).

Although the development of other types of applications is already foreseen, the priority of the next developments of the platform is above all given to the communicative part. The idea is to build inbounding procedures for each type of intervention so as to establish with the users a precise path of progressive knowledge of a specific product that is eventually completed, once the actual interest has been verified, with access to the tools already implemented in technical design.

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2