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A methodology for evaluating the cost-effectiveness of residential building stocks retrofits in Italy and Denmark

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A methodology for evaluating the cost-effectiveness of residential building stocks retrofits in Italy and Denmark

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Preface - Acknowledgments

"The journey of a thousand miles begins with one step"
(Lao-tzŭ)

This thesis represents the result of my personal PhD path and research experience and was performed during 3 years of study spent both in Italy and Denmark.
Actually, during the first part of my doctorate, the initial steps of investigation - along with its main *top-down* statements and hypotheses - were appointed and developed in Italy; while instead, during the research-period spent in Denmark, such an approach has been entirely reversed, shifting to a *bottom-up* working criterion.

Along with these two different approaches and according to the respective working hypotheses, two distinct algorithms and modeling tools were implemented and consequently used.
Such a choice came from the purpose of performing a more precise and complete analysis, also achieving a deeper understanding of the key-role played - at the respective scales - by the different factors mainly involved in the assessment (investigation contexts, boundary conditions…) and appraising to what extent they affect the final results.

First of all, my sincere gratitude goes to Prof. Salvatore Mura - my Italian supervisor - for his fundamental and constant support and help to achieve the goals, for believing in me and in my ideas, giving me the opportunity to obtain this PhD.

Certainly, writing this thesis was more difficult than initially expected with respect to many aspects, both during my stay in Sardinia and in Denmark. Nevertheless, the invaluable presence of many helpful people enabled me to carry out my work and to conclude the task successfully.

I am grateful to my Italian co-supervisor Eng. Giuseppe Desogus, for his skillful suggestions and advices, for his support and precious critical comments during my research-path, as well as to Prof. Roberto Ricciu, for his useful availability and kind helpfulness.

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Furthermore, recalling the external research period I've spent in Denmark and recognizing the important value added to my work by such a formative experience, I would like to express my gratefulness and sincere thanks to my supervisor and co-supervisor from Aalborg University (respectively Prof. Per K. Heiselberg and Assistant Prof. Anna J. Marszal) for their availability, helpfulness and fruitful suggestions, along with Prof. Peter B. Frigaard (Head of the Civil Engineering Department of Aalborg University), for his gentle acceptance and reception as a guest PhD student.

Last, but not least, I would like to thank, for their kind support, all the Danish employees from Aalborg University, as well as all the other colleagues from the "International Research Group" I've met and I worked with, also sharing such nice moments.

It goes without saying that my family and parents, along with all my best and close old friends, (from Italy, Portugal and Denmark as well) were fundamental into encouraging me thorough the rough patches that turned up on the road of my research. With their love and their all support, they sustained me during my difficult and happy times, patiently sharing all the "ups-and-downs" occurred during my PhD experience.
I particularly thank them from the bottom of my heart for patiently listening and sincerely steering me: without them this thesis would never have been finished…

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Abstract

Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow[1].

The rising energy costs, the growing concern about environmental issues and the approaching exhaustion of world energy resources are urging the entire European Community and the several national governments to improve energy management. Special attention is usually paid to public administrations, as European and national legislations often point out that these bodies must provide energy efficiency measures, as well as for the reasons mentioned above, also in order to represent an example for the entire community and for citizens as well.

But it is also very important to find out how to foster and encourage energy efficiency improvements and saving measures in private dwellings to achieve the double advantage of reducing the global energy consumption level within the private sector and increasing investments, favoring the creation of additional cash flows as well.

The possible combination of such multiple benefits makes the building sector a crucial field for policy makers at EU and national levels. Hence a policy framework that supports national markets in unlocking these potentials is strongly needed. With overall European policy aimed at significantly decarbonizing its economy by 80% to 95% by 2050, the building sector must undoubtedly play a key role. And any strategy to tackle the challenge in this field will clearly require both a significant amount of financial investments and long-term political commitments.

The main goal of the present research is to propose an optimized methodology and cost effective decision-making process - based on the main facts emerging from the adoption of the key energy policies and financial instruments currently in force at European level (particularly in Italy and Denmark) - also to outline the next policy steps in improving the energy performance of buildings.

After a global overview of the policies adopted at European level, the analysis focuses on the two different regulations implemented at the national level by Italy and Denmark. Furthermore, to define the best mixture of energy retrofit measures for the different geographical areas of Italy - applying a methodology based on simple and available data to improve residential buildings' energy efficiency - the work started with the analysis of the several reports produced by ENEA (the Italian Research Agency for Energy Efficiency) since year 2007. These were based on the data collection performed in order to assess the effectiveness of the Italian government's financial policies established to support energy saving actions in private dwellings.

The first steps of such a top-down analysis are then carried out both through manual cost/benefit spreadsheets, as well as with the implementation of a linear programming analysis tool.

The study defines different linear programming models, depicting different optimization problems (e.g. energy saving maximization vs. retrofit cost minimization), along with the respective different background scenarios.

Such investigations are therefore carried out through the implementation and development of *Dantzig*'s *simplex algorithm*.

Moreover, to carry out a global comparison between the overall Italian and Danish situations, also achieving a deeper single-dwelling-focused analysis, further studies are developed through a Building Energy Optimization tool, implementing the *EnergyPlus* dynamic energy simulation software.

Thence, the research moves on to a more specific analysis, shifting to a bottom-up approach and involving in the enquiry a comparison between the different assessment settings (climatic, political, economic, cultural) depicted both by Italy and Denmark.

Two different dwelling models are defined for the above countries, focusing the analysis on those building typologies most representative of such European nations and thence different retrofit solutions are depicted and analyzed.

The results obtained by means of this dynamic assessment are then used to group the respective energy savings vs. retrofit cost considerations within a global cost-effectiveness assessment.

Finally, some “guidelines” are outlined to address the challenge of renovating the existing building stock, also in order to keep pace with the aims of both the nations and the European Union.

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INTRODUCTION

"Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only ***the largest industrial sector in economic terms, it is also the largest in terms of resource flow".*** (P.Hawken in *The HOK Guidebook to Sustainable Design* – S.F.Mendler, W.Odell).

1 Aim and research questions.

1.1 National Italian Policies assessment

The main aim of the first part of research is to assess the cost-effectiveness of mixing and combining different energy retrofit measures for the several geographical areas of Italy. The work is based on the statistic analysis of the results supplied by the several Reports drawn up by ***ENEA*** - the ***Italian National Agency for New Technologies, Energy and Sustainable Economic Development*** - year by year since 2007. The work is centered on finding out a criterion, based on simple and available data, able to identify the most cost-effective retrofit measures to improve dwellings' energy efficiency.
With the final objective of adjusting and addressing subsidies and policy makers' decisions in the most profitable way, some comparative cost-effectiveness analyses were developed and there were highlighted the most consistent kinds of renovation, both with the current economic outlook and depending on the specific geographical and climatic background.

This part of research presents and discusses the consequences of Italian government leaders' policies and purposes of reducing energy demand in the residential sector, in order to facilitate the development of a consistent plan and extension of public incentives and tax deductions for dwellings' energy-saving retrofits.
Thence, it would be instrumental into defining a worthwhile reference point, on the one hand helping decision-makers and relevant stakeholders appreciate how targets have been used till now and how effective they could be, on the other hand, providing evidence to be used in the upcoming policy development discussions.
Actually, as the assessment proves, the earlier outcomes connected with the current National Energy Strategy reveal that some adjustments and refinements are needed to make it really effective and worthwhile.
Although the praiseworthy initiative and aim that underlies such a political-economic venture, it shows several gaps and faults that should be offset and filled up.

The first part of work consists in a report and a review of the most representative financial measures introduced in Italy since the enactment of the Finance Act 2007 (and its successive 2008, and 2009 editions), i.e. the Fiscal Incentives for Energy Savings in the Household Sector (a.k.a. "Energy Efficiency 55%") financed by the Ministry for Economic Development.
Actually, despite the initial global review of those policies and regulations currently in force in Denmark, the first part of analysis was centered on the specific Italian context.
It is in particular focused on those only kinds of building renovations related to the three last Commas (i.e. 345, 346 and 347) of the First Finance Act Article, carried out in private dwellings within the time span of 2007-2010.
With reference to the several Reports drawn up by ENEA in order to relate the Authorities about costs and results of the above incentives, different spreadsheets, schedules and graphs were carried out to collect and sum up all the data and information that could be the most significant ones to define an all-embracing cost-benefit assessment.

The main purpose of the current issue is in fact addressed to assessing the results until now obtained in terms of their cost-effectiveness, resting on an amount of data large enough to take stock of the early stages of the Government Campaign.
Thanks to that it could be possible, in the foreseeable future, adjusting Italian Energy Policies and addressing politicians' decisions in order to encourage specific kinds of renovation, where they would be more cost-effective, and instead give up and/or limit such a financial support, whereas some other interventions reveal their lacks and disadvantages.

Actually, the rising energy costs, the growing concern about environmental issues and the approaching exhaustion of world energy resources are urging the whole European Community and the several National Governments to improve their energy management.
With European overall policy being to significantly decarbonize its economy by 80% to 95% by 2050, the building sector - which accounts for 40% of the region's energy consumption and almost the same level of GHG emissions - must undoubtedly play a key role.
And any strategy to tackle the challenge in the building sector will clearly require a significant amount of financial investments and therefore long-term political commitments.

Hence, the main goal of the present work is to gather key facts derived from the use of some such financial instruments as the next steps to improve energy performance of buildings: the assessment shows the primary Italian tax reliefs already in place and points out the main observations related to the impact of such a policy in an all-embracing assessment.
In general, a particular attention is usually paid to Public Administrations, as European and National Legislations often point out that these entities must provide energy efficiency measures, as well as for the reasons above indicated, also in order to represent an example for the entire community and for the citizens too.

But it's very important also to find out how to foster and encourage energy efficiency improvements and energy saving measures in private dwellings, in order to achieve the double advantage, both to reduce the global energy consumption level within the private sector, and to increase investments favouring the creation of additional cash flows too.
Hence, the possible combination of some such multiple benefits makes the building sector a crucial field for policy makers at EU and national levels.
Therefore, a policy framework that can support the national markets in unlocking these potentials is strongly needed.
And moreover, most of the previous, several researches already developed, demonstrate that financial and environmental aims are not necessarily a contradiction, but can actually support each other.

1.2 Italian global context versus Danish overall boundary conditions

The second part of research was developed after having shifted the analysis approach from an all-embracing assessment, to the smaller "single dwelling scale".
Besides, it has been focused on the comparison of different refurbishment and energy retrofitting strategies, both for Italy and Denmark, in order to understand to what extent the respective boundary conditions play their key roles.

Actually, one of the main reasons which have led to the above, so different contexts' choice and analysis, is directly connected to the primary purpose of approaching the same problem under two distinct perspectives.

On the one hand, a typical Mediterrranean country - along with its respective temperate and relatively warmer climate – is analyzed. While, on the other hand, one of the most representative Northern European country – as well as its more harsh and severe weather patterns - is examined.

Moreover, such a study allows depicting and describing two so different political, economic, financial and social backgrounds, also resposable for their current distinct policies and overall energy-saving strategies.

During this section the potentialities disclosed by an optimization software are exploited, along with the further economic assessments and evaluations ad hoc developed.

PART I

2 The background of the previous knowledge and the potentialities disclosed by the research

There were already depicted, at European International level, various reports and surveys that have taken a closer look at how financial instruments are currently being used in Europe, providing some evidence of their effectiveness too.
In particular, they underlined a great variety of financial instruments available throughout the EU to support the improvement of the energy performance of buildings, but - although their undoubtable relevance - none of them analyzed into details the respective implications at a "single-nation-level". As a matter of fact, this particular topic isn't thoroughly discussed, neither in scientific literature, nor in specific technical guidelines: thus, the example offered by the ENEA Reports could represent, at a national level, a very important instrument to develop a concrete strategy with the aim of creating some guidelines to optimize and address the challenge of renovating the existing building stock, keeping also pace with the ambitious aims of both the Italian Nation and the European Union.
Actually, all the data on costs and energy savings collected through the last four years by the ENEA and provided by such reports, represent a valuable source that should be used systematically to evaluate the financial policies' current approach and to give some guidance on the future. And moreover, since achieving energy savings in buildings is a complex process, policy making in this field requires a meaningful understanding of several aspects and characteristics of the building stock: reducing the energy demand involves the deployment of effective policies which, in turn, make it necessary to understand what affects people's decision making processes, the key characteristics of the building stock, the impact of current policies etc…
As already mentioned in the recent literature, many other authors have already pointed out that there are many obstacles to the spreading of good practices. One of the main problems is the cost-effectiveness of home energy retrofits that is rarely taken into account in national policy programs.

In particular, the literature review highlights some critical issues:

- national legislation can be too strict and prescribe energy efficiency requirements that make retrofits cost-ineffective for homeowners;
- energy price is fictitiously low because social costs of production are often hidden and not charged directly on users' bills;
- uncertainties on future energy price make the economic feasibility analysis of works really difficult;
- public subsidies are necessary to reduce payback time and increase economic benefits for investors.

Taking account of such remarks and focusing the attention on Italy and on its own financial policies and energy regulations, it reveals very important (after due considerations related to the previous, early stages of the public incentives established till now) to plan and address the future energy policies so them to be consistent and profitable.

Therefore, Enea Reports and their analysis in depth could play a fundamental role to understand which and where some kinds of building renovation reveal their cost-effectiveness (and thence should be encouraged with a suitable financial support), and when instead they display a lower all-embracing consistence.

3 An overview of the European sector: energy and consumption trends

An all-embracing assessment carried out considering the main information sources and data available about this issue has led to the following remarks:

- during year 2010 the EU-27 final residential energy consumption accounted for 26,65% of total final energy consumption: only the transport sector had a bigger share of total consumption (31,67%), while instead industry and the services sectors were both smaller in terms of final energy consumption with a share of 25,29% and 13,21% respectively.
  The residential sector plays therefore a fundamental role in energy efficiency programmes and policies;
- moreover a further important element to be highlighted is that, despite energy consumption trends for the residential sector has started to decrease in these latest years, however - in 2010 - the final residential energy consumption grew again substantially reaching the highest level of the last 20 years;
- furthermore, looking at the consumption statistics available in this field it was found that, between 2005 and 2010, final energy consumption in the EU-27 for the residential sector grew by 1,69%, reaching the lowest level of the last 20 years in 2007. The tangible decrease registered in 2007 (-4% compared to 2006) could be explained with such warmer temperatures during that year which led to lower values of heating degree days.

To globally sum up, it's possible to state that, while in 1990 the total consumption in the EU-27 has been of 1.078.628 ktoe, during year 2010 the total final energy consumption in the EU-27 reached 1.153.319 ktoe: this equals a growth of 6,92% during the last 20 years.
In order to be more precise, up to year 2005, the consumption has been growing rapidly every year, reaching the consumption peak of 1.192.536 ktoe in 2005; while instead, from then on, the consumption started to decrease until 2009.
Between 2008 and 2009 the total final energy consumption decreased by -5,2% (but again, between 2009 and 2010, it grew as above highlighted by 3,56%).

However, such a global decreasing trend could be ascribed to the financial and economic crisis of the year 2009, whereas the increase in 2010 is likely due to economic rebound effects.
Actually, the above remarks reveal themselves fundamental in order to achieve a better comprehension of the global European framework that lay behind the present research.

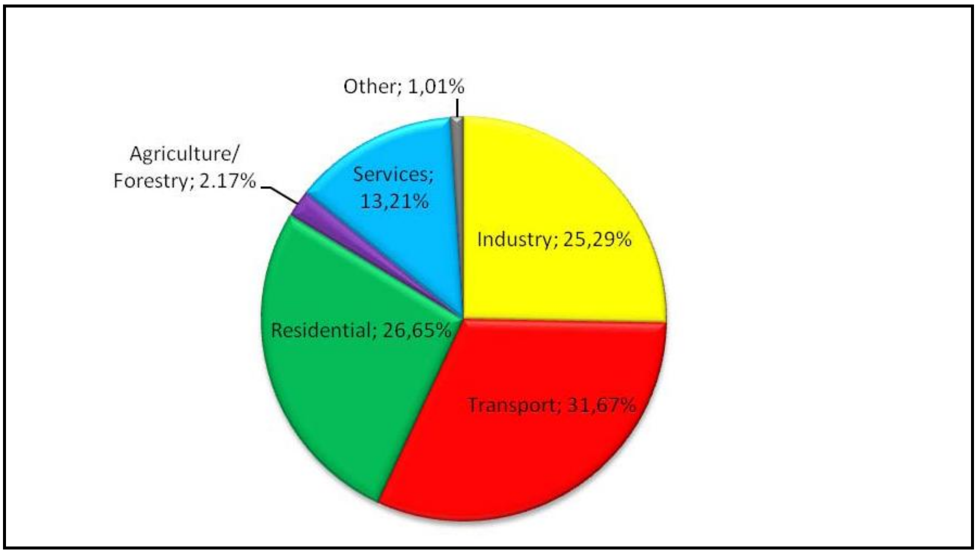


Fig. 3.1 Final energy consumption breakdown into sectors within the EU-27 (source Eurostat, 2010)

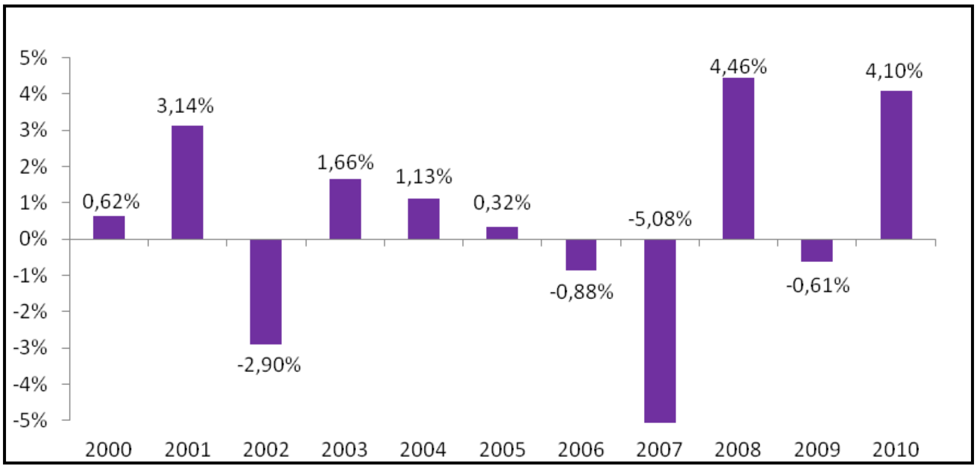


Fig. 3.2 Residential energy consumption growth trends: percentage fluctuation over the latest years (source Eurostat, JRC)

Focus on the European residential sector: main influence factors for the residential energy consumption

In order to gather the most important key fact from the available energy consumption statistics, it's important to consider, beside the energy consumption value itself, also those other different factors which impact such an energy demand.

In particular the **population size**, the respective **economic development level** (and the GDP per capita), along with the different **weather conditions** (i.e. actual heating degree days), the **number of dwellings** per country, the average **number of person per household** (by the way, the average household size in terms of number of people in the EU-27 was, in 2009, **2,4** persons per households and **Denmark reached the lowest** value of **2,0**).

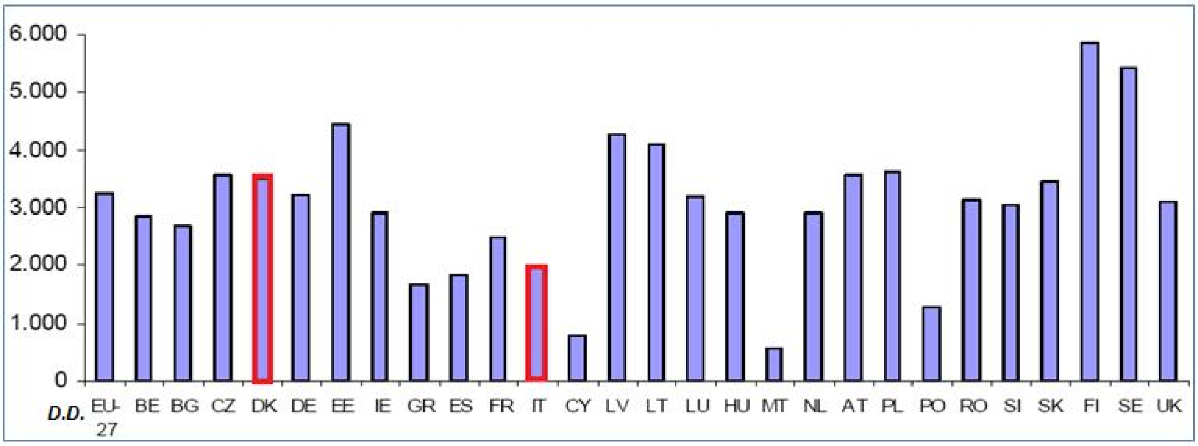


Fig. 3.3 Mean heating degree days assessment during the time span 1980-2004 in the EU-27 (source Eurostat)

Actually, some possible explanations for consumption patterns could also be attempted by simply comparing energy consumption with the trends observed for some of the above factors.
Indeed they reveal rather important in order to better understand the link between energy consumption and efficiency trends in the residential sector (for instance, in some case, a decrease in total energy consumption may also be explained by a population decrement and not by a more efficient use of energy…).
Regarding this task it's quite clear that economic development is positively correlated with the total final energy consumption. Moreover, especially in the residential sector, the recent economic growth in the EU has been generally accompanied by a more efficient way of using energy: in the household sector this is highly related to a global more efficient use mainly ascribable to such more efficient appliances and equipment, more advanced heating systems and better insulated buildings in general. However, considering the significant increase in energy consumption registered during year 2010, it's still fundamental to exploit the existing potentials for energy efficiency improvements, pushing all the EU members into developing more fruitful energetic strategies and policies.

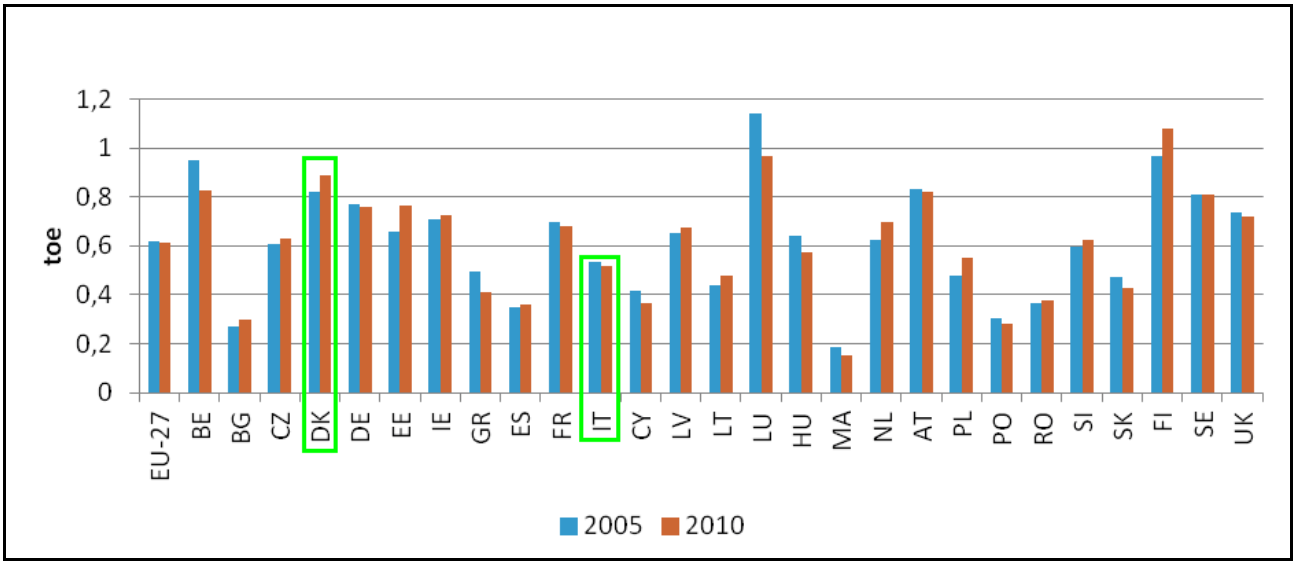


Fig. 3.4 Residential energy consumption per capita in the EU-27: year 2005 versus year 2010 (source Eurostat, JRC)

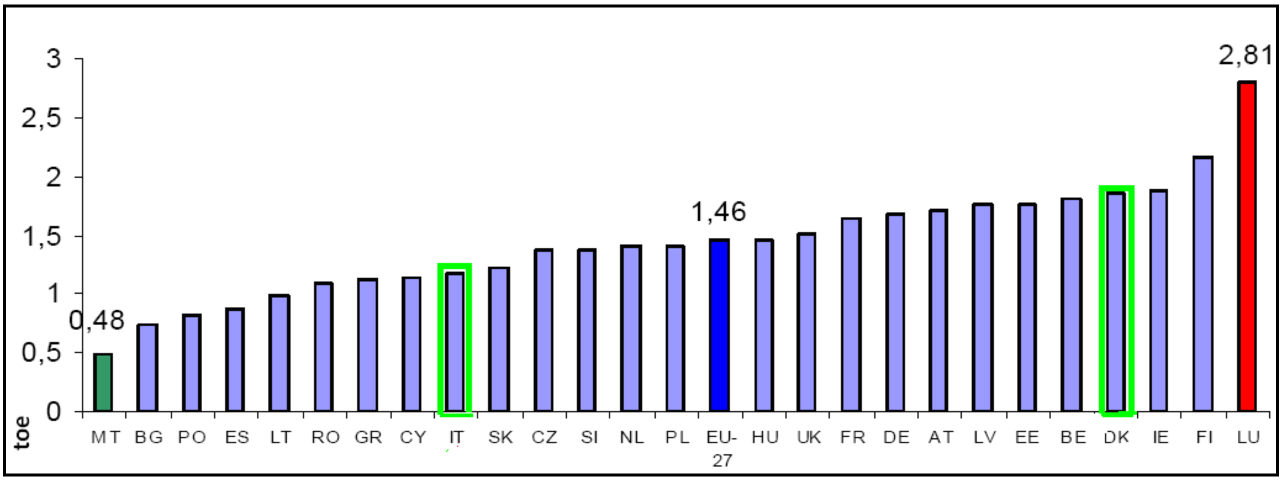


Fig. 3.5 Final Residential energy consumption per dwelling in the EU-27 (year 2009 – source Eurostat)

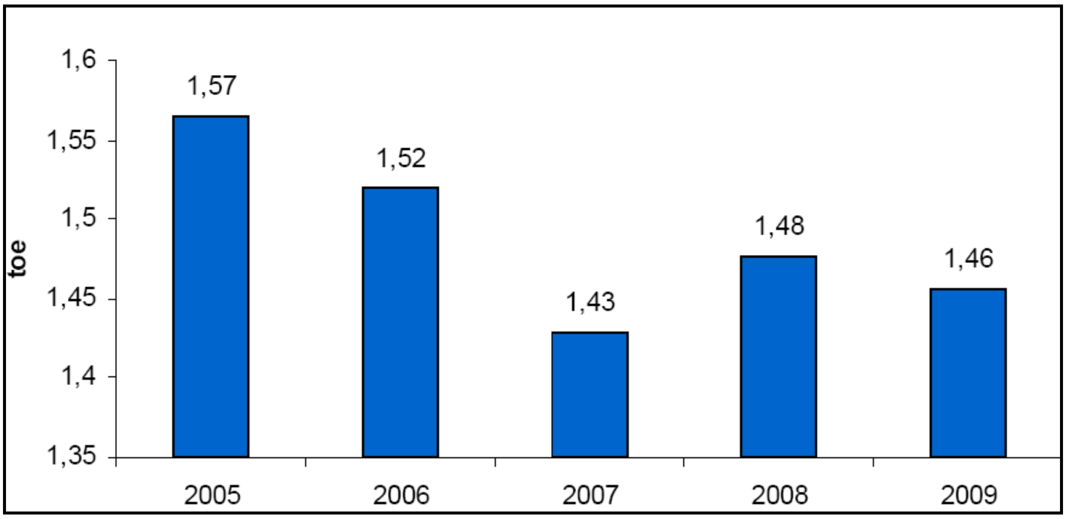


Fig. 3.6 Final Residential energy consumption per dwelling in EU-27 during the time span 2005-2009 (source Eurostat, JRC)

The main Energy key-factors: Electricity Consumption and Natural Gas Consumption

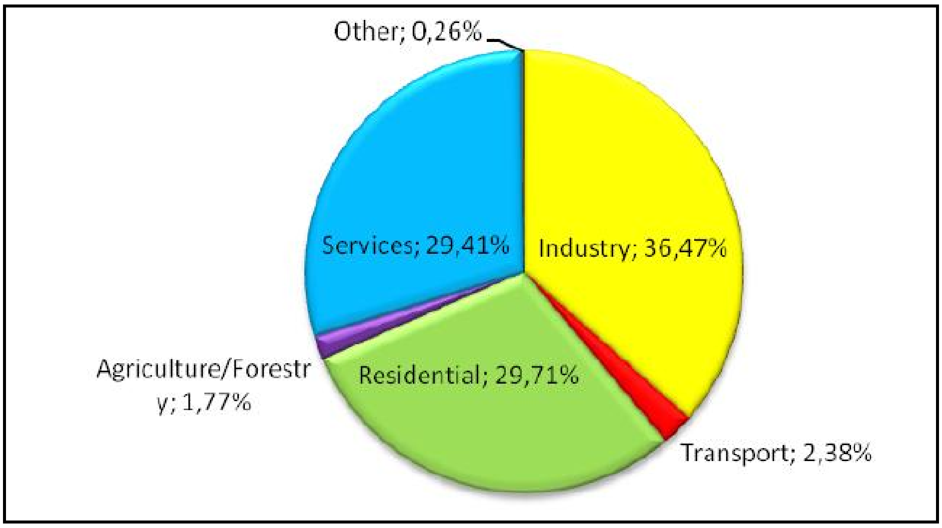
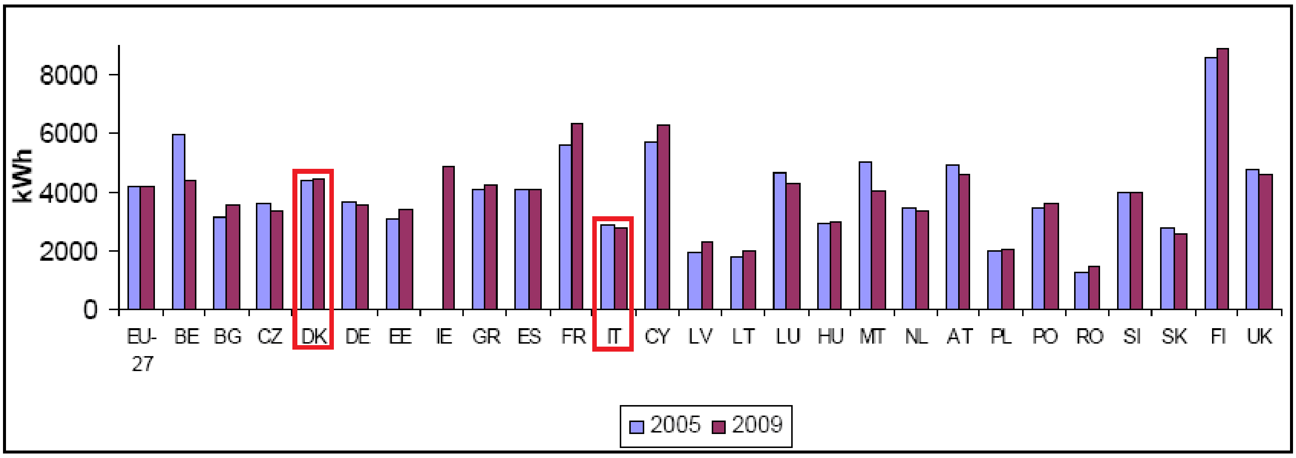


Fig. 3.7 Final Electricity consumption breakdown into sectors in the EU-27 (source Eurostat)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
EU-27	714,320	738,931	746,837	781,148	795,814	805,494	818,092	811,110	815,662	821,495	842,663
BE	23,738	24,396	25,921	26,026	26,543	26,007	22,722	21,856	19,982	20,210	20,276
BG	9,858	9,751	9,306	9,311	8,770	9,046	9,305	9,376	10,027	10,302	10,559
CZ	13,822	14,239	14,121	14,508	14,525	14,719	15,198	14,646	14,703	14,687	15,028
DK	10,215	10,159	10,190	10,262	10,332	10,449	10,573	10,349	10,280	10,096	10,389
DE	130,500	134,000	136,500	139,100	140,400	141,300	141,500	140,100	139,500	139,200	141,700
EE	1,466	1,585	1,584	1,594	1,618	1,620	1,675	1,773	1,845	1,884	2,023
IE	6,375	6,728	6,579	6,966	7,346	7,512	8,083	8,063	8,526	8,105	8,507
GR	14,207	14,546	15,775	16,444	16,852	16,875	17,676	17,957	18,126	18,131	18,130
ES	43,619	49,685	50,636	54,235	58,046	62,584	70,734	71,328	73,149	75,344	77,604
FR	128,720	133,887	132,998	141,554	147,088	144,548	147,104	145,755	150,899	151,733	162,470
IT	61,112	61,553	62,957	65,016	66,592	66,960	67,635	67,220	68,389	68,924	69,550
CY	1,055	1,042	1,157	1,295	1,316	1,433	1,500	1,608	1,683	1,722	1,738
LV	1,189	1,239	1,317	1,421	1,467	1,572	1,728	1,794	2,031	2,000	1,938
LT	1,767	1,818	1,811	1,918	2,090	2,162	2,374	2,489	2,730	2,725	2,590
LU	792	801	808	822	839	845	831	844	776	904	925
HU	9,792	10,130	10,440	11,063	11,032	11,115	11,451	11,250	11,460	11,235	11,202
MA	559	540	570	629	615	623	659	658	645	570	475
NL	21,808	22,111	22,815	23,329	23,531	24,232	24,833	24,294	24,798	24,156	24,703
AT	14,962	16,209	16,730	17,275	17,119	17,489	17,471	17,301	17,543	17,723	18,057
PL	21,034	21,376	21,659	24,852	25,476	25,253	26,467	26,369	27,115	27,534	28,615
PT	10,056	10,625	11,382	11,835	12,432	13,242	13,406	13,863	13,444	14,190	14,522
RO	7,652	7,724	7,771	8,243	8,043	9,234	9,999	10,389	10,400	11,021	11,329
SI	2,601	2,675	2,704	3,008	3,012	2,951	3,055	3,021	3,182	3,137	3,219
SK	5,419	5,222	5,157	5,039	4,817	4,701	4,577	4,602	4,531	4,428	4,362
FI	18,140	19,373	19,942	20,404	20,338	20,648	21,342	21,491	21,169	22,047	23,649
SE	42,020	42,180	41,473	41,998	41,375	42,663	41,490	39,638	38,929	40,946	40,422
UK	111,842	115,337	114,534	123,001	124,200	125,711	124,704	123,076	119,800	118,541	118,681

Fig. 3.8 Final residential electricity consumption along the EU-27 Member States (source Eurostat)



Final residential electricity consumption trends per dwelling in the EU-27 Member States: 2005 versus 2009 (source Eurostat)

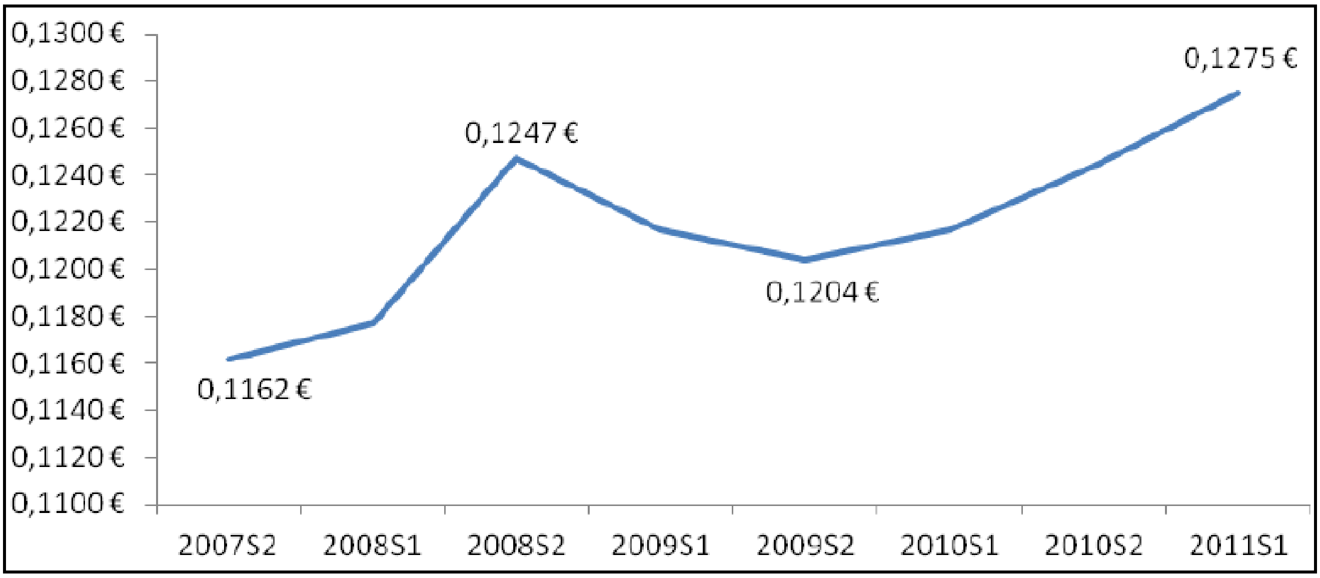


Fig. 3.9 Residential electricity price trends in the EU-27: six-monthly distinction over the latest years given in € per kWh of electricity and for a Domestic Consumption Band of 2500 kWh – 5000kWh (source Eurostat)

Considering now the overall gas consumption trend for the residential sector, it's possible to infer that its global final consumption has started decreasing by year 2004 until the year 2009.
In particular, the EU-27 total gas consumption dropped by -5,73% between 2005 and 2010.

During year 2010, the total gas consumption assessed in the EU-27 was 268.516 ktoe, compared to 229.009 ktoe in 1990 (resulting in a 17,25% increase by the year 2010).
The final gas consumption has been decreasing since 2005 until 2009, while instead, during 2010, it has started to grow once again.
This latest increase could also be ascribed to the unusual quite cold winter registered in 2010 and, besides, to the economic rebound effect after the crisis in 2009.
In particular, for the residential sector, the pattern has been analogous and also decreasing until 2010.

Moreover, considering that - during 2010 - the final residential gas consumption in the EU-27 was 119.075 ktoe, it's also possible to gather that, between 1990 and 2010, the final residential gas consumption in the EU-27 increased by 52,26%; and, more precisely, between 2000 and 2010 it increased by 5,98%.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
EU-27	112,362	112,602	111,883	118,675	122,840	122,966	119,970	113,087	116,419	115,603	119,075
BE	3,293	3,622	3,456	3,599	3,765	3,726	3,457	3,279	3,299	3,313	3,826
BG	0	1	1	3	6	14	24	33	39	51	49
CZ	2,049	2,377	2,230	2,402	2,351	2,311	2,275	2,036	2,047	2,059	2,382
DK	658	699	671	717	713	705	683	635	633	641	751
DE	23,441	24,729	24,728	26,903	28,383	29,027	28,813	28,164	29,024	28,805	22,976
EE	42	42	37	37	39	45	46	49	49	51	55
IE	438	481	475	538	600	606	631	592	667	623	708
GR	5	5	9	19	35	73	139	177	208	256	255
ES	2,020	2,261	2,534	2,962	3,035	3,187	3,662	3,779	3,640	3,687	4,027
FR	17,180	12,908	13,226	13,154	14,764	14,452	14,614	12,941	14,003	14,194	13,871
IT	14,975	15,746	15,301	17,273	17,937	18,746	17,017	15,942	16,015	16,821	18,698
LV	63	72	79	88	95	100	103	110	112	103	124
LT	104	107	110	117	127	134	140	147	146	145	158
LU	157	173	175	188	204	204	189	188	201	196	196
HU	3,025	3,304	3,413	3,947	3,568	3,928	3,644	3,174	3,294	3,182	3,238
NL	7,968	8,278	7,825	8,014	7,900	7,522	7,371	6,634	7,107	7,462	8,641
AT	1,123	1,256	1,174	1,240	1,211	1,285	1,235	1,157	1,173	1,220	1,340
PL	3,052	3,198	3,039	3,051	3,021	3,229	3,315	3,170	3,141	3,223	3,547
PT	99	120	147	158	181	200	203	220	230	264	299
RO	2,217	1,995	2,352	2,561	2,544	2,301	2,548	2,067	2,189	2,147	2,206
SI	59	62	68	86	98	98	93	85	102	106	114
SK	1,642	1,657	1,603	1,609	1,487	1,418	1,283	1,110	1,182	1,206	1,332
FI	23	27	30	29	31	30	34	37	39	43	48
SE	103	120	76	69	70	71	56	54	53	75	85
UK	28,626	29,362	29,126	29,909	30,677	29,552	28,395	27,307	27,824	25,731	30,149

Fig. 3.10 Final residential gas consumption registered in in the EU-27 Member States expressed in ktoe (source Eurostat)

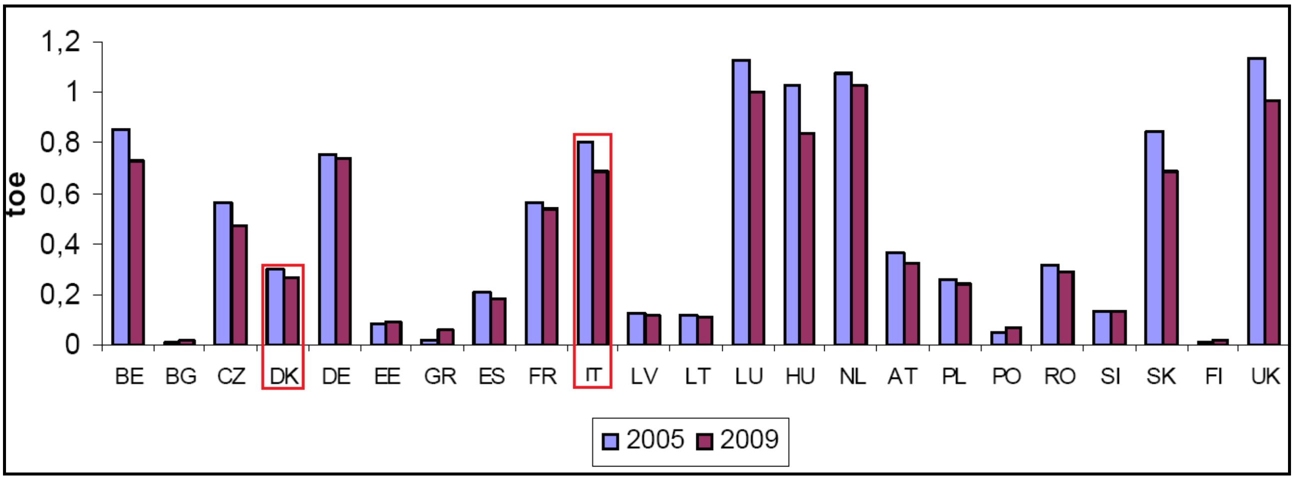


Fig. 3.11 Final residential gas consumption per dwelling in the EU (excluding Cyprus, Malta, Ireland and Sweden - source Eurostat)

3.1 Implementation of the Energy Performance Directive - EPBD – Energy Efficiency status report

Reaching energy savings by mean of existing building stock's retrofit and refurbishment is one of the most attractive and straightforward options to reduce CO_2 emissions, also potentially improving energy security thanks to the reduction of fossil fuels' imports.
Actually, as demonstrated by the present research, there is wide evidence that undertaking energy efficient renovations at current energy prices might also pay for themselves.

Besides, in addition to the permanent benefits such renovations may bring, they could also push and power the European economy in such a period of economic underperformance, spare capacity and record low real interest rates for a considerable number of EU countries.
Moreover, buildings stock's renovation could produce a wide range of other co-benefits: a healthier indoor climate, along with an improved health due to less air pollution, will lead to fewer hospitalizations also improving workers' productivity.
Actually, harvesting renovation opportunities could bring huge benefits to the EU economy over the coming decades.
Basing on available estimates of the potential for energy savings from renovation of buildings, recent studies (ref. *"Multiple benefits of investing in energy efficient renovation of buildings"- Copenhagen Economics*) suggested a monetized permanent annual benefit to society of approximately 104-175 billion of Euros in 2020 - depending on the level of investments made from 2012 to 2020.
Besides, such studies reported an amount of 52-75 billion of Euros from lower energy bills and at least 9-12 billion of Euros from the co-benefits of reduced outlay on subsidies and reduced air pollution from energy production. Finally, also including those health benefits from an improved indoor climate (indeed quite evidents, but also uncertain to estimate), such values increase by an additional 42-88 billion of Euros per year.

Another element to be highlighted is that, while most of the benefits from increased investments accrue to society as a whole, also governments themselves may reap additional net revenue gains: a lower level of total energy consumption might reduce public spending on energy bills (like public buildings and institutions) and would involve lower public spending through less hospitalization, also reducing need for subsidies to energy consumption; this would finally facilitate the achievement of EU's 2020 renewable energy targets and reductions of greenhouse gases with such lower global costs.

Of course, attaining these benefits will require investments and man power, but the current economic climate is ideal for starting such projects: real interest rates are at record low levels in most of the EU Member States, while unemployment has risen in nearly all countries since 2008 and it's likely to remain at "structural" levels for another 3-5 years.
Investment costs are therefore low and there's a wide range of available labor resources.
Thence, by harvesting such investment opportunities dealing with energy efficiency retrofits for the existing building stock, can stimulate economic activity at an appropriate time: this would lead to a jobs' rising for approximately 760.000 – 1.480.000 people and bring benefits to GDP of 153 - 291 billion of Euros depending on the level of investments.

The above values correspond to between 1,2% and 2,3% of EU GDP.

<u>Thus, considering such enlightenments, it's possible to gather that energy savings projects would represent a very attractive combination of boosting the economy and improving public finances at the same time.</u>

But actually still some **<u>barriers</u>** stand in the way of such investment plans as, for instance:

- the current rent regulations in both publicly and privately owned residential houses, which often prevent landlords from passing on the costs for improvement in the quality of buildings, including a lower energy bill to tenants: indeed, this condition greatly concurs into reducing landlords' incentive to invest in energy efficient refurbishments, as such investments would only reduce the total housing bill for the tenant.

A rent regulations adjustment and modernization is therefore required in order to allow both landlords and tenants to split the gains from energy efficient renovation of buildings.
In addition, this purpose could also be achieved without any direct cost to public finances;

- besides, it has to be highlighted that dealing with the risks connected to such renovation projects has traditionally been a weak point: actually, in this field investors may face high up-front costs, which imply that they run more substantial risks than for a similar project with lower up-front costs. In reference to this latest task it's then important understanding how to better set up, monitor and evaluate performance contracts which ensure the owners (and/or the users) of the building concretely get such final benefits, in order to pay back the substantial and not-reversible investment cost over time.

Concepts like, for instance, Energy Service Companies (ESCO) and Energy Performance Contracts (EPC) - which are explicitly designed to align risks and responsibility for the outcome of such projects - should thence been adjusted and strongly boosted.
Moreover, also properly sized and well designed risk-sharing programmes could help governments, along with private building owners, into achieving such cost savings with more limited budget costs.

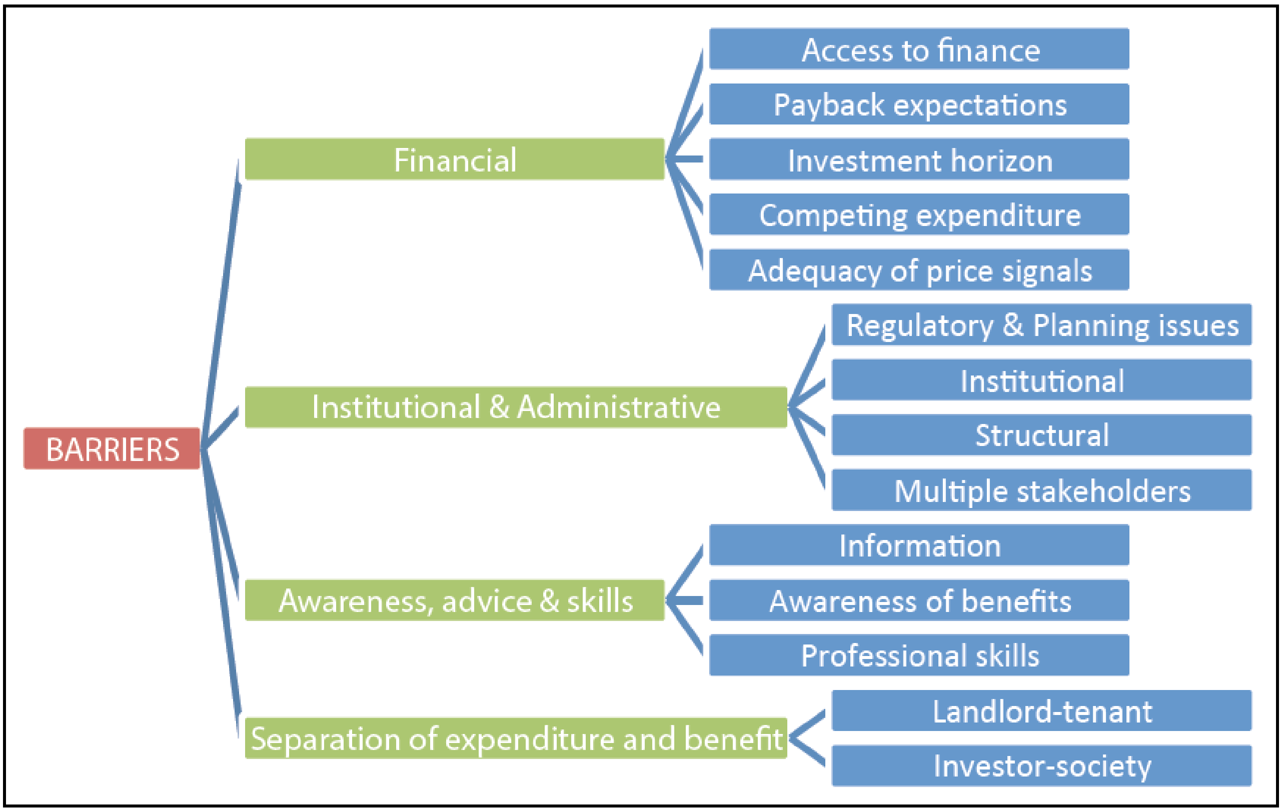


Fig. 3.12 The most significant types of barriers encountered in building renovation (Source BPIE)

"Buildings represent the largest untapped source of cost effective energy saving and CO_2 reduction potential within Europe, yet the sector continues to suffer from significant underinvestment" (*BPIE - A guide to developing strategies for building energy renovation*).
It's therefore timely that the **Energy Efficiency Directive** (**EED**, 2012/27/EU) established in October 2012 includes such requirements for Member States to develop and put into effect proper long term renovation strategies for their national building stocks.
Regarding this task it's necessary to recall that the Energy Efficiency Directive replaced the two previous Directives on Energy Services and Cogeneration, seeking to promote the energy efficiency across the European Union. Actually, it has been adopted in order to help delivering the EU's 20% headline target on energy efficiency by 2020, also paving the way for further improvements thereafter.

The EED contains several measures designed to deliver energy savings across all sectors: from overall national energy efficiency targets, till to the setting of energy efficiency obligations for energy companies.
But beside the above Directive, it's necessary to specify that, particularly the **Energy Performance of Buildings Directive** (EPBD, 2010/31/EU) - recast in 2010 – prescribes a large set of requirements, including energy performance certification of buildings, inspection regimes for boilers and air conditioning plants, also introducing requirements for new buildings to be nearly zero energy (aka NZEB).
Moreover, the EPBD also sets minimum energy performance standards for buildings undergoing renovation.

Thence, together, EED and EPBD provide a valid framework for Member States to drive the reduction of energy use in buildings, also delivering a wide range of economic, environmental, societal and energy security benefits.
In particular, one of the most significant elements and prescriptions settled out by the EED is referred to Building Renovations (as appointed by the **article 4**).
Actually, this article requires that "*Member States shall establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private*" (ibidem).

Furthermore the above Directive also yields additional reference points for Member States to gear their policy package towards the delivery of such a long term building renovation strategy - as following synthetically recalled, also with reference to the present research's main goals:

article 3 (*Energy efficiency targets*);

article 8 (*Energy audits and energy management systems*): actually such audits could be the instrumental first step in order to stimulate investments in energy savings; hence Member States should consider which support measures need to be put in place to ensure these audits lead to deep renovations;

articles 9 (*Metering*), **10** (*Billing information*) and **article 12** (*Consumer information and empowering programme*): since raising awareness of the cost saving potential for building renovation can be achieved by mean of a proper use of the regular communication channels (i.e. meters and energy bills) to bill payers, as well as through other ways of engaging with building owners and energy consumers;

article 14 (*Promotion of efficiency in heating and cooling*);

article 15 (*Energy transformation, transmission and distribution*): regulatory structures, tariffs and incentives in the energy supply system need to be assessed in order to ensure they are fruitful enough to invest in the field of demand side energy saving measures (also including the connection of micro-energy generators, such as buildings integrated renewable technologies and combined heat and power systems);

article 17 (*Information and training*): of course, the availability of trustworthy information and advices, as well as an adequately trained workforce and awareness campaign, is a necessary pre-requisite for the scaling up of national renovation activities;

article 20 (*Energy efficiency national fund, financing and technical support*): since all these factors represent a necessary tool to promote and enable large scale investments in the building stock, in order to deliver the potential benefits; this is thence a pre-requisite for a successful and effective renovation strategy.

Furthermore, additional measures, tipically focused on the building field, are provided by EPBD, whose prescriptions actually represent a complementary tool for a wider renovation strategy.

In particular, as following recalled:
article 4 (*Setting of minimum energy performance requirements*): in order to ensure that minimum energy performance requirements are properly settled, with a view to achieving cost-optimal levels both for existing, as well as new buildings. Actually, such minimum energy performance requirements need to be reviewed and updated at least every five years, also taking into account technological development in building materials and systems;

article 7 (*Existing buildings*): when restoring and refurbishing existing buildings (totally or partially), their energy performances (or at least for the renovated part) need to be upgraded in order to meet minimum energy performance requirements;

article 8 (*Technical building systems*): this article highlights that the overall energy performance of efficient, appropriately sized and controlled equipment providing heating, hot water and lighting - as well as air conditioning and ventilation - represent a key component in order to reduce energy consumption. Thence, Member States are required to accordingly set proper technical building system requirements;

article 9 (*nearly Zero-Energy Buildings*): it requires that Member States define national plans in order to increase the number of nearly zero-energy buildings. Actually, it provides for the greatest synergy with such a renovation strategy, also reinforcing the key message about the level of ambition (i.e. energy saving) that should be sought when retrofitting buildings;

article 10 (*Financial incentives and market barriers*): dealing with the same topics highlighted by Articles 19 and 20 of EED, this one stresses even more the importance of addressing market barriers and providing appropriate financial incentives in order to improve energy performances of the building stock;

articles 11, 12, 13 (*Energy Performance Certificates*): since an effective EPC frame properly raises awareness, as to the actual energy performance of buildings, favouring the opportunities to improve their performances;

articles 14, 15, 16 (*Inspection of heating and air conditioning systems*): actually, through the development of an adequate inspection regime, it's possible to settle a fruitful basis for identifying opportunities in order to improve (and/or upgrade) the essential energy systems' performances;

article 17 (*Independent experts*): a properly trained group of experts - qualified within the framework of such an independent certification and accreditation system - represents another key component of ensuring the correct certification of buildings and energy systems, also detecting the most suitable renovation opportunities.
But in order to achieve a more complete overview about this task, it's necessary to underline that the frame depicted by the above Directives has got a complementary character – even though coactive – and thence specific EU legislations are still required.
Actually, with the final aim to support a holistic approach into developing such renovation strategies, Member States should be aware that national legislations (such as energy planning or regional development plans) can play a fundamental role, also strengthening all the renovation objectives.
Moreover, equally important is the long term dimension of such renovation strategies. As above highlighted, European Directives require that national renovation policies are reviewed and updated every three years: revisions that need to be grounded on the actual evaluations of such policies' impact and properly sized accordingly to the specific context.

When undertaking and developing an economic appraisal for any energy saving investment and building's refurbishment, it's necessary to be aware that those only benefits which are normally and usually monetized by the potential investor is the energy cost savings: but following this assessment criterion, the investment full impact is going to be necessarily undervalued.
Actually, many other benefits accrue to society at a larger scale and hence are not valued by individual investors.

Indeed, broadly speaking, the impacts of undertaking sustainable energy renovation of buildings could be summarized under the following headings:

• **Economic Benefits:**

- Energy cost saving: actually, also a deep renovation scenarios analysis recently carried out by BPIE (http://bpie.eu/eu_buildings_under_microscope.html) demonstrated the wide potential of net energy costs savings for end users. Besides, the consequent increased disposable income ascribable to a reduced expenditure on energy utilities, could lead to an increased expenditure on other goods and services, therefore producing economy-wide benefits;

- economic stimulus: the employment and economic impact stimulated by investing in a more sustainable building stock can be seen across a wide range of players in the value chain, from the manufacturing and installations, through to the provision of other professional services such as financing and project management;

- impact on the Gross Domestic Product (GDP): the Commission Energy Efficient Directive's impact assessment identified that the achievement of targeted savings would result in an increase of EU's GDP evaluated in 33,8 billion of Euros in 2020 (+2,7% compared to baseline) ref.*http://ec.europa.eu/energy/efficiency/eed/doc/2011_directive/sec_2011_0779_impact_assessment.pdf;*

- property values: actually, there's a significant body of evidence that buildings with high energy performance are more valuable (in terms of resale, or with reference to the rent they can command and/or in terms of occupancy levels) than their less efficient counterparts (source: BuildingRating.org);

- research and development, industrial competitiveness and export growth: addressing towards more efficient ways to reduce energy consumption in buildings, such policies directed to a major building renovation could spur the research & development field, also leading to an enhanced industrial competitiveness along with export opportunities;

- impact on public finances: as reported by a recent *Copenhagen Economics* assessment commissioned by *Renovate Europe* (ref: *http://www.renovate-europe.eu*), a huge investment in building retrofits, given prevailing high levels of unemployment in many Member States, would have a positive impact on public budgets estimated in about 0,5-1,0% of GDP;

- energy import bill: EU already imports the majority of its energy needs, for a total annual cost evaluated in 355 billion of Euros. And according to the latest IEA projections in World Energy Outlook 2012, this import dependency for both oil and gas is projected to substantially increase over the coming years (ref. *http://www.worldenergyoutlook.org/publications/weo-2012/*).

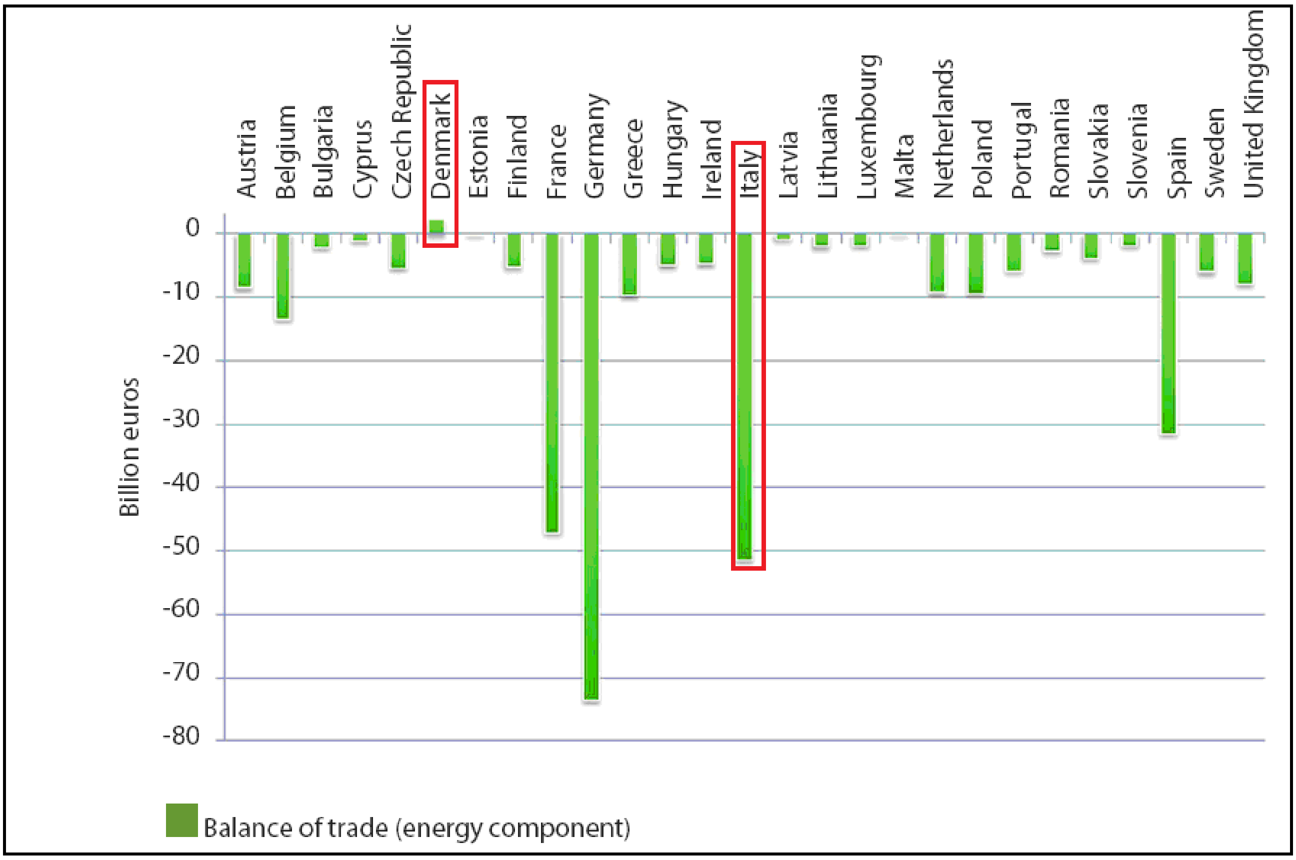


Fig. 3.13 Energy bill import dependency in 25 EU Member States (Source IEA, Eurostat)

- **<u>Societal Benefits:</u>**
  - <u>reduced fuel poverty;</u>
  - <u>health benefits;</u>
  - <u>increased comfort and productivity</u>: homes and workplaces which, as a result of thermal renovation are easier to be maintained at comfortable temperatures (avoiding both over-heating in summer as well as under-heating in winter) can lead to a better working environment, also increasing the average productivity. Actually, as already assessed by a recent research (year 2003), *"thermal discomfort caused by high or low temperature had negative influence on productivity"* (ref. Lan, L., Z. Lian, and L. Pan - The effects of air temperature on office workers' well-being, workload and productivity-evaluated with subjective ratings; Applied Ergonomics).

- **<u>Environmental Benefits:</u>**
  - <u>carbon saving;</u>
  - <u>reduced air pollution;</u>

- **<u>Energy System Benefits:</u>**
  - <u>energy security:</u> actually, as also stated by the report "*A Strategy for Competitive, Sustainable and Secure Energy*" published by the European Commission - where top priority is ascribed to achieving the biggest energy saving potentials, namely in buildings and transport - the energy demand reduction is recognized as a strategic key component of global energy security;

- avoided new generation capacity: also according to a recent European Commission assessment, the achievement of the 20% energy efficiency target would avoid the construction of an equivalent of 1.000 coal fired power stations, or 500.000 wind turbine installations (*http://eur-lex.europa.eu*);
- reduced peak loads.

In the light of the above enlightenments it's then possible assessing that the enhancement of existing building stock's energy efficiency, would lead to a wide range of benefits: but actually, while some of these occur directly (for instance through a reduced energy consumption level), other ones may occur more indirectly (e.g. the improved health over several years).
Furthermore some of these benefits have direct and tangible effects on public budgets, while other ones reveal themselves positive for the society on a larger scale, without having any specific public finance effect.

To sum up, such a wide array of benefits could be depicted by the following all-embracing overview:

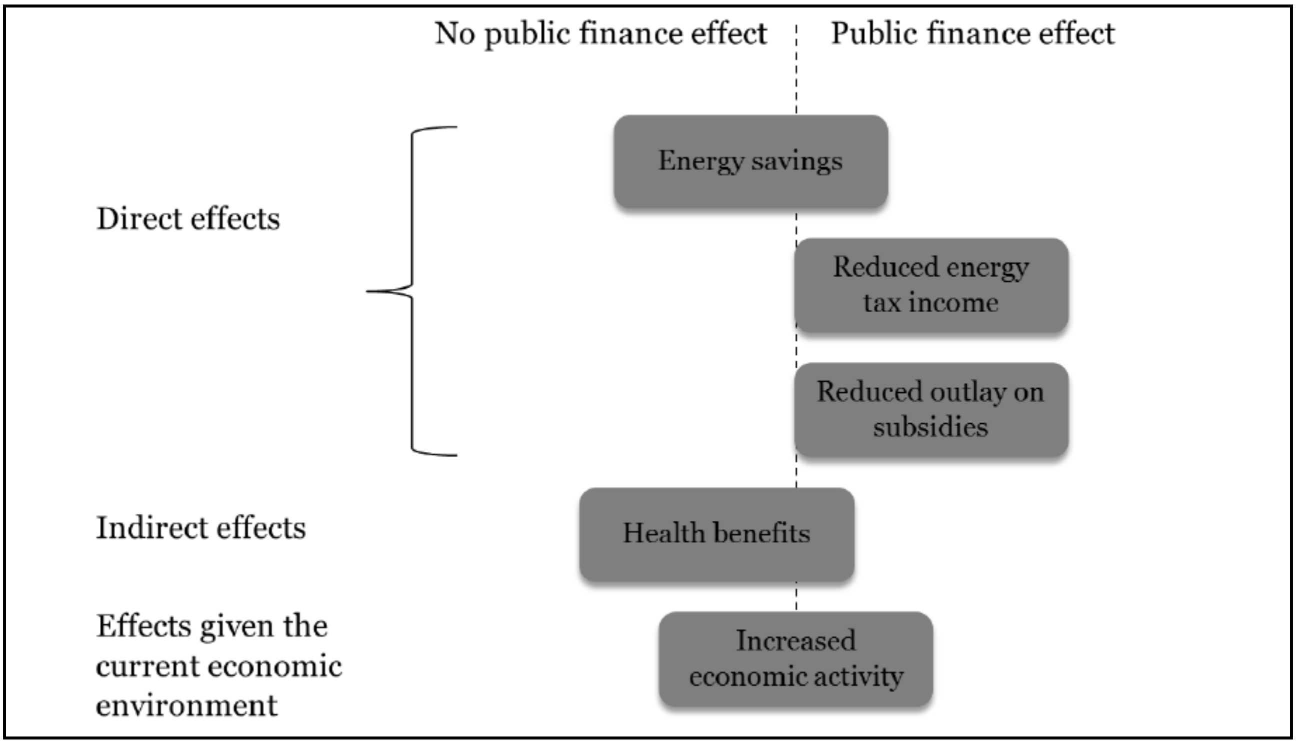


Fig. 3.14 Effects of energy efficient renovation of buildings (Source Copenhagen Economics)

Energy Efficiency

Council Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

Energy Labelling of Domestic Appliances

Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances and its amendments and implementing measures ("Energy Labelling Directive") repealed by:

Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (recast)

Ecodesign of Energy-related Products

Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005, as amended by Directive 2008/28/EC of the European Parliament and of the Council of 11 March 2008, establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council ("Ecodesign Directive"), replaced by Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast)

Energy Performance of Buildings

Directive 2002/91 of the European Parliament and of the Council of 16 December

2002 on the energy performance of buildings and its amendments repealed by its recast Directive:

Directive 2010/31 of the European Parliament and of the Council of 17 May 2010 on the energy performance of buildings and its amendments (the recast Directive entered into force in July 2010, but the repeal of the current Directive took place on 1/02/2012)

Repealed Directives

End-use Efficiency & Energy Services – Now repealed.

Directive 2006/32 of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive

93/76/EEC ("The Energy Services Directive").

Cogeneration - Combined Heat and Power (CHP) – Now repealed.

Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels.

Fig. 3.15 Energy Efficiency Directives in force: overall framework (Source: *Understanding the Energy Efficiency Directive-Steering through the maze #6-* European Council for an Energy Efficient Economy *eceee* – December 2013)

3.2 European energy policies vs. National Laws and Regulations

Before going deeper into developing an all-embracing overview about the two European Countries mainly involved in the current analysis, it's important to recall and highlight the following key elements. The huge importance of an effective building stock renovation strategy is disclosed by the awareness that it would engage building owners as well as the supply chain, including the investment community (which actually is widely diversified from a country to another as well): hence all the several Member States need to consider the specific policy landscape which is necessary in order to increase renovation activity, including removal of those barriers that are currently holding back investments (as before highlighted).
Furthermore, beside the definition of a long term strategy with interim milestones, such a policy should set out a detailed plan of action for the next 5-10 years, focusing on the specific actions and measures needed in order to scale up renovation activity and identifying priority sectors.

In addition, such proper efforts aimed to increasing the rate and depth of renovations would stimulate the development of new technologies and techniques to deliver energy savings.
Hence, also in the light of this latest consideration, when planning an adequate strategy it reveals rather important to factor in the entire technological sector's development, as well as the cost reductions that can be achieved through scaling up activity levels (as hereinafter highlighted). Therefore, assumptions about the future costs and renovation potential must not be limited by today's technologies, construction techniques and costs, but should be wisely weighed up.

Last but not least, other key factors to be considered into developing such a long term vision are connected to the need of delivering a renovation strategy flexible and dynamic: actually the wider benefits arising from energy saving renovations need to be balanced with the inertia among building owners and the above depicted tenant-landlord barrier.

Focusing now the analysis on the current European context and before centering on the two European Countries mostly involved in the present job, it's necessary to remark the following topic: despite several Member States have already set out a long term vision for the evolution of the entire building sector, none of them has currently developed such policies able to gear up renovation measures to the extent required in order to effect a transformation in national building renovation activity (source BPIE).
Moreover, still according to a BPIE analysis **"*delivering the long term renovation strategy will require a fundamental review of the policy landscape and the introduction of new policies and measures on a scale not previously witnessed*".**

Actually, with regard to this latest remark, it's possible to observe that:

- **Denmark** has got a long tradition of active energy policy ever since the oil crises of the 70's: in 2012, widespread political support was ensured for a further package of measures – also including building retrofitting – which has led this country closer to the ultimate goal of eliminating fossil fuel use in the energy and transport sectors by 2050 (as reported by the Danish Energy Agency - ref. *http://www.ens.dk*).
  Nevertheless, nowadays no incentives or other financial measures and tax reliefs have been established in order to support refurbishment activities and energy saving investments in private dwellings.
  And actually this aspect doesn't only apply to energy efficient renovation of buildings, but to the maintenance of buildings in general: also a recent study (Rambøll - 2010 quoted by a Copenhagen Economics report) refers that "*the local municipalities were not making sufficient maintenance renovations to maintain a sustainable building stock quality and condition*".

- Under this point of view the **Italian** political framework has instead disclosed a more evident and tangible financial support in order to promote energy efficient investments in private, as well as in public buildings (as hereinafter further detailed).

3.3 Italian assessment: Standards, Energy Requirements and main Regulations

In this European Union Member, the *Italian Ministry for Economic Development* holds the overall responsibility for the implementation and application of the EPBD Recast.
At this purpose, since 2005 several regulations and laws have been established - and year by year revised and adjusted - in order to meet the even stricter and tighter requirements settled at European level.
In particular, during this year a first decree has been enacted in order to set the bases for the main framework of such energy strategy: and as above highlighted, a consistent number of legal acts (Legislative, Ministerial and Presidential Decrees) were issued, progressively defining and regulating step by step every single task involved in the entire EPBD transposition.
At this reference, a clarification is needed concerning the implementation of such regulations along the entire country: actually, according to the Italian Constitution, energy related topics are a theme to be equally shared between the State and all the 21 Regions and Autonomous Provinces.

Hence Regional Authorities could establish and apply their own autonomous EPBD transpositions (as long as they don't contradict the general principles and requirements provided both by National and EU Regulations).
Those Regions which haven't instead published their own legislation must follow the National Regulation.
Currently, 11 Regions and Autonomous Provinces out of 21 have enacted their local transposition of the EPBD; namely, they are the following ones:

- **Regions:** Liguria, Emilia Romagna, Toscana, Val d'Aosta, Lombardia, Friuli Venezia-Giulia, Puglia, Sicilia, Toscana;
- **Autonomous Provinces:** Trento and Bolzano.
  Furthermore, at the end of 2012, 6 of them (i.e. Liguria, Emilia Romagna, Toscana, Val d'Aosta, Lombardia and Bolzano) have transposed the EPBD recast.

With the purpose of analyzing and describing more in details the progress and the current status of Italian legislative framework it's important to refer, in first instance, that just last March – precisely on 14/03/2013 – finally came into force the final version of the so called ***SEN*** (the new ***National Energy Strategy***), after a wide-ranging public debate and a public consultation aimed to openly address its main statements with all the stakeholders therein involved.
The main measures established by such a strategy (which extends, essentially, to 2020), are intended to allow energy-related issues definitely stop being a structural disadvantage for the Italian country, as well as a factor which increasingly weighs onto household budgets.
One of the most important goals declared by the Institutional Ministerial channels concerns the possibility to maintain and improve the "*already high environmental, security and safety standards, thanks to the substantial investment expected in the sector*".
In particular, such a national energy policy should *"enable the system to evolve, gradually but significantly, and to surpass the 20-20-20 European targets"*.

In particular, the overall results expected by 2020 (assuming an economic growth in line with the most recent European Commission forecasts) could be summed up as follows:

- the wholesale prices of all the energy sources – electricity, gas and fuels – should be aligned with the average European price levels;
- the total expenditure on energy imports (currently estimated in 62 billion of Euros), should be reduced every year by about 14 billion of Euros, while instead the dependency on foreign supplies should pass from the percentage of 84% to the level of 67%: actually, such results should be achieved by mean of a higher level of energy efficiency, an increased production from renewable energy sources, lower electricity imports and an increased production from national resources;
- it was planned to invest – by mean of private investments partly supported by public incentives - up to 180 billion of Euros in the so called *green* and *white economies* (renewable energy sources and energy efficiency) and in traditional sectors (electricity and gas networks, re-gasification plants, storage, hydrocarbon development): such an investment trend would also generate positive economic returns for the entire country;
- thanks to such a strategy, it is expected that Greenhouse gas emissions will fall by about 19% (thence fully meeting the European targets for Italy, settled in a 18% reduction of the emission levels registered in 2005);
- renewable Energy Sources (a.k.a. *RES*) should account for 20% of the gross final consumption (compared with about 10% in 2010), while instead fossil fuel use should pass from the level of 86% to the percentage of 76%;
- directly related to this latest issue it is expected that *RES "will become the primary source in the electricity sector, equivalent to - or slightly overtaking - gas to account for about 36-38% of consumption (compared with 23% in 2010)"*;
- finally, with reference to the primary consumption level, it should fall by about 24% by 2020 compared with the reference scenario (i.e. an estimated 4% below 2010 levels): hence this latest objective reveals indeed quite ambitious, since the expected results exceed European targets by -20%, (and it should be mainly reached thanks to energy efficiency measures).

Italian Energy performance requirements: The national implementation of existing regulations process - current status

Focusing now on the main Italian regulations framework it's necessary to distinguish between new buildings' requirements and existing buildings' prescriptions:

New Buildings

Since January 2010, after a transition phase which had settled intermediate requirements, all new residential and non-residential buildings must fully comply with the minimum requirements for winter performance established by the Legislative Decree 192/2005 (as amended).

The exact value of EP (or more precisely the $\boldsymbol{EPi_{lim}}$ – *Limit for the Energy Performance Index for winter heating*) changes according to the specific building type to be assessed, along with several other factors (as below recalled):

- the EP for residential buildings is expressed in terms of $kWh/m^{2}*year$ of primary energy, while EP index for non-residential buildings is expressed in terms of $kWh/m^{3}*year$ of primary energy;
- the EP specific value varies according to the climatic zone and the local degree days;
- the EP depends on the surface area to volume ratio of the single building, as following depicted:

surface area to volume ratio	Climatic zones (by degree days)									
	A	B		C		D		E		F
	≤600 dd	>601 dd	≤900 dd	>901 dd	≤1400 dd	>1401 dd	≤2100 dd	>2101 dd	≤3000 dd	>3000 dd
≤0.2	**8.5**	**8.5**	**2.8**	**12.8**	**21.3**	**21.3**	**34**	**34**	**46.8**	**46.8**
≥0.9	**36**	**36**	**48**	**48**	**68**	**68**	**88**	**88**	**116**	**116**

Fig. 3.16-a Minimum EP requirements for winter heating in residential buildings (kWh/m^2*year)

surface area to volume ratio	Climatic zones (by degree days)									
	A	B		C		D		E		F
	≤600 dd	>601 dd	≤900 dd	>901 dd	≤1400 dd	>1401 dd	≤2100 dd	>2101 dd	≤3000 dd	>3000 dd
≤0.2	**2**	**2**	**3.6**	**3.6**	**6**	**6**	**9.6**	**9.6**	**12.7**	**12.7**
≥0.9	**8.2**	**8.2**	**12.8**	**12.8**	**17.3**	**17.3**	**22.5**	**22.5**	**31**	**31**

Fig. 3.16-b Minimum EP requirements for winter heating in non-residential buildings (kWh/m^3*year)

Furthermore, the Presidential Decree n.59/2009 has also introduced - the first time for Italian legislative iter - specific Energy Performance requirements for summer cooling (along with the *EPe* reference values), as below recalled:

Climatic zones (by degree days)					
A	B	C	D	E	F
<600	from 601 to 900	from 901 to 1400	from 1401 to 2100	from 2101 to 3000	over 3000
40	40	30	30	30	30

Fig. 3.17 Minimum EP requirements for summer cooling in residential buildings (kWh/m^2*year)

Climatic zones (by degree days)					
A	B	C	D	E	F
<600	from 601 to 900	from 901 to 1400	from 1401 to 2100	from 2101 to 3000	over 3000
14	14	10	10	10	10

Fig. 3.18 Minimum EP requirements for summer cooling in non-residential buildings (kWh/m^3*year)

Existing Buildings:

The minimum requirements for these buildings are distinguished depending on the specific degree of planned renovation.

- In particular, the same minimum EP requirements valid for new buildings must be equally applied in the following cases:
  - demolition and consequent reconstruction;
  - renovation of all the building elements (for buildings with heated floor area > 1000 m^2);
  - building enlargements over 20% of the original volume (only for the newly built section).

- In case of any other degree of refurbishment a set of basic requirements and prescriptions must be fulfilled with reference to every single building element (as summed up by the following table).

	U-values (W/m².K)				
Climatic zones	walls	roof	floors	windows	window glass only
A	0.62	0.38	0.65	4.6	4.6
B	0.48	0.38	0.49	3.0	3.0
C	0.40	0.38	0.42	2.6	2.6
D	0.36	0.32	0.36	2.4	2.4
E	0.34	0.30	0.33	2.2	2.2
F	0.33	0.29	0.32	2.0	2.0

Fig. 3.19 Minimum required U-values for any single building element (kWh/m^2*K)

Furthermore, both in case of **new Buildings** and in case of **major renovations for existing buildings**, the designer must fulfill the following prescriptions:

- to compulsorily introduce window sun shades, also evaluating the respective contribution both to the winter and summer performance;
- to either check that:
  - the mass of the external walls, except North-East to North-West, is larger than 230 kg/m^2 (ref. Legislative Decree n.311/06) ;

    or
  - the above walls have got a value for periodic thermal transmittance (a dynamic parameter introduced by the European Standard UNI EN ISO 13786:2008) lower than 0,12 W/m^2*K;
  - to check that the periodic thermal transmittance only for North-East to North-West external walls is lower than 0,20 W/m^2*K.

It must be also highlighted that, starting from year 2006, also for heating systems and heat pumps were introduced (and subsequently adjusted) minimum efficiency requirements and specific prescriptions.

Finally, a particular attention has been focused on the **Public Buildings** sector, which actually plays a strategic role in the path to such *nearly-zero energy performances* and has been deeply investigated and regulated in the *Italian National Energy Efficiency Action Plan* (***NEEAP***).

At this reference, directly related to the above topic, the ***Second National Energy Efficiency Action Plan*** - issued in July 2011 - contains some preliminary milestones for setting an effective *National Strategy for Nearly Zero-Energy Buildings (NZEB).* Namely, among all its main requirements, it prescribes that:

- new minimum requirements for building EP and for building elements shall be set: the requirements must be settled with a global view to achieving the Cost-Optimality;
- incentive schemes: the Ministry of Economy and Finance and the Ministry for Economical Development shall join in a task force to plan and manage a National Incentive Scheme;
- social housing: shall be planned the introduction of an incentive/bonus for those projects which adopt and implement innovative solutions (e.g. cool roof, active building envelope systems, etc.), integration of renewable energy sources, use of ecologic components and materials, optimization of local economic resources;
- introduction of standardization in the use of Building Energy Management Systems (*BEMS*) for public buildings;
- with reference to the residential buildings: a particular focus should be addressed to the cluster of those existing buildings built before year 1976 (which actually represents more than 70% of all buildings), also providing adequate incentives by mean of low interest rates, revolving fund schemes for renovations etc…

- stakeholders involvement: actually, the *Italian National Agency for New Technologies, Energy and Sustainable Economic Development* (***ENEA***) will involve the most relevant stakeholders in several working groups, with the final goal of proposing new lines of action;
- an observatory will be settled to assess and monitor the effectiveness of all the main programmes and schemes ad hoc developed;
- school buildings: simplified procedures aimed to actively involve Energy Service Companies (*ESCO*s) shall be established.

Focus on the Calculation methodologies for the Energy Performances of Buildings: Compliance and Quality Assurance (QA) and Monitoring activities

The evaluation of the EP levels which must fulfill the mandatory requirements established by Law are based on the National Standard ***UNI TS 11300***: such a technical specification and calculation method is an application of the European Standard ***EN ISO 13790:2008***.
Other specific, regional calculation methodologies are almost entirely referred to the Italian National Standard, while only the *Lombardia* Region and the Autonomous Province of *Bolzano* have adopted their own standards directly derived from the ***EN ISO 13790:2008***.
Italian Municipal Authorities are responsible for carrying out special checks and assessments in order to verify and certify the compliance of minimum requirements.
Actually, the issue of a building permit is bound to such a compliance check: building owners are required to deliver to the municipal authority of reference an opportune technical report showing the specific Energy Performance level and thermal transmittance calculations, also recalling that local authorities may carry out onsite visits during or after the construction works. In addition, a final report - signed by an engineer - must be also filled up confirming the compliance with the town planning rules, the building regulations and the EP requirements.

Finally, it must be highlighted that the Italian Ministries of Economical Development and of Environment, along with the Regional Governments, are also responsible for monitoring the state of EPBD implementation at national level, periodically providing a report to the Parliament.

The Italian Incentives' Policy for Buildings' Retrofit

As hereinafter more deeply analyzed and explained in details in a specific chapter, Italian Government has launched an incentive scheme, starting from 2007 and currently still operative: it is based on a tax credit calculated as a percentage rate of those investments incurred for buildings energy renovations and dwellings energy efficient refurbishments.
At this reference, ENEA provides regular reports about the state of such a policy's implementation and, starting from year 2008, has published annual specific documents and synthetic reportages.
The latest official results are referred to year 2010 and have provided the following key data:

- 4.600 Millions of Euros of total investments;
- 2.000 GWh of primary energy savings;
- 430.000 ton of CO_2 emissions yearly avoided.

Italian Energy performance certification scheme: current prescriptions and implementation

It must be recalled that Regional Authorities may independently implement autonomous transpositions of the EPBD – as well as regional EP certification schemes - as long as these don't contradict the general principles and requirements provided both by National and European Regulations; at this reference, the following map highlights such a distinction.

Fig. 3.20 Regional EPBD regulations: the grey color highlights those regions which autonomously absorbed and implemented the European Directive (source: *European Union's Featuring Country Reports 2012)*

Moreover it must be highlighted that, while until 2012 it had been allowed to omit the certification of a building if its performance was in the lowest class (G) – simply through a self-certification by the building owner - a Ministerial Decree issued on the 22nd of November 2012 has now removed such a possibility.

In addition, according to the Decree 28/2011, every sale and rental contract (for buildings or single units) must contain a specific clause confirming that the buyer or manager has received all the necessary information and documents concerning the building Energy Performance Certificate (EPC).
Furthermore, it has to be specified that, while up to now - only in case of rental – it hadn't been compulsory to produce such a certification, the Decree Law n.63 issued on 04/06/2013 has recently extended (Article 6[2]) the certification to all buildings also when rented.

Besides, it must be observed that the legal validity for an energy certificate is 10 years and that the EPC needs to be updated whenever the building envelope or its main systems are modified.
The standard graphic layout of its dashboard is shown by the following image, which is specifically referred to a "B-class" unit.

Some further information are also summarized in a special section of the certificate, providing those recommendations and improving action suggested, along with the consequent results achievable and the respective payback time.

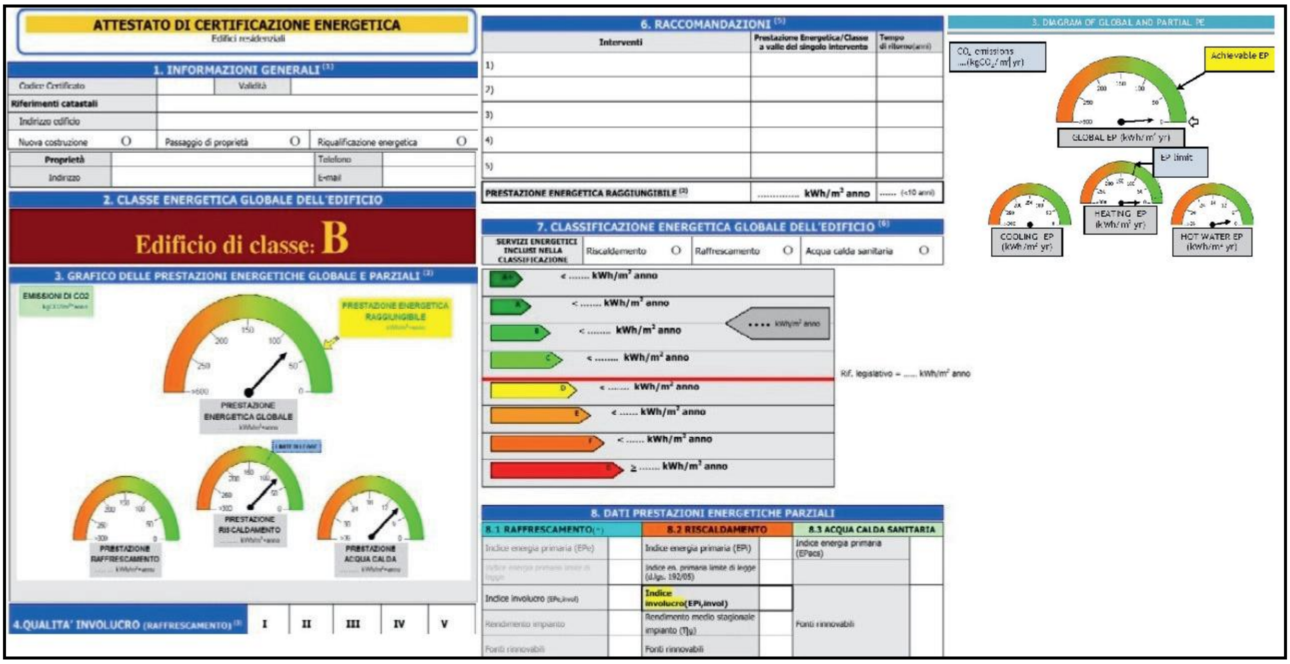


Fig. 3.21 National EPC format (a.k.a. *APE* in Italian)

As above shown, the EP level may be expressed by a single-letter-mark varying within the range from A+ to G class.

The building EP – which as already specified is expressed in terms of primary energy use in *kWh/m²*year* for residential buildings and in *kWh/m²*year* for non-residential ones - reports the energy level required by any building, also distinguishing among the single end uses: heating, domestic house water, cooling.
The global Energy Performance (*EPgl*) is the sum of all such partial EP indicators.

The Italian structuring process adopted for EP classes' definition is based on percentage variations in respect to a reference value (expressed as the EP minimum requirements for new buildings).

Heating classes are thence defined with reference to the minimum EP requirements (which came into force on 1st January 2010) and it's also important to highlight that, for any class, such EP varies with the climatic zone and the shape factor (i.e. ratio of envelope surface to heated volume) of the specific building.

	Class A+	< 0.25 $EP_{Lim\ (2010)}$ + 9 KWh/m^2.year
0.25 $EP_{Lim\ (2010)}$ + 9 KWh/m^2.year ≤	**Class A**	< 0.50 $EP_{Lim\ (2010)}$ + 9 KWh/m^2.year
0.50 $EP_{Lim\ (2010)}$ + 9 KWh/m^2.year ≤	**Class B**	< 0.75 $EP_{Lim\ (2010)}$ + 12 KWh/m^2.year
0.75 $EP_{Lim\ (2010)}$ + 12 KWh/m^2.year ≤	**Class C**	< 1.00 $EP_{Lim\ (2010)}$ + 18 KWh/m^2.year
1.00 $EP_{Lim\ (2010)}$ + 18 KWh/m^2.year ≤	**Class D**	< 1.25 $EP_{Lim\ (2010)}$ + 21 KWh/m^2.year
1.25 $EP_{Lim\ (2010)}$ + 21 KWh/m^2.year ≤	**Class E**	< 1.75 $EP_{Lim\ (2010)}$ + 24 KWh/m^2.year
1.75 $EP_{Lim\ (2010)}$ + 24 KWh/m^2.year ≤	**Class F**	< 2.50 $EP_{Lim\ (2010)}$ + 30 KWh/m^2.year
	Class G	≥ 2.50 $EP_{Lim\ (2010)}$ + 30 KWh/m^2.year

Fig. 3.22 Energy classes distinction based on the minimum global requirements

	$\mathbf{A_{DHW}}$	< 9 KWh/m^2.year
9 KWh/m^2.year ≤	$\mathbf{B_{DHW}}$	< 12 KWh/m^2.year
12 KWh/m^2.year ≤	$\mathbf{C_{DHW}}$	< 18 KWh/m^2.year
18 KWh/m^2.year ≤	$\mathbf{D_{DHW}}$	< 21 KWh/m^2.year
21 KWh/m^2.year ≤	$\mathbf{E_{DHW}}$	< 24 KWh/m^2.year
24 KWh/m^2.year ≤	$\mathbf{F_{DHW}}$	< 30 KWh/m^2.year
	$\mathbf{G_{DHW}}$	≥ 30 KWh/m^2.year

Fig. 3.23 Domestic Hot Water requirements for residential buildings

Finally, the summer Energy Performance level (below depicted) is based on the building cooling load's evaluation.

EPe, envelope (kWh/m^2)	**Evaluation**	**Performance class**
$EP_{e,\ envelope}$ < 10	Optimal	I
10 ≤ $EP_{e,\ envelope}$ < 20	Good	II
20 ≤ $EP_{e,\ envelope}$ < 30	Medium	III
30 ≤ $EP_{e,\ envelope}$ < 40	Sufficient	IV
$EP_{e,\ envelope}$ ≥ 40	Poor	V

Fig. 3.24 Cooling performance classes

The EPC administration system is managed at regional level by mean of special registries and databases and currently, in Italy, six regional EPC databases exist, while in the future other eleven ones are going to be implemented (as below depicted).

Actually the several Regions are responsible for the control and quality assessment of the entire EPC system process, also guarantying the fulfillment of national quality standard.

Sanctions and penalties are indeed provided in case of EPC not compliant with the allowed methodologies or in case of any falsification.

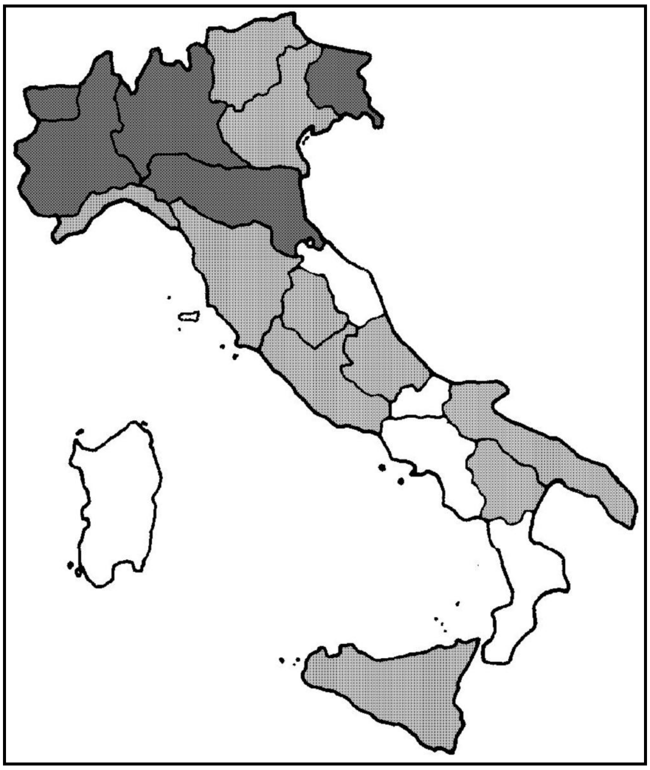


Fig. 3.25 Regional EPC databases: in dark grey color are highlighted those regions which have already their own database; in light grey color are distinguished those regions which have oncoming regional EPC databases (source: *European Union's Featuring Country Reports 2012)*

3.4 Danish assessment: Standards, Energy Requirements and main Regulations

Since year 2008 Danish energy policies had established the target to save 1,5% of the **total final energy consumption** per year: nevertheless, it wasn't clear enough how and to what extent such a goal has been properly related to the primary energy consumption levels.

Actually nowadays Denmark has expressed (as below specified) its main final targets in term of **gross energy consumption**.

Indeed, at this regard, the nature of expressing an energy saving target in gross consumption terms means that an increasing share of wind power in the electricity mix could effectively contribute to meeting such final goals.

In Denmark two main national energy efficiency targets (ref. *National Energy Efficiency and Energy saving targets – ecee.org*) are currently in force:

- the first one prescribes the gross energy consumption to be reduced, in absolute terms, by 2% by 2013 compared to 2005;
- the second one requires instead the 4% absolute reduction by 2020 compared to 2006, despite as highlighted by *The European Council for an Energy Efficient Economy* in the targets final report carried out in 2011, this latter goal should be adjusted and increased by the Danish government up to the 6% by 2020.

Moreover, it's important to recall that the Independent and official Danish Climate Commission has also outlined recommendations for a zero fossil fuel economy by 2050. At this regard, in order to meet such final goals, the Commission envisaged that final energy demand would need to fall by nearly 1/5 on 2008 levels, with large reductions in the residential and transport sectors aimed to balance small increases in the industrial and service sector demand.

In order to supply a more complete and detailed overview of the Danish Energy Regulation framework the following remarks should be done, along with the further specifications hereinafter provided.
In particular, according to the all-embracing assessment and the review of its main energetic policies, it's useful to recall that the Directive on the Energy Performance of Buildings (EPBD) adoption in Denmark it's currently under transposition and implementation.
Indeed, in this country, the implementation of EPBD is under the responsibility of the ***Danish Energy Agency (DEA)***.

The Danish building Energy Performance (EP) certification scheme has undergone a major revision in 2010 and a revised scheme has been published in the spring of 2011.
In the ***Danish Building Regulations*** (a.k.a. ***BR10***) targets for the next tightening in 2015 are specified and fixed according to an additional 25%.
Furthermore, as referred by a recent report published in 2013 by the European Union (and promoted by the Intelligent Energy – Europe Programme), a new "***Building Class 2020***" has been lately introduced according to the proper Danish Nearly Zero-Energy Buildings (*NZEB*) definition.

Such a global revision process, on the one hand introduces requirements concerning the recast EPBD published in 2010, on the other hand also aims to widely improve the entire methodology and certification processes, in function of the experience gained during the latest years.

Danish Energy performance requirements: current status and progresses

Focusing now on the main Danish regulations framework it's once again necessary distinguishing (as already done for Italy) between **new buildings requirements** and **existing buildings prescriptions:**
the Energy Performance requirements for **new buildings** and the EP evaluation method had been implemented in their current form in 2006, i.e. after the implementation of the first EPBD version.
Such requirements also included forecasts and programmes for tightening the EP limits in 2010 and 2015 (compared with the 2006 requirements) by approximately the 25% in each step.
During year 2009 such targets were revised and actually, in the Danish Building Regulations (BR10) issued in 2010, they were tightened by 25%.
Moreover, since the revision carried out in 2010 hadn't included any further forecast for the 2020 EP, the building industry sector has required for a consequent proper projection.
This led to the development of a cost analysis process aimed to define and settle adequate levels for EP requirements: hence, the main outcome of such an assessment led to the definition and the forecast for the respective EP requirements concerning new buildings in 2020 (i.e., as above declared, the *Danish NZEB definition*).

Furthermore, the restrictions established for **existing buildings** were initially adopted according to the same 25% rule's definition reported by EPBD (despite no area threshold was implemented), in combination with component requirements.
Moreover, according to the earlier Danish Building Regulation, all the cost-effective measures had to be implemented in case of more than 25% of the building envelope (or the entire value of the building) were affected.
But actually, as highlighted by the most recent report published at this regard, several studies focused on the adoption of such energy saving measures identified this rule as a hindrance on the path towards energy savings achievement.

It was thence established to increase the uptake of energy saving measures in the existing building stock by implementing more strict requirements while replacing or renovating the different, single building elements.
The BR10 indeed draws up a list of the minimum requirements, also considering most of them economically profitable and viable under normal conditions.

	2006	2010	2015	2020
Residential, 150 m² of heated gross floor area	84.7	63.0	36.7	20.0
Non-residential, 1,000 m² of heated gross floor area	97.2	73.0	42.0	25.0

Fig. 3.26 Development of EP requirements (annual kWh of primary energy per m² of heated gross floor area) for typically sized residential and non-residential buildings (ref. www.ens.dk, www.sbi.dk)

Nevertheless, in the light of a more careful analysis of such a fundamental point of reference for a wide range of buildings and dwellings, it's necessary to pinpoint the following main distinctions and enlightenments:

- **New buildings:** whose prescriptions are contained and widely disclosed in the main sections of the document, also including *Fire safety prescriptions* (Chapter 5), *Indoor climate specifications* (Chapter 6), as well as *Building services and main Appliances systems* (Chapter 8) and, in particular *Energy Consumption* Requirements (Chapter 7.1 and 7.2).
  Actually, Danish Building Regulations set minimum energy requirements for all the different typologies of new buildings. In particular, such prescriptions involve the global building energy frame and its envelope.
  Besides, in addition to such minimum requirements, Danish Regulations also set the requisites for two voluntary classes: ***Low-energy Class 2015*** (BR10, Chapter 7.2.4) and the ***Building Class 2020*** (as below summed up).
  These two classes are in fact expected to be introduced as the minimum requirements by 2015 and 2020 respectively.

Energy performance framework (kWh/m2 floor area per year)	Dwellings	Other buildings
BR10	52,5 + 1650/A	71,3 + 1650/A
Lavenergiklasse 2015	30 + 1000/A	41 + 1000/A
Bygningsklasse 2020	20	25

Fig. 3.27 Energy performance framework for Danish buildings (ref. http://www.paroc.dk)

The energy frame is the maximum allowed primary energy demand for a building and thence involves thermal bridges assessment, solar gains contributions, ventilation, heat recovery, cooling, boiler and heat pump efficiency, electricity for operating the building, as well as and sanctions and penalties.
Furthermore it must be specified that such an energy frame for the primary energy demand in new buildings has been recently stiffened and tightened by 25% compared to the previous 2006 baseline.

Thereby, the *Low-energy Class 2015* has introduced a 50% tightening compared with the 2006 baseline, while instead the *Building Class 2020* further tightened the energy frame by 25%, (consequently reducing the allowed energy frame by 75% in comparison with the 2006 baseline).

Besides, still with reference to new buildings, the Danish legislation also sets requirements for the calculation of design transmission heat loss for the opaque part of building envelope (BR10 Chapter 7), as well as the minimum requirements for components and installations: such minimum component requirements are primarily intended to eliminate the risk of mould growth due to cold surfaces.
It's also fundamental remarking that it's not possible to construct a building which respects the energy frame exclusively by fulfilling the minimum component requirements: actually, it must be highlighted that both sets of requirements (building envelope and installations) simultaneously work, concurring to fulfill the legal requirements for the energy frame.

Such requirements were settled to avoid the construction of new dwellings and/or building components and installations with high levels of renewable energy (Appendix 6) but a low insulation level.

Floors	2006	BR10	Low-energy 2015	Building Class 2020
1	6	5	4	3.7
2	7	6	5	4.7
3	8	7	6	5.7

Fig. 3.28 Maximum allowed design transmission heat losses through the opaque part of building envelope [W/m²]

BR10 Calculation procedure

The calculation procedure adopted by BR10 was recently updated according to the latest requirements and is described in the ***SBi*** *(Danish Building Institute)* ***Directive n. 213*****:** ***Energy demand in buildings*** *(*ref. www.anvisninger.dk*)*.
This procedure mainly follows relevant CEN standards and also involves the application of the PC calculation program known as ***Be10***.

The calculation core implemented by this software must be adopted by all the other programs used for compliance checks and energy certification, with the final purpose of guarantying the application of identical assessment criteria for buildings energy performances.

All existing buildings	Changed use and extensions	Pavilions	Single component requirements	Secondary homes	Maximum requirements, new buildings
U-value requirements [W/m².K]					
External walls and basement walls towards ground	0.15	0.20	0.20	0.25	0.30
Slab on ground etc.	0.10	0.12	0.12	0.15	0.20
Loft and roof constructions	0.10	0.15	0.15	0.15	0.20
Windows	1.40	1.50	1.65 (doors)	1.80	-
Roof windows	1.70	1.80	1.65	1.80	1.80
Cold bridges [W/m.K]					
Foundations	0.12	0.20	0.12	0.15	0.20
Joints between windows and walls	0.03	0.03	0.03	0.03	0.06
Minimum energy gain [kWh/m².year]					
Facade windows	-	-	-33	-	-33

Fig. 3.29 U-values and cold bridges requirements – global overview according to the *BR10* prescriptions

- **Existing buildings** and ***change of use and/or extensions*** (Chapter 7.3), along with *buildings' **Conversion and other alterations*** to their main *energy-related* systems (Chapter 7.4).

Concerning this topic - particularly significant for the current research work - it must be noticed that BR10 further tightened, for all the different building typologies, the previous energy performance requirements for individual building components.
Its prescriptions must be applied in case of replacements or major renovations of such elements. However it's fundamental recalling that all the measures must be economically feasible, i.e. the annual savings multiplied by the expected lifetime of the measure divided by the investment **should be higher than 1,33** or - in other terms - any specific measure must have a **simple payback time of less than 75%** of its expected lifetime.
However, in case of full replacement for a building component (like for instance a new roof, new window, new outer wall), such a new component must meet the requirements established by the BR10, regardless of its profitability.

At this reference, examples of cost-effective measures are provided by the Appendix 6 of the Regulations (as, for instance, following depicted).

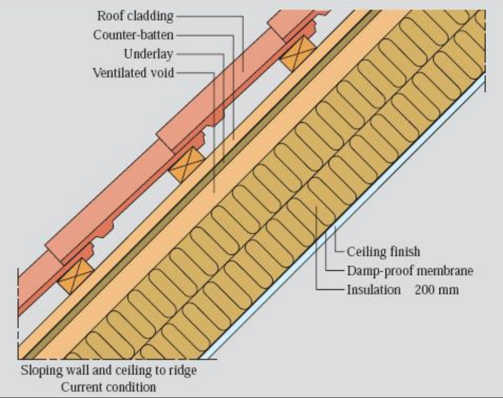
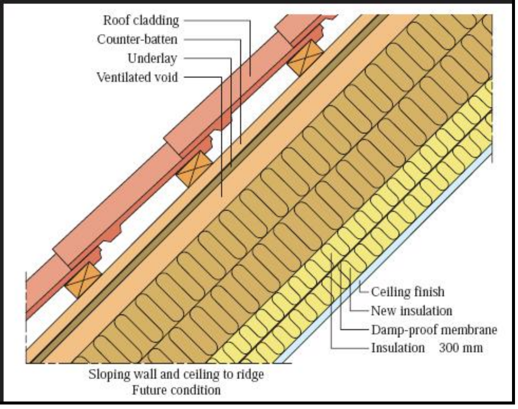
Current condition/ Intact insulation	Action: Insulation, thicknesses approximately corresponding to the requirements of Table 7.4.2
U > 0,20 W/m² K Insulation ≤ 200 mm	BR 10 Table 7.4.2 Insulation 300 mm
	

Fig. 3.30 Example of sloping wall and ceiling to ridge refurbishment: requirements for retro-fitted insulation met by replacement roofing (BR10 – Appendix 6)

However (as declared by BR10 themselves) further guidance and references about the choice of solutions with better insulation are also reported by the "*Videncenter for energibesparelser i bygninger*" website (the Knowledge Centre for Energy Saving in Buildings – ref: http://www.byggeriogenergi.dk). More complete and specific reference limits prescribed by the BR10 in case of maintenance and replacement interventions are depicted by the table of below:

Requirements for Insulation of the building envelope and linear losses	
Table of U values	**W/m²K**
External walls and basement walls in contact with the soil.	0.20
Partition walls and suspended upper floors adjoining rooms/ spaces that are unheated or heated to a temperature more than 5 K lower than the temperature in the room concerned.	0.40
Ground slabs, basement floors in contact with the soil and suspended upper floors	0,12
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.15
External doors, hatches, secondary windows and skylight domes	1.65
Linear losses	**W/mK**
Foundations.	0.12
Joint between external wall, windows or external doors and hatches.	0.03
Joint between roof structure and rooflights or skylight domes.	0.10

Tab. 3.1: Main requirements for insulation of the building envelope and linear losses currently in force in Denmark

Some of the most important energy strategies and policies introduced and listed by the ***Danish Action Plan*** are for instance the following ones:

- **energy savings initiative for the energy supply companies**:
  the Danish supply companies are obliged to provide energy savings corresponding to 2,6% of the national energy consumption (except the transport sector) in 2013-2014, and 3,0% in the time span 2015-2020.
  Actually such an obligation increases by 75% in 2013 and 2014 compared with the interval 2010-2012, and by 100% in 2015-2020;

- **strategy for an energy renovation of the existing building stock:**
  the Government is obliged to develop an all-embracing strategy with the purpose of achieving a powerful and wide renovation of the existing building stock.
  Such a strategy should be based on the analysis of existing buildings, also assessing their potential energy savings;
- **transition to renewable energy:**
  as a general rule, with effect from 2013 nor oil, neither natural gas boilers are going to be allowed in new buildings. Furthermore, from 2016 oil burners mustn't be installed in existing buildings in areas with district heating or natural gas supply.
  Actually, Danish government also established several grants in order to support such initiatives for energy efficient alternatives replacing traditional fossil fuel supplies;
- **public action:**
  obviously, public buildings should take the lead in implementing energy saving measures: every year, at least the 3% of the publicly owned and occupied buildings must carry out opportune energy upgradings;
- **Danish Energy Agreement:** on the 22nd of March 2012 most of the Danish Parliament parties subscribed an agreement which promotes a large number of initiatives to be implemented during the time-span 2012-2020.

In particular, one of the most significant measures to be implemented is the ***Strategy for Energy Renovations of the Existing building Stock*** (as recalled by the *Featuring Country Report 2012-Implementing the EPBD* published by UE), which is expected to be completed by the end of 2013. Such a plan will collect and provide a consistent number of actions and other proper measures to be implemented in order to increase the number of energy renovations in the most cost-efficient way.
Actually, a wide network of building companies (representative for the construction sector), as well as several other delegates from the most relevant fields, were involved in the drafting of such a strategy, providing their own knowledge and ideas.

Danish Energy performance certification scheme: current prescriptions and implementation
According to the latest EPBD Implementation Status Report promoted by European Union, "*Denmark has the longest history of energy certification and profiling of the building stock*".

The Danish energy performance certificates (EPC) framework has been interested by a major revision in 2011 and, among the most important modifications, the following ones may be highlighted:

- its validity period: it was extended from 5 up to 7 or 10 years (depending on the potential energy savings achievable). However it's necessary to specify that, if the EPC identifies major energy savings with a simple payback time less than 10 years and with a total saving larger than 5% of the building energy consumption, its validity should be reduced to 7 years;

- for single-family houses built less than 25 years prior to the certification, the EPC process can take place without any onsite visit to the building;
- the energy certification of a certain building can be based on the calculated or measured energy consumption level. In particular, buildings which can be certified by a measured energy use, also include multifamily buildings with a detailed and updated operational log;
- other building categories which can also have certificates based on the effective measured energy consumption are those ones classified as transport facilities, wholesale, retail trade, banks, insurance offices, liberal profession firms, public administrations, hotels, cinemas, libraries, museums, educational buildings, hospitals, day-care institutions, secondary homes, holiday camps and sport facilities.

It's important to highlight that in July 2012 a new act and a new order implementing the recast EPBD 2010 was established. Its main prescriptions must be applied from the 1st of January 2013, and involve mandatory advertising requirements and sanctions.
EPC criteria provide for the attribution of a specific energy rating for nearly all types of buildings and list cost-effective measures for improving their energy performances.
The energy assessment process has been settled by the ***Act number 636*** (issued on the 19th of June 2012), the ***Ministerial Order number 673*** (of the 25th of June 2012) and by the ***DEA's Handbook for Energy Advisers***.
In Denmark, the responsibility of implementing the Energy Performance Certification lies with the ***DEA***: a secretariat running the daily operations ascribed to the EP certification scheme was established in May 2010 and it also manages Quality Assurance (QA): it's therefore designed to contribute to the future development and the marketing of such a scheme.
Staring from May 2011 the energy Performance Certificate can be issued only by properly certified companies, whose license is competence of the ***Danish Accreditation Agency*** *(DANAK)* or of any other corresponding European Accreditation Agency under the European Accreditation Organization *EA (**European Co-operation for Accreditation**)*.

The EPC bases the buildings rating process on an energy efficiency scale range: as below depicted, such a range covers different energy classes from the A (high energy efficiency buildings) to G (poor energy efficiency). In turn, the A Class is divided into two sub-categories (A1 and A2).

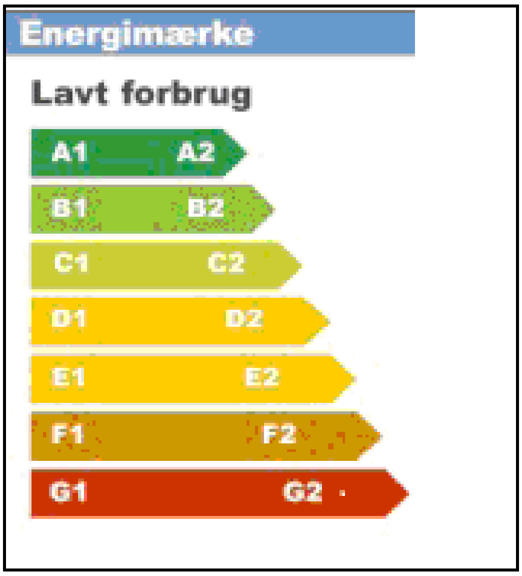


Fig. 3.31 Danish Energy Label Scale

The main benefits and advantages introduced by EPC consist in the strategic recommendations and suggestions provided to the building owner involved in the certification process.
Actually, the suggested improvements include their brief description, an estimation of the respective costs, savings and payback time, as well as their impact on the energy rating achievable by the building through the implementation of all the improving actions.
Some of the above suggestions may be referred to the following building elements and appliances:

- old roofs and attics;
- old windows, glass doors, and overhead lighting;
- oil boilers and old gas boilers;
- electric heating systems.

If the rules regarding the EPC are not fulfilled, the building owner may face fines and further penalties. Besides, he may also receive an injunction from the DEA to display the EPC or to have an EPC issued.

The Danish Building Stock global assessment and overview:

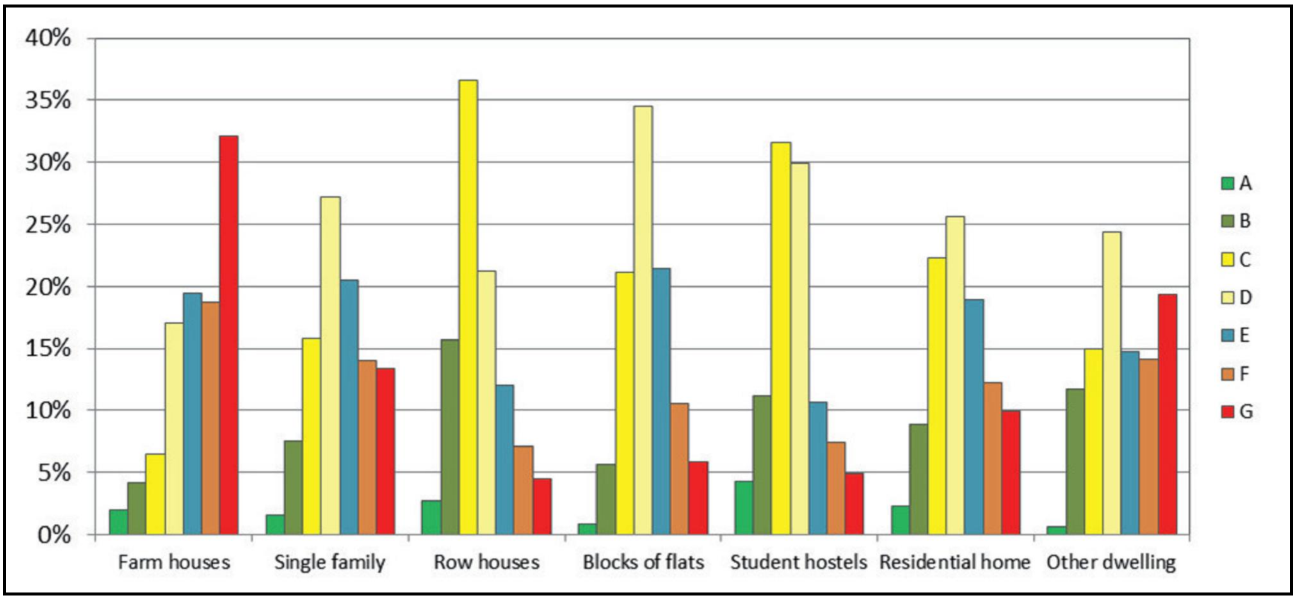


Fig. 3.32 Distribution of energy certification classes for Danish dwellings since 2006

The Danish Information Initiatives and Awareness Campaigns

The information and advices provided to buildings owners (as well as to all the Danish citizens) in order to reduce the energy consumption of existing buildings is one of the most important elements provided by the Danish Energy Agreement issued on 22/03/2012.
Actually, during the latest years, several activities were organized with the purpose of producing cost-efficient information tools in cooperation with the most relevant stakeholders.
Indeed the local perspective, as well as the private ownership knowledge, plays a key role in such a process.
At this regard, both DEA and the Secretariat host *ad hoc* websites which provide general and specific information on the achievable energy savings, along with the main EPC criteria.
Furthermore, DEA is currently involved in an awareness campaign aimed to raise the public sensitivity about the importance of EPC and its use.

The DEA has also planned and implemented several information and awareness initiatives in order to promote, in areas not yet covered by district heating, heating sources and other technologies than the traditional oil boilers (or, at least, boosting the improvement of the existing ones).
Regarding this task, a series of economic incentives were introduced - e.g. granting a subsidy when replacing oil boilers with an alternative heating system - and hence, also by mean of such a measure, the replacement of approximately 16.000 oil boilers has been reached.
Moreover, Energy Companies do also have energy efficiency commitments that include support for the improvement of heating systems producing energy savings.

Ultimately, and as further final remark, it must be noticed that, since in Denmark the EPBD transposition process has been completed, several energy requirements for new buildings were tightened up and a detailed definition for the Nearly Zero-Energy Building (NZEB) requirements for 2020 has been also settled.

Moreover, as already highlighted, also the existing building stock has to provide its contribution with the final goal of achieving the "***CO_2-emission free country by 2050***" government's target: hence, in case of major refurbishments for such buildings and/or their components' replacement, even more strict prescriptions must be fulfilled.

The new UN-backed Energy Efficiency Hub established in Copenhagen

Just in Denmark (at Copenhagen) was recently launched (October 2013) a new energy efficiency hub under the umbrella of the **UN Secretary-General's Sustainable Energy for All initiative (*SE4ALL*).**
In particular, such a hub has got the primary aim to serve as a centre of global efforts to double energy efficiency by 2013.
Furthermore, as declared by the current General Secretary of United Nation (Ban Ki-Moon) during its official launching, *"Copenhagen is now also home to the UNFCCCC* - United Nations Framework Convention on Climate Change *(...) and I count on these entities to contribute to global green growth in the coming decades*".
The hub has been established thanks to the joint activities of the *UNEP* (United Nations Environment Programme), the Danish Government and the *DTU* (Technical University of Denmark) and furthermore, as highlighted by Ban Ki-Moon during the opening ceremony, "*Denmark, host of the opening session forum and founding member of the United Nations, is a world leader in energy efficiency and climate-friendly technology and policy*".

3.5 Energy Efficiency Policies in buildings - implementation and use of financial instruments at European Union Members level: focus on Italy and Denmark

Quoting the global results referred by the document published on August 2012 by the Buildings Performance Institute of Europe (BPIE) about this issue (and available on the website http://www.bpie.eu), it's possible to report the following key-findings:

- currently, all European Members do have on-going programmes settled in order to fulfill the EPBD, meeting its main targets: actually, in order to support and improve buildings energy performances, both conventional and innovative funding were established;

- while most of the financial instruments detected within the entire European Country have targeted existing buildings (in particular residential dwellings), a fewer programmes involved the commercial building stock;
- besides - as it's also possible to gather analyzing the bar chart of below - the most exploited financial measures here detected were **grants** and **subsidies**: actually, in Denmark they were recognized as the only kind of financial incentive applied while instead, for Italy, **reduced VAT rate** and **tax credit** have been primarily used.
  And indeed this latest fiscal facility (i.e.the tax credit) - even though widely implemented - hasn't reached yet the same level of grants;

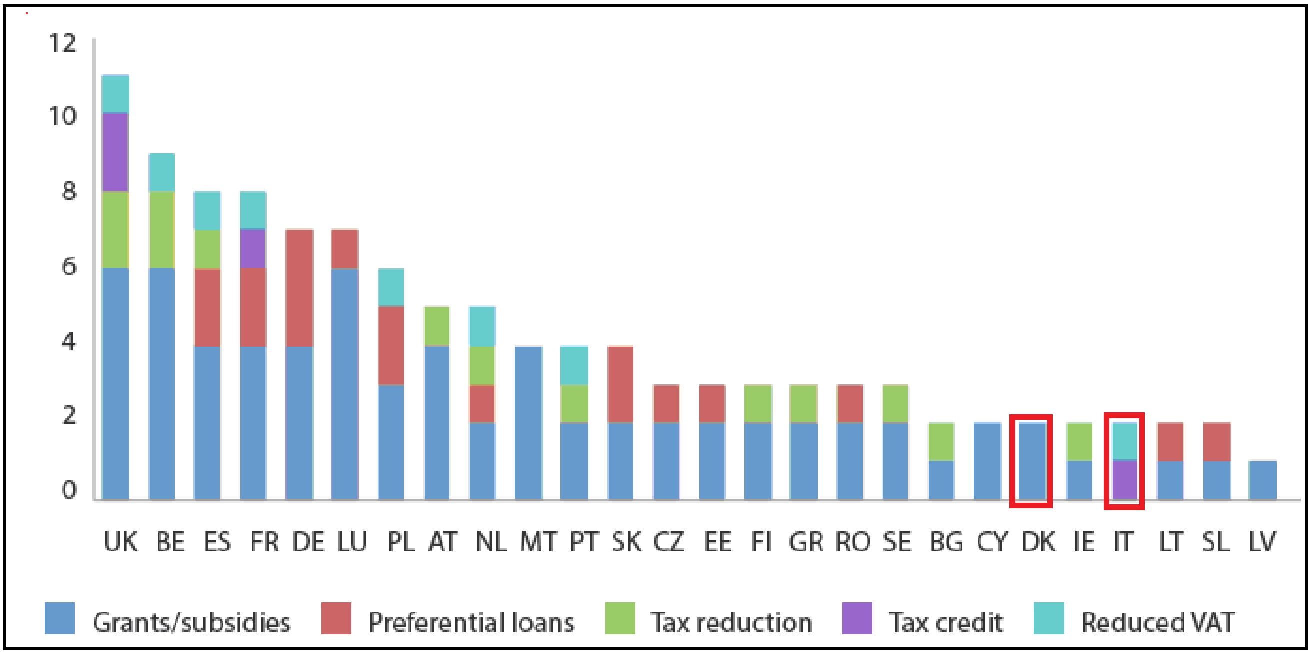


Fig. 3.33 Number of identified programmes by type of instrument and country (year 2011–Source *BPIEE*)

- despite a consistent number or such programmes are currently running, their proper knowledge and overall effectiveness hasn't been clarified and adequately assessed yet: actually, very few of them settled *ex-ante* goals and targets, and even fewer achieved a deep awareness level about their effectiveness.

Furthermore, not a sufficient number of such initiatives settled a fruitful on-going monitoring process (feedback overview).

- Only few financial instruments are addressed to deep renovation processes with low energy buildings as a final target;
- despite several of such instruments have targeted specific, more advanced technologies or have been focused on particular building aspects, only 1/3 of them adopted and supported a holistic approach;
- a rather important and strategic aspect to be highlighted is however ascribable to the current increase and consolidation of Europe-wide and international funding streams: actually, measures such as the ***EU Structural Funds*** and institutions like the ***European Investment Bank*** are significantly strengthening their action and can also play an even greater role in the future.

Notwithstanding, it should be noticed that some Member States are still almost entirely dependent on such funding incentives into setting their national programmes.

Ultimately, and in the light of such an all-embracing assessment and global overview, the main European policies currently aimed to improve buildings energy performances, led to the following main statements:

- **a Higher level of ambition is needed**: actually, the final targets of such programmes should be raised and strengthened in order to lead to a wider and greater impact, also unlocking further private investments and disclosing deeper renovations opportunities;

- **a deeper retrofit:** directly linked to the above issue, a holistic approach may obviously offer a great contribution into achieving such deeper refurbishment levels: however, *"funding a major retrofit strategy will require the bundling of several financial instruments because of the up-front cost of a deep retrofit"* (ibidem);

- **a long-term strategy should be adopted:** actually, it must be recalled that financial instruments currently in place were established in order to meet only the today's level of retrofit. Hence there's an undoubtable need for scaling up such measures according to a long-term strategy and far-seeing objectives too.

Conventional and Innovative Instruments: even though there are several on-going financial programmes, their overall effectiveness is still too much unclear and there is currently a lot to learn from them in order to get their deeper and wider comprehension.

Furthermore, while it's still too much difficult reaching a global awareness on how, across the entire European Union, such measures have been assessed and evaluated, it's even more difficult to compare them by mean of a fairy criterion: indeed, since Member States use different key performance indicators, there is no standardized way to monitor and evaluate the individual programmes.

This last observation should therefore taken into account while comparing the main tools and financial instruments established in the two countries - i.e. Italy and Denmark - mostly involved in the present job.

Besides, such an assessment has been mainly focused on the **existing buildings stock:** actually, at this regard it should been recalled that this building category represents the biggest potential for reducing green-house-gas (GHG) emissions, while instead new buildings only add about 1% per year to the total building stock.

Moreover, according to the latest data and information gathered at EU level, it has been estimated that, on the average, buildings may offer their contribution for approximately 75-80% into improving global energy performances.

In the light of the 2011 BPIE survey, along with the support of some other external studies, it's possible to provide the following overview on the main financial instruments currently in place in Europe, also distinguishing among the main current typologies.

At this reference, the following scheme depicts an all-embracing and complete pan:

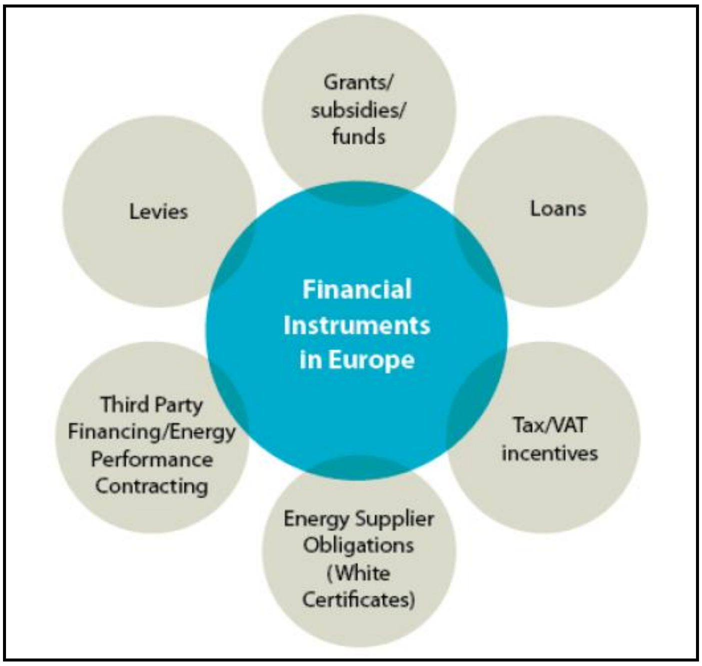


Fig. 3.34 Main typologies of the existing financial instruments boosting buildings' energy performances

In particular:
Subsidies: they allow prices to be kept low. Hence they may be provided, for example, to manufacturers of energy efficient equipments and appliances in order to make them more affordable.

Grants: are targeted at households, commercial, industrial or other energy consumers in order to allow them to pay - for part or entirely - the cost of introducing energy efficient processes (e.g. enhanced building insulating solutions).
Both Grants and subsidies may be financed directly through the state or local authority budget or by mean of the so called *hypothecated taxes* (a.k.a. *ring-fenced* or *ear-marked taxes* and which provide for the devolution of the revenue from a specific tax to a particular expenditure purpose).

Loan schemes: they could be implemented in order to encourage energy efficient practices with subsidized interest rates or through credit risk support; such a fiscal policy may be provided by the local authority or state budget to banks offering low interest rates.

Value Added Tax (VAT): normally affects the final consumer and differential VAT rates can be used to influence the choice of energy efficient technology by householders.

Levies (on consumption or production): such instruments can be used to create an *ad hoc* fund (e.g. a levy on electricity sales could be used to fund renewable energy schemes).
Furthermore, going down to an approach and an analysis level closer to the single country scale, it's possible to state the following considerations:
While Belgium and the United Kingdom do have the greatest number of detected instruments, **Denmark** only implemented one kind of on-going nationwide fiscal program during 2011 (i.e. grants and/or subsidies).
Italian regions have instead developed a series of programmes with the support of EU Structural Funds and Italian Government has recently established the tax credit financial support going on also in the future.

BE (Walloon Region)	50% (biomass heating system) Up to 60% (energy audit) Up to 75% (equipment)
BE (Flemish Region)	Max 75% (equipment) 30% (envelope, equipment)
BG	20% (envelope, other)
CY	30% of eligible costs (envelope) 45/55% of eligible costs (equipment)
CZ	Up to 85% of a project's total eligible expenditures (envelope, equipment)
DK	25% (or €1 343.52 (DKK 10 000 DKK/)y per residence) (equipment) 20% (up to €1 343.52 (DKK 10 000) (envelope)
EE	10% (no more than €4 000 for the reconstruction project) (envelope)
FI	15/25% (equipment, energy audit) 40/50% (energy audit)
FR	20/35% (envelope, equipment) 50% (energy audit)
LV	Up to 50% (envelope)
LT	50% (preparation technical project and construction supervision) 15% (envelope, equipment) 100% (of renovation costs for low income families and single persons)
MT	20% (up to €233) (envelope, equipment)
PL	45% of the loan (equipment)
RO	67% (envelope)
SK	Up to the 50 % of eligible costs (or max 500 SKK/m2 of flat floor area) (envelope)
SL	25% of eligible costs (envelope, equipment)
SE	25% (equipment)
UK (Scotland)	100 % (envelope, other)
UK (Wales)	100% (other)

Fig. 3.35 Assessed percentage level of support for grants (source BPIEE)

	Level of support
FR	40% on the interest of the home for 7 years (complements the zero interest rate loan) (envelope, equipment)
IT	36/55% (envelope, equipment)
UK	100% tax relief on the cost (equipment) €1 860 /y (£1 500/y) (envelope, equipment)

Fig. 3.36 Assessed percentage level of support for tax credit (source BPIEE)

	Level of support
BE	6% (envelope, equipment) instead of normal rate of 21%
ES	8% (envelope, equipment) instead of normal rate of 18%
FR	5,5% (7% from 1°of January) (envelope, equipment) instead of normal rate of 19,60%
IT	10% (envelope, equipment) instead of normal rate of 21%
NL	6% (envelope) instead of normal rate of 19%
PL	8% (envelope, other) instead of normal rate of 23%
PT	13% (equipment) instead of normal rate of 23%
UK	5% (envelope, equipment) instead of normal rate of 20%

Fig. 3.37 Assessed percentage level of support for reduced VAT rate (source BPIEE)
N.B. From the 1st October 2013 the current normal rate for Italy has increased by 1%, reaching the 22%

Some recapitulative observations and considerations:

In the light of the overall framework previously depicted at European level – and particularly for Italy and Denmark – it's possible to state the following remarks:

- in first instance, several analogous policies may be recognized and highlighted at national level with reference to the establishment and development of specific energy saving measures, awareness campaigns, energy certification processes and – in general – any kind of action aimed to implement the EPBD in the most efficient way;
- despite such a dynamic process should be recognized as a common element both for Italy and Denmark, several differences may be clearly detected between these countries:
  - in first instance the different transmittance limit values to be respected at any single building element level (for new buildings as well as in case of refurbishments);
  - the different energy certification processes established, along with the respective energy class distinguishing criteria...etc;
  - in particular, the principal and most important aspect to be highlighted (as hereinafter more deeply analyzed) is referable to the financial support for energy saving refurbishments (a.k.a. *Ecobonus*) only implemented at Italian level (starting from year 2007 and currently in force);
  - another common element, strongly highlighted both by the Danish and the Italian "energy-saving-retrofit" related Regulations, concerns the economic aspects referable to any energy-saving measure to be implemented in private and public dwellings as well. Actually, such rules require the implementation of those only actions which reveal convenient under an economic point of view, i.e. enough cost-effective.

In particular, as specified by the **Danish Building Regulations** at Chapter 7.4: "*As a guide, structural measures are deemed to be cost-effective if the annual saving multiplied by the lifetime, divided by the investment, is greater than 1.33 which amounts to the measure concerned paying for itself within 75% of its expected lifetime*".

Furthermore, a summary of those measures which could be often considered cost-effective is shown in its Appendix 6 and can be also picked out in the Danish web-site: *http://bygningsreglementet.dk/*

Energy-saving measure	Years
Retro-fitted insulation to building elements	40
Windows with secondary windows and coupled frames	30
Heating systems, radiators and underfloor heating and ventilation ducts and fittings including insulation	30
Heat appliances etc., for example boilers, heat pumps, solar heating systems, ventilation units	20
Light fittings	15
Automation for heating and climatic control equipment	15
Joint sealing works	10

Fig. 3.38 Reference Lifetimes to be applied for the cost-effectiveness assessment (BR10–Appendix 6–Tab. 2)

Also the Italian **D.Lgs. n.311 -** issued on 29/12/2006 - requires the implementation of cost-effective actions and energy-saving measures convenient enough under a "technical-economic" aspect.

To sum up, it's however widely recognized on a global scale that those "*energy savings through reduced energy consumption is a direct benefit stemming from increased energy efficiency*" (cfr. Copenhagen Economics - 2012 *Renovate Europe* report).

Furthermore, while in private dwellings such benefits typically involve building owners or building users, for public buildings they accrue to the public or the users of publicly rented apartments, also positively improving public budgets. Hence, directly linked to such savings are also the avoided capital cost required for building additional power plants, as these capital costs are included in the price of electricity.

Moreover, analogous considerations may be also applied to investments in new grid capacity, which is included in the grid tariffs paid by consumers.

In addition, a more indirect advantage may be referred to health benefits: actually, most of such energy efficiency measures will improve indoor temperature and, also improving indoor climate, considerable health benefits can be achieved by mean of fewer diseases, a reduced mortality rate, an improvement in workers' productivity, and thence enhancing the global quality of life.

In particular, while most of these benefits accrue to society in general, public budgets may also be involved in such a "virtuous circle" through fewer hospital expenses and fewer sick days.

Additional benefits may also be recognized in the reduction of air pollution due to NO_x, SO_2, CO_2 levels, as well as small particle matters ($PM_{2,5\ \mu m\ diameter}$) pollution.

Furthermore, given the current economic downturn characterized by spare capacities, such energy efficiency investments can increase economic activities, improving public budgets by reducing unemployment levels and unemployment expenses and consequently increasing tax revenue from a boosted economic activity level.

More in details, such positive effects from a higher tax revenue, globally involve the VAT contribute, the labor income tax, corporate income tax etc.

Also the value of reducing EU's energy supply dependence on third-countries, as well as the reduced dependence on volatile fossil fuel prices must be recalled.

Finally, other additional benefits – even more difficult to be directly quantified, but still quite relevant - may be ascribed to the globally improved life quality level.
And strictly related to such an aspect – particularly for those factors directly linked to the climate mitigation and environmental benefits achievable through a proper energy policy - may be ascribed to the so called ***Kyoto Protocol (KP)***.

3.6 The *Kyoto Protocol*: its main targets and implementation at European Union Members level – the *20/20/20 targets* - focus on Italy and Denmark

The Kyoto Protocol is an international agreement linked to the *United Nations Framework Convention on Climate Change* (Kyoto, Japan - 11/12/1997), which commits its Parties by setting internationally binding emission reduction targets.
Indeed, recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere (as a result of more than 150 years of industrial activity), the Protocol settles a heavier burden on the most developed nations under the principle of *"common but differentiated responsibilities"*.
Even though the Kyoto Protocol had been subscribed in December 1997, it entered into force only on 16/02/2005, while detailed rules for its implementation were adopted during the *COP 7* (the Seventh session of the Conference of Parties) in Marrakesh – Morocco - during year 2001, and are referred to as the "*Marrakesh Accords*".

Its ***first commitment period*** started in 2008 and ended in 2012. During such a period, 37 industrialized countries and the European Community committed to reduce Green House Gas (GHG) emissions to an average of 5% against 1990 levels.
During the ***second commitment period*** (from 01/01/2013 to 31/12/2020), the Parties committed to reduce GHG emissions by at least 18% below 1990. At this reference, it must be highlighted that the composition of Parties in this last commitment period was different from the first one.
Besides, it must be also recalled that, on 8/12/2012, the ***"Doha Amendment to the Kyoto Protocol"*** were adopted in Doha - Qatar.
At European level, it has to be highlighted that the so called EU-15 (as one entity comprising the 15 pre-2004 Member States, i.e. those 15 European Members of 1995: Belgium, France, Germany, Italy, Luxembourg, Netherlands, Denmark, Ireland, United Kingdom, Greece, Portugal, Spain, Austria, Finland, Sweden), have settled a common target to be collectively achieved under the "***burden-sharing agreement***".
Such an agreement sets differentiated emission limitation and reduction targets for each EU-15 Member State.

Moreover, other eleven current EU-Member States (all except Cyprus and Malta), Iceland, Liechtenstein, Norway and Switzerland have individual GHG reduction and limitation targets under the KP.
More precisely, each one of such Kyoto targets corresponds to an emission budget (i.e. 'a quantity of Kyoto units') for the first commitment period of the KP.
Hence, in order to achieve their respective Kyoto targets, countries must balance their own emissions with the amount "*Kyoto units*" they are holding.
And such a balance can be achieved by limiting or reducing their domestic emissions and by increasing their emission budget through the contribution of ***Land Use***, ***Land-Use Change*** and ***Forestry*** (a.k.a. ***LULUCF***) activities.
In other terms, such objectives may be reached through the management of "*A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities"* (UNFCCC website - Glossary of climate change

acronyms), as well as exploiting the *KP*'s flexible mechanisms whereby they can acquire Kyoto units from other countries.

Furthermore, widening the scope of such an energy policy and hence also considering the latest energy policy targets adopted by European Members for 2020, it's possible to summarize as follows such broadened objectives:
Actually, also considering the aim of increasing the share of renewable energy sources (a.k.a. RES) to the 20 % of EU's gross final energy consumption (recalling the European Directive 2009/28 EC of 23/04/2009) and boosting energy efficiency by 20 %, it's possible to summarize them into the so called ***20/20/20 triple objective*.**

This policy therefore involves the following main tasks:
- a 20 % reduction of the EU's GHG emissions compared to 1990;
- a 20 % share of renewable energy in the EU's gross final energy consumption;
- a 20 % increase of the EU's energy efficiency.

Progress towards the 2020 GHG targets: are European Members close to reaching target ahead of schedule?

As declared by the EEA Report N° 10/2013 of reference, during the latest 2011-2012 time-span the total GHG emissions level of EU-28 decreased by 1 %, while when considering the global scope of EU's climate and energy package (which also includes emissions from international aviation), the reduction of 2012 EU emissions is about 18 % compared to 1990 levels.
Hence, according to such data, the European Union appears very close to reaching its 20% reduction target, eight years ahead of 2020.
Moreover, other aggregated projections from Member States indicate that total EU-28 emissions will further decrease between 2012 and 2020 and, also considering the complete set of national domestic measures currently in place, EU emissions are expected to reach a level that (in 2020) should be 21% below 1990 levels.

Furthermore, thanks to the implementation of those additional measures at planning stage in EU Member States, a reduction of 24 % below 1990 levels is expected to be achieved in 2020.

It must be highlighted that such projected reductions should be achieved both in the sectors covered by the ***EU ETS-Emission Trading System*** (mostly energy supply and industry, where an emission cap is determined at EU level) and in those other sectors covered by national emission targets under the so called ***ESD-Effort Sharing Decision***.
However, as also recalled by the European Environment Agency, the largest reductions are expected from those measures supporting renewable energy sources, as established by the ***RED-Renewable Energy Directive***, along with through the implementation of the ***IED-Industrial Emissions Directive***, which indeed covers large combustion plants.
In particular, the majority of EU Member States expect that their individual emission targets for the non-trading sectors under the *ESD* will be met through those policy measures already in place, even though 13 EU Countries should need to implement some additional measures (currently in the planning stage), or use flexibility mechanisms in order to achieve their targets.
And especially energy efficiency measures in the residential, along with in the services sectors, will deliver key contributions towards further emission reductions by 2020.

Moreover, for 6 Member States (Austria, Belgium, Finland, Ireland, Luxembourg and Spain), the latest projections indicate that even additional measures planned at national level will not be sufficient to bring 2020 emissions below their respective 2020 target under the ESD: hence, such countries are required to increase their efforts planning and adopting emission-reducing policies and measures, and must also seriously consider the use of flexibility mechanisms.

Focusing instead on the Renewable energy targets it has to be highlighted that (since *RES* contributed for a 13% of gross final energy consumption in the EU-28 during 2011) the EU in its whole has therefore met its 10,8 % indicative target for 2011–2012: hence it's currently on track towards its target of 20 % of renewable energy consumption in 2020.

Furthermore, both the ***RED***- *Renewable Energy Directive* and the Member States' 2010 ***NREAPs***- *National Renewable Energy Action Plans* outlined two sets of interim targets for the share of RES in gross final energy consumption (referred to as indicative and, respectively, expected trajectories) towards final 2020 RES targets: such plans also settle average target values for the time-span 2011/2012.

In particular, during 2011 **14 Member States** (including **Italy)** had met or exceeded their indicative and expected 2011-2012 trajectories both for the *RED* and their respective *NREAPs*. Besides, **7** EU Members, also including **Denmark**, had reached or exceeded their average 2011–2012 indicative trajectory from the *RED*, but not the one from their *NREA*.

However, considering the European Union as a whole, EEA highlighted that "*EU Member States need to double their use of renewable energy by 2020 compared to the 2005–2011 period to reach the legally binding renewable energy target*".
Actually, even though EU Member States are moving towards the level of ambition required by the EED (since their collective primary energy consumption in 2020 is expected to be close to the level required by EU of 1.483 Mtoe) such results will still remain insufficient to achieve the 20 % energy efficiency target.

Despite the energy efficiency policy landscape has recently considerably changed in a lot of EU countries, all the different sectors are not equally addressed: while on the one hand building sector received a particular attention through the implementation of the Energy Performance of Buildings Directive (EPBD), on the other hand those measures addressing appliances and the transport sector were often limited to the minimum requirements settled by European legislation.

Only **4 EU Member States** (once again including **Denmark** too) are making considerable progresses in reducing energy consumption and primary energy intensity through well-balanced policy packages across the most relevant sectors; while instead, as highlighted by EEA, most of the EU countries haven't established national policies sufficiently developed or properly implemented across their relevant sectors yet.
This may be ascribed to an insufficient enforcement and application of such policies, along with the huge impacts arising from the overall economic crisis.

In conclusion, globally considering the survey and the assessment performed by the European Environment Agency about such an issue, it's possible to observe that, despite a *"good overall progress across EU Member States towards the 20/20/20 targets"* may be recognized, the progresses globally registered for energy efficiency on the path of European decarbonization still remain too much slow and EU's efficiency still lags behind its triple energy targets.

However, the following summary-table shows how the entire European Union is globally achieving relatively good results and improvements towards its climate and energy targets settled by 2020.

Countries	EEA assessment of progress		
	National GHG targets under the ESD	National targets on RES share in gross final energy consumption	Improving energy efficiency
Austria	↘	→	→
Belgium	↘	↘	→
Bulgaria	→	↗	↗
Croatia	↗	n.a.	n.a.
Cyprus	↗	→	↘
Czech Republic	↗	→	→
Denmark	↗	→	↗
Estonia ([a])	↘	↗	↘
Finland	↘	↗	→
France	↗	↘	↗
Germany	→	↗	↗
Greece	↗	↗	→
Hungary	↗	↗	→
Ireland	↘	→	→
Italy	→	↗	↘
Latvia	→	↘	→
Lithuania	→	↗	→
Luxembourg	↘	↗	↘
Malta	↗	↘	↘
Netherlands	→	↘	→
Poland	↗	→	→
Portugal	↗	→	→
Romania	↗	↗	↘
Slovakia	↗	↗	↘
Slovenia	→	↗	→
Spain	↘	↗	↘
Sweden	↗	↗	→
United Kingdom	↗	↘	→
EU	↗	↗	→

Note: 'National GHG targets under the ESD' (second column):

- ↗ 2012 non-ETS emissions were below the 2013 ESD targets and 2020 non-ETS emissions are projected to be lower than the 2020 ESD target with existing measures;
- → 2012 non-ETS emissions were below their 2013 ESD targets and 2020 non-ETS emissions are projected to be lower than the 2020 ESD target only if planned additional measures are implemented;
- ↘ 2012 non-ETS emissions were above the 2013 ESD targets or 2020 non-ETS emissions are projected to be higher than the 2020 ESD target even if the planned additional measures are implemented.

'National targets on RES share in gross final energy consumption' (third column):

- ↗ the 2011 RES share was above the RED and NREAP 2011–2012 trajectories;
- → the 2011 RES share was above the RED 2011–2012 trajectory, but below the NREAP 2011–2012 trajectory;
- ↘ the 2011 RES share was still below the RED and NREAP 2011–2012 trajectory values.

'Improving energy efficiency' (fourth column):

- ↗ a well-balanced policy package exists across relevant sectors and good progress is made in reducing energy consumption and primary energy intensity;
- → some progress is made in reducing energy consumption but further improvements are necessary to further develop policies or to better implement the existing ones;
- ↘ limited progress is made so far in improving energy efficiency and further efforts are needed to develop polices across the relevant sectors and to implement them.

Fig. 3.39 Progress towards the 2020 climate and energy targets in the European Union (source: *European Environment Agency)*

The *Kyoto Protocol targets* & the essential *Low Energy Building Concepts*

As highlighted and clearly illustrated by the *low energy buildings design strategy* developed *by IEA – Energy Conservation in Buildings and Community Systems Programme - ECBCS Annex 44,* an exemplary model combining both the Kyoto protocol's main targets with the main low energy buildings concepts and principles, may be provided by the so called ***Kyoto Pyramid*** strategy.
Such a planning and designing method is neatly described by the following scheme, which indicates the key-factors laying behind a **holistic building project's approach**, also defining and specifying the concept more in depth and therefore addressing towards the most useful direction to be adopted in a preliminary building design phase.

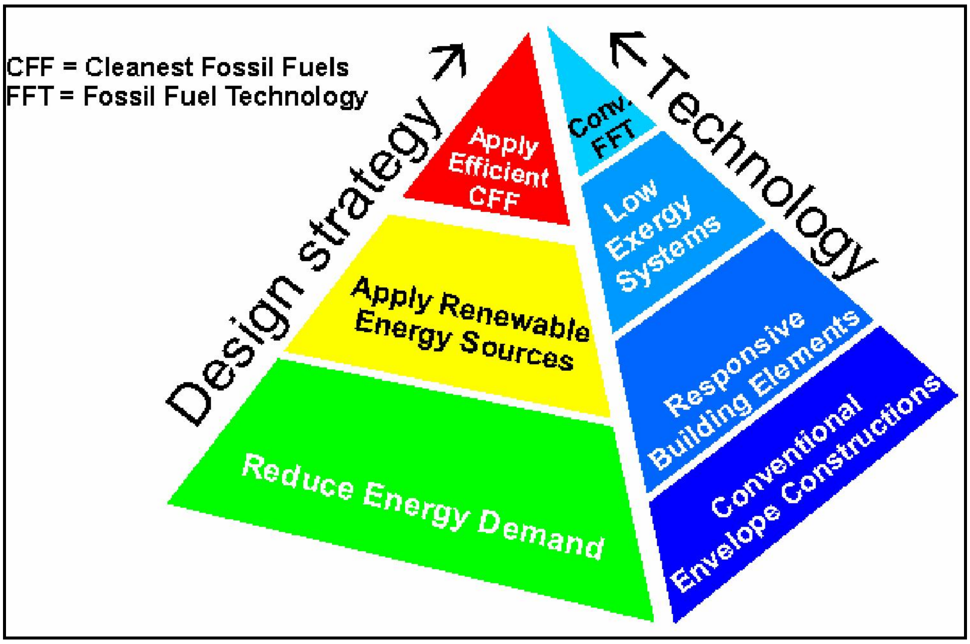


Fig. 3.40 Illustration of the *Kyoto Pyramid* (as depicted by *Annex 44 Design Strategy and corresponding Technologies* and quoting P.Heiselberg's paper on *Low Energy Building Concepts*)

Actually, as above specified, such an integrated building scheme should consider several aspects and elements through a well-structured and an all-embracing planning concept: the overall building architecture should be properly designed, along with its façades, its bearing structure, the construction materials, acoustic and security aspects, indoor environmental quality and, in particular, an opportune and well-balanced energy use.
Therefore, to sum up, the most significant key-factors involved in such an integrated low energy building concept and which should also be adopted in order to address a strategic and efficient policy, could be pointed out as follows:

- an **architectural** building concept;
- a **structural** building concept;
- an **energy and environmental** building concept.

In particular, analyzing the Kyoto Pyramid's configuration it's possible to detect (in its left side) the design strategies' aspects, while its right side stresses the importance of those technical solutions to be applied in each step of an integrated and well-structured overall building design strategy.
The adoption of such a planning criterion therefore addresses towards the following steps:

1) **the energy demand reduction** by mean of a building shape's optimization and a proper zoning process. Hence, a proper building envelope insulation, its air tightness, the application of efficient heat recovery of ventilation during heating season, the installation of efficient electric lighting and

equipment, as well as the application of responsive building elements and – if appropriate – also including advanced façades with optimal windows orientation, the exploitation of daylight, the proper use of thermal mass, the redistribution of heat inside the building etc;

2) **the use of renewable energy sources** providing an optimal use of **passive** renewable energy sources such as solar heating, day lighting, natural ventilation, night cooling, earth coupling, the installation of solar collectors, solar cells, geothermal energy, ground water storage, biomass etc.…as well as the application of **active** renewable energy sources and the RES optimization by applying low exergy systems;

3) **the efficient use and conversion of fossil fuels,** using least polluting fossil fuels and providing for their use in a more efficient way (e.g. through the installation of heat pumps, high-efficient gas fired boilers, gas fired CHP-cogeneration or combined heat and power units etc) and also implementing an intelligent demand control of systems.

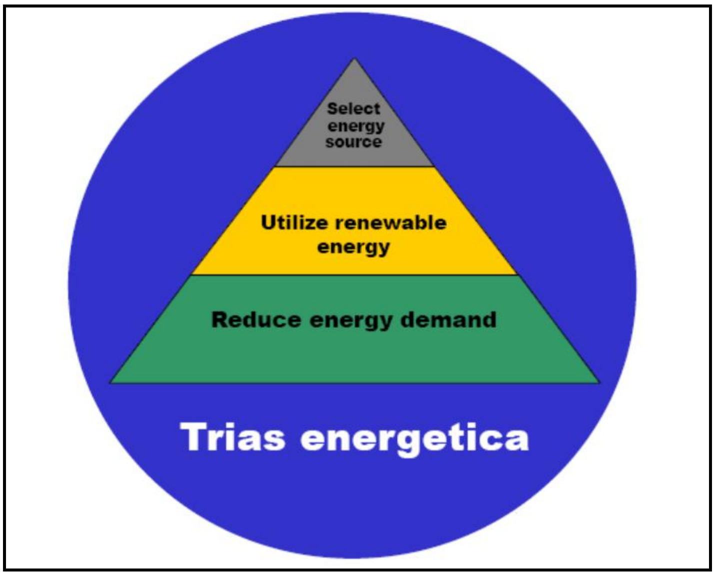


Fig. 3.41 Illustration of the *Trias Energetica* (as depicted by the *Norges teknisk-naturvitenskapelige universitet* *http://www.ntnu.no/* *Det Skapende Universitet*)

The above shown ***Kyoto Pyramid (KP)*** is a strategy developed for the design of low energy buildings in Norway, (Dokka and Rødsjø, 2005) and is based on the so called ***Trias Energetica Method*** described by Lysen (1996).
Actually, the main benefits ascribable to such a method consist into the enlightenment of the importance into reducing main energy loads before adding further systems for energy supply and therefore promoting efficient and "*robust solutions with the lowest possible environmental loadings*" (quoting a Per Heiselberg's paper published about this issue).

Indeed the fundamental principles pointed by a consistent and efficient planning criterion must provide – as above depicted – for the following tasks:

- the reduction of energy demand by avoiding waste and implementing energy-saving measures;
- the use of sustainable (renewable) sources of energy instead of finite fossil fuels;
- the production and use of fossil energies in the most efficient way possible.

3.7 Italy vs. Denmark: conclusive remarks, global summary and overall comparisons

In the light of the previous enlightenments and with the purpose of providing some final conclusive remarks about the different contexts and backgrounds to deal with, the following summary table and overall outlooks reveal rather useful and clarifying

SYNOPTICAL - COMPARISON TABLE – U_{REF} VALUES ITALY (e.g. climatic *C Zone*) vs. DENMARK		
REQUIREMENTS FOR INSULATION OF THE BUILDING ENVELOPE		
BUILDING ELEMENT	ITALY (REGULATIONS - U_{REF} LIMIT valid from 1st January 2010 – e.g. *C Zone*)	DENMARK
OPAQUE SURFACES HORIZONTAL OR SLOPING – GROUND SLABS, BASEMENT FLOORS IN CONTACT WITH THE SOIL	0,42 $W/m^2{*}K$	0,12 $W/m^2{*}K$
EXTERIOR WALLS OPAQUE VERTICAL SURFACES	0,40 $W/m^2{*}K$	0,20 $W/m^2{*}K$
CEILING AND ROOF STRUCTURES, INCLUDING JAMB WALLS, FLAT ROOFS AND SLOPING WALLS DIRECTLY ADJOINING THE ROOF	0,38 $W/m^2{*}K$	0,15 $W/m^2{*}K$
TRANSPARENT OPENABLE VERTICAL SURFACES (i.e. WINDOWS including PANES and FRAME)	2,60 $W/m^2{*}K$	1,65 $W/m^2{*}K$

Tab. 3.2: Synoptical – Comparison table (Italy-*Climatic Zone C* vs. Denmark): Main prescription and transmittance limits to be respected for the single building element

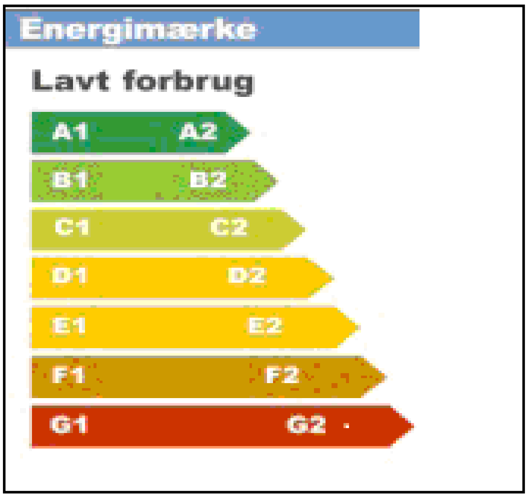


Fig. 3.42-a *Danish Energy Labelling Scheme*: global rating criteria

Fig. 3.42-b *Italian Energy Labelling Scheme*: global rating criteria (e.g. depending on the specific climatic zone of reference)

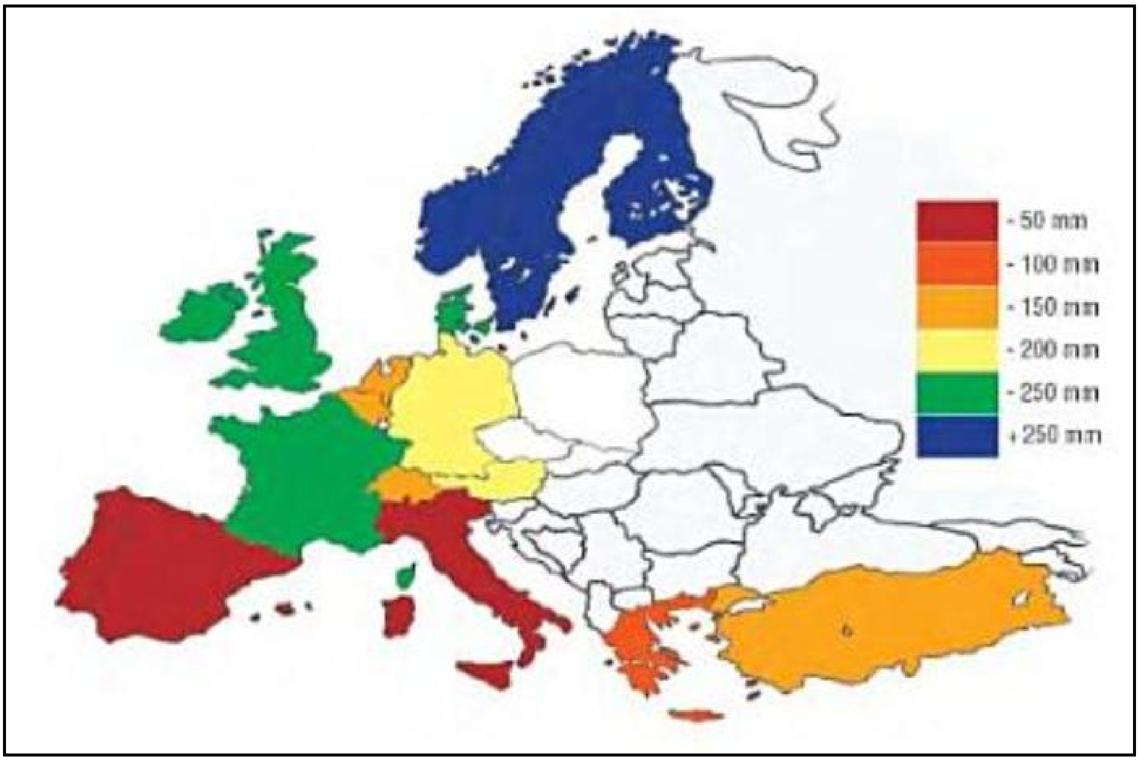


Fig. 3.43-a Average insulation thickness for <u>Roofs</u> in Europe: overall assessment – year 2001 (Source *EURIMA - European Insulation Manufacturers Association*)

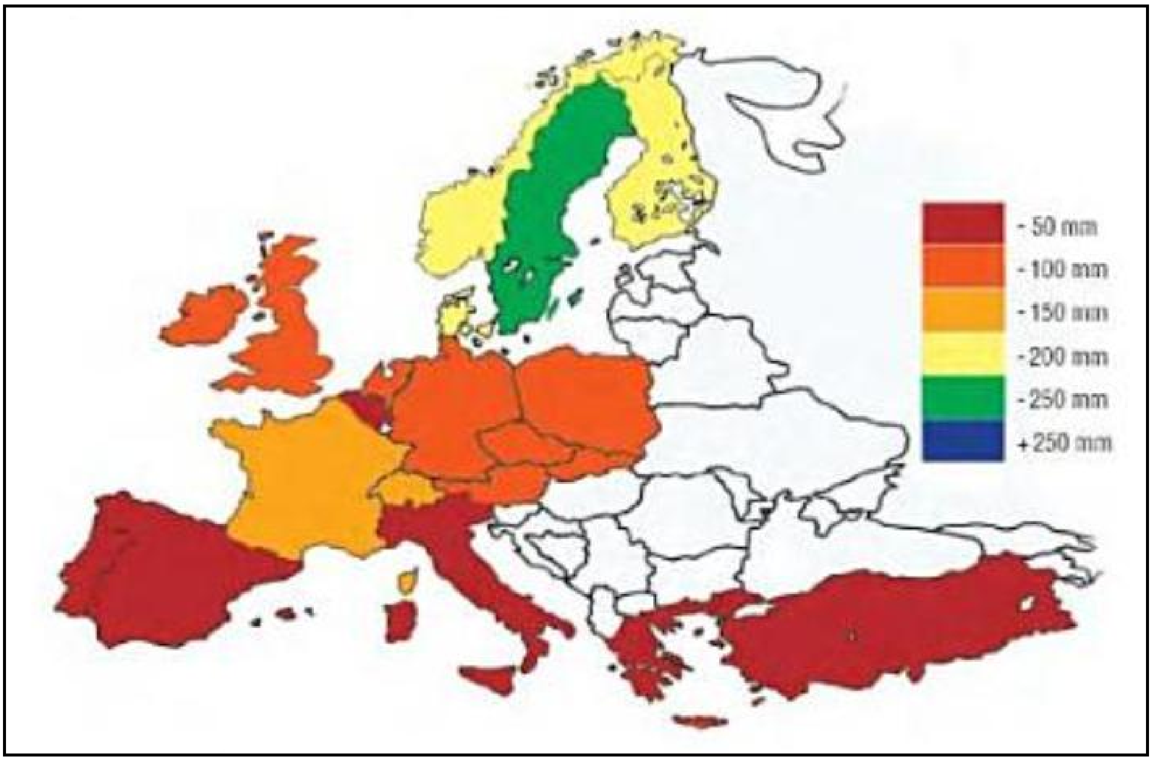


Fig. 3.43-b Average insulation thickness for <u>Walls</u> in Europe: overall assessment – year 2001 (Source *EURIMA - European Insulation Manufacturers Association*)

PART II

4 Focus on the Italian assessment

"I believe that renovation of buildings to high energy performance standards could be one of the most cost effective investments a nation can make, given the benefits in terms of job creation, quality of life, economic stimulus, climate change mitigation and energy security that such investments deliver".

(Oliver Rapf, Executive Director of the Buildings Performance Institute Europe - BPIE)

4.1 The ***ISTAT Census*** and the ***ENEA Reports*** assessment tools

With the aim of defining the best mixing of energy retrofit interventions for the different geographical areas ("climatic zones") of Italy and in order to adopt a methodology, based on simple and available data, to improve buildings energy efficiency, the current assessment started with the analysis of *ISTAT* Census, along with the several reports drawn up by the *ENEA* Energy Agency year by year, since 2007.

- The ***ISTAT Census:***
  available at the following web-page:
  http://dawinci.istat.it/MD/dawinciMD.jsp?a1=m0GG0c0I0&a2=mG0Y8048f8&n=1UH10009OG0

  It's a report which contains the evaluation of Italian population and buildings in their entirety: this document is drawn up - every 10 years - by the ***National Italian Institute for Statistics (ISTAT)*** and, in this case, the present analysis is based on those information and data provided by the 14° ISTAT Census issued during year 2001 (since, when the current research had started, the latest 2011 census was still incomplete and not well-defined yet).

  The ISTAT Census is a very important source of data and inputs, since it reports the global number of residential buildings existing in Italy, distinguished in the following 5 different "Macro Geographical Areas" (and besides, it also provides other important information, like those ones related to the age of dwellings etc):

  1) **North-West Area**, which involves the following regions: Piemonte, Valle d'Aosta, Lombardia and Liguria (with a total number of **7.444.761** dwellings);
  2) **North-East Area**, that includes the following regions: Trentino-Alto-Adige, Veneto, Friuli-Venezia-Giulia and Emilia-Romagna (with a total number of **5.075.838** dwellings);
  3) **Central Area**, which accounts Toscana, Umbria, Marche and Lazio (with a total number of **5.137.694** dwellings);
  4) **South Area**, that includes Abruzzo, Molise, Campania, Puglia, Basilicata and Calabria (with a total number of **6.260.594** dwellings);
  5) **Islands**, with the two biggest Italian islands: Sicilia and Sardegna (and a total number of **3.349.993** dwellings).

  According to ISTAT Census, the entire Italian country has therefore reached - in 2001- a total number of dwellings estimated in **27.268.880**.

Istat 14° Censimento Generale della Popolazione e delle Abitazioni — Censimento 2001

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Torna alla lista iniziale delle tavole

	Tavola selezionata	Pagina visualizzata
Oggetto	Abitazioni in edifici ad uso abitativo	
Classificazioni	Numero di abitazioni nell'edificio	
Territorio	Italia (dettaglio ripartizionale)	
Anno	2001	

Puoi classificare i dati anche per: | Epoca di costruzione |

Tavola: Abitazioni in edifici ad uso abitativo per numero di abitazioni nell'edificio - Italia (dettaglio ripartizionale) - Censimento 2001.

RIPARTIZIONI GEOGRAFICHE	Numero di abitazioni nell'edificio						
	1	2	3 o 4	Da 5 a 8	Da 9 a 15	16 e più	Totale
Italia Nord-Occidentale	1.390.251	1.120.340	860.382	842.018	941.218	2.290.552	7.444.761
Italia Nord-Orientale	1.241.582	1.015.038	726.784	706.428	584.436	801.570	5.075.838
Italia Centrale	1.033.001	820.854	706.964	670.436	656.044	1.250.395	5.137.694
Italia Meridionale	1.903.496	1.050.930	800.121	703.387	650.928	1.151.732	6.260.594
Italia Insulare	1.333.758	553.694	384.342	301.492	285.091	491.616	3.349.993
Italia	**6.902.088**	**4.560.856**	**3.478.593**	**3.223.761**	**3.117.717**	**5.985.865**	**27.268.880**

Fig. 4.1 One of the several synoptic tables available for the XIV° Istat Census

- The ***ENEA REPORTS**:*
  available at the following web-page: *http://www.acs.enea.it*
  They consist in all the main information and data collection performed by the ***Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)*** in order to test and assess the effectiveness of Italian laws and regulations related to the so-called "55% tax reductions" for building retrofitting in Italy.
  ENEA has in fact collected, starting from year 2007 (i.e. since the earliest incentives settled by the Finance Act of 2007) the several paper works and files sent by postal service and/or e-mail by all those citizens which would enjoy the tax cut, a.k.a. "55% reduction", provided by the Italian law.
  The above reports were issued, year by year, in order to monitor and assess the results of the financial policies adopted in Italy in order to increase the Nation's energy efficiency.
  They involve the entire country and, splitting that into 5 different geographical macroareas, allow to carry out an investigation and to develop an analysis centered both on the single macroarea level and on the whole Italian level too.
  In line with EU general objectives (and most of all in the light of both the recent 2006/32/CE and the 2010/31/CE Directives enactment) - besides the so-called *EU 20:20:20* energy saving planks - the primary goal of Italian energy policy concerns the implementation of several measures addressed to liberalize and increase the overall efficiency of the entire energy sector.
  Actually, in order to align with the above mentioned European policies and objectives, the Italian Government has in fact adopted a strategy aiming at the diversification and the penetration of new energy forms in power generation, with a concurrent improvement of energy efficiency and conservation in end uses, as well as with a wider exploitation of renewable energy sources.

Thence, on the one hand it is attempting to incentive mechanisms and methodologies for quantifying energy consumptions and energy savings in dwellings, and on the other hand (since the Finance Act issued in 2007 and in order to increase energy savings for winter heating in existing buildings) has established a system of generous financial incentives. They allow a tax deduction of 55% for all the investments sustained both by private, individual citizens and by companies.

4.2 Legislative iter: transmittance limits and percentage relief

During year 2007 Italian regulations L.27/12/06 n.296 (also known as the "*Financial Law 2007*") established the first tax breaks and financial relief to be granted in case of energy retrofit and energy saving improvements into buildings and dwellings.

Actually the tax allowance has been settled as an ***IRPEF (Individual Income Tax)*** and an ***IRES (Corporate Income Tax)*** burden relief.

- In particular, ***IRPEF*** is the Italian direct personal tax that affects some types of income tax like those revenues related to real estate income, capital gains, income from self-employment, income from employment, corporate revenue and other incomes.
- While instead ***IRES*** is the Italian tax directly applied to those companies and enterprises resident in Italy.

More precisely, the first version of the norm allowed the 55% tax reduction for the total amount of costs and expenses coped in order to restore and retrofit buildings and constructions with the final goal of reducing their energy consumption.

Specifically, the different articles and paragraphs of the rule are related to the several technological solutions and possible energy-saving measures, like heating plants replacement, insulation of roofs and/or walls, windows frame replacement, solar panels installation.

The total tax relief is evenly spread in several annual instalments for the first ten years after the different possible refurbishments (only the initial version had involved the first three years after retrofit) and could currently reach the maximum global amounts below depicted:

RETROFIT TYPOLOGY	MAXIMUM TAX ALLOWANCE
OPAQUE HORIZONTAL SURFACES (art.1 comma 345)	**60.000 € (55% of 109.090,90 €)**
OPAQUE VERTICAL SURFACES (art.1 comma 345)	**60.000 € (55% of 109.090,90 €)**
WINDOWS FRAME REPLACEMENT (art.1 comma 345)	**60.000 € (55% of 109.090,90 €)**
SOLAR PANEL INSTALLATION (art.1 comma 346)	**60.000 € (55% of 109.090,90 €)**
THERMAL PLANT REPLACEMENT (art.1 comma 347)	**30.000 € (55% of 54.545,45 €)**

Fig. 4.2 Main guidelines and limits required by the Italian Revenue Agency for exploiting the building retrofit tax relief

N.B.

- A *conditio sine qua non* it's possible joining the above incentives consists into retrofitting or improving the appliances for those buildings already existing, independently of their specific purpose and end use;
- besides, for any typology of the above refurbishments the tax cut can't be drawn concurrently with any other kind of tax relief (such as, for example, the 36% tax allowance granted in case of a general dwelling's renovation);

- last, but not least, a further, essential requirement which must be fulfilled in order to join such financial incentives concerns the transmittance limits to be respected by any specific typology of building retrofit (and according to the different Italian climatic areas distinction). Actually, recalling that Italian country involves five different climatic zones (from *A* to *F* in function of the specific degree days values), the main regulations established about this issue were adjusted and amended - year by year - also tightening the different limits to be respected (as hereinafter shown).
After the earliest regulations which had been referred to D.Lgs. n.192/2005 (in a successive step modified by the D.Lgs. n.311/2006 and then followed by the D.M.19/02/2007), the Financial Law established in 2008 settled the following limits (given in W/m^2): **Fig. 4.3**

CLIMATIC ZONE	OPAQUE VERTICAL SURFACES	OPAQUE HORIZONTAL SURFACES		WINDOWS
		ROOFS	FLOORS	
A	0,72	0,42	0,74	5,0
B	0,54	0,42	0,55	3,6
C	0,46	0,42	0,49	3,0
D	0,40	0,35	0,41	2,8
E	0,37	0,32	0,38	2,5
F	0,35	0,31	0,36	2,2

According to the successive D.M. 11/03/2008 (annex B), the limits were tightened as follows:

CLIMATIC ZONE	OPAQUE VERTICAL SURFACES	OPAQUE HORIZONTAL SURFACES		WINDOWS
		ROOFS	FLOORS	
A	0,62	0,38	0,65	4,6
B	0,48	0,38	0,49	3,0
C	0,40	0,38	0,42	2,6
D	0,36	0,32	0,36	2,4
E	0,34	0,30	0,33	2,2
F	0,33	0,29	0,32	2,0

While instead, between 1st January 2010 and 13th March 2010, the tighter limits in force were:

CLIMATIC ZONE	OPAQUE VERTICAL SURFACES	OPAQUE HORIZONTAL SURFACES		WINDOWS
		ROOFS	FLOORS	
A	0,56	0,34	0,59	3,9
B	0.43	0,34	0,44	2,6
C	0.36	0,34	0,38	2,1
D	0.30	0,28	0,30	2,0
E	0.28	0,24	0,27	1,6
F	0.27	0,23	0,26	1,4

Finally, by mean of the amendments introduced by D.M.26/01/2010 the above values were settled and reshaped as follows:

CLIMATIC ZONE	OPAQUE VERTICAL SURFACES	OPAQUE HORIZONTAL SURFACES		WINDOWS
		ROOFS	FLOORS	
A	0,54	0,32	0,60	3,7
B	0.41	0,32	0,46	2,4
C	0.34	0,32	0,40	2,1
D	0.29	0,26	0,34	2,0
E	0.27	0,24	0,30	1,8
F	0.26	0,23	0,28	1,6

Along with such an "eventful" limit values calibration and variation, also the tax relief percentage was interested by successive modifications and adjustments: actually, after a "transition and uncertainty period", such incentives have risen reaching the value of 65% and are going to become permanent (even though varying their specific relief's percentage) starting from year 2014 (as settled by the latest D.L. 63/2013 also called *Ecobonus*).

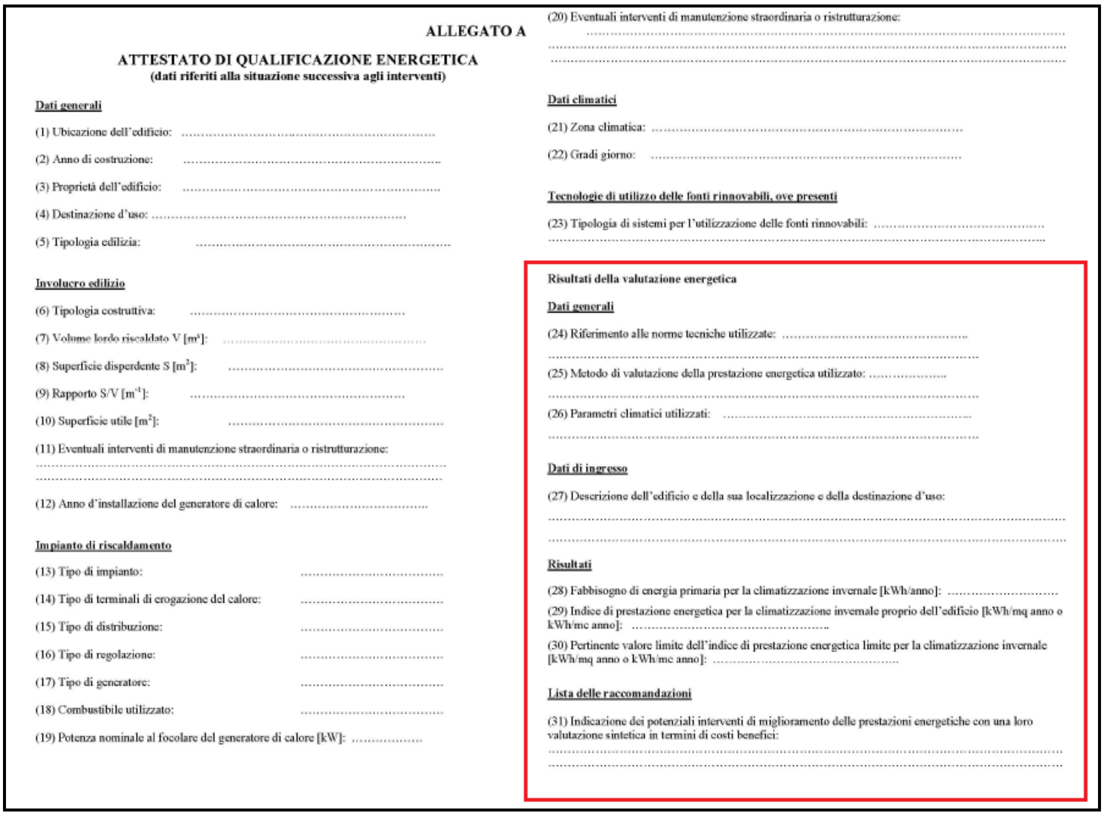
N.B.

The above limits mustn't be confused with the transmittance maximum values settled by the Italian Regulations currently in force: actually, they were established by Italian Revenue Agency only in order to govern the tax relief's mechanism, also regulating such incentives.
And indeed they all are generally stricter than the ones prescribed by law.

4.3 Procedure of investigation

"*If you cannot measure it, you cannot improve it*" (Sir William Thomson, Lord Kelvin).

The present analysis is based on all the statistical data provided by the several Enea Reports issued in these latest four years. Actually, such data consist in a huge set of statistical information related to the following main and most significant key-elements: the number of different kind of renovations respectively worked out in the several Italian macroareas; their respective average costs and the consequent energy savings (as respectively assessed by mean of specific Energy Certifications filled in by qualified experts figures) and economical benefits achieved (see **Fig.4.4-a** and **Fig.4.4-b**).
After the initial scanning and collecting of the most relevant results summed up by the reports issued in 2008 (based on the 2007 Energy Campaign results), 2009 (based on 2008 results), 2010 (related to 2009 Campaign) and 2012 (based on 2010 results), several resume schedules were in fact filled up, drawing the respective graphs and summary tables in order to follow and outline the evolution and the statistical changes occurred during the whole time-span analyzed (as hereinafter detailed).



ALLEGATO A

ATTESTATO DI QUALIFICAZIONE ENERGETICA
(dati riferiti alla situazione successiva agli interventi)

Dati generali

(1) Ubicazione dell'edificio: ……………
(2) Anno di costruzione: ……………
(3) Proprietà dell'edificio: ……………
(4) Destinazione d'uso: ……………
(5) Tipologia edilizia: ……………

Involucro edilizio

(6) Tipologia costruttiva: ……………
(7) Volume lordo riscaldato V [m³]: ……………
(8) Superficie disperdente S [m²]: ……………
(9) Rapporto S/V [m⁻¹]: ……………
(10) Superficie utile [m²]: ……………
(11) Eventuali interventi di manutenzione straordinaria o ristrutturazione: ……………
(12) Anno d'installazione del generatore di calore: ……………

Impianto di riscaldamento

(13) Tipo di impianto: ……………
(14) Tipo di terminali di erogazione del calore: ……………
(15) Tipo di distribuzione: ……………
(16) Tipo di regolazione: ……………
(17) Tipo di generatore: ……………
(18) Combustibile utilizzato: ……………
(19) Potenza nominale al focolare del generatore di calore [kW]: ……………
(20) Eventuali interventi di manutenzione straordinaria o ristrutturazione: ……………

Dati climatici

(21) Zona climatica: ……………
(22) Gradi giorno: ……………

Tecnologie di utilizzo delle fonti rinnovabili, ove presenti

(23) Tipologia di sistemi per l'utilizzazione delle fonti rinnovabili: ……………

Risultati della valutazione energetica

Dati generali

(24) Riferimento alle norme tecniche utilizzate: ……………
(25) Metodo di valutazione della prestazione energetica utilizzato: ……………
(26) Parametri climatici utilizzati: ……………

Dati di ingresso

(27) Descrizione dell'edificio e della sua localizzazione e della destinazione d'uso: ……………

Risultati

(28) Fabbisogno di energia primaria per la climatizzazione invernale [kWh/anno]: ……………
(29) Indice di prestazione energetica per la climatizzazione invernale proprio dell'edificio [kWh/mq anno o kWh/mc anno]: ……………
(30) Pertinente valore limite dell'indice di prestazione energetica limite per la climatizzazione invernale [kWh/mq anno o kWh/mc anno]: ……………

Lista delle raccomandazioni

(31) Indicazione dei potenziali interventi di miglioramento delle prestazioni energetiche con una loro valutazione sintetica in termini di costi benefici: ……………

Fig. 4.4-a Example of one of the main documents to be delivered to Enea in order to join the tax cut facilities (source ENEA)

ALLEGATO E

Scheda informativa per interventi di cui all'articolo 1, comma 344,345, 346 e 347 della Legge 27 dicembre 2006, n. 296

1. Dati identificativi del soggetto che ha sostenuto le spese :
Se persona fisica indicare : Codice Fiscale, Cognome, nome, comune e data di nascita, sesso;
Titolo a cui sono stati fatti i lavori: possessore, detentore, contitolare;
Se persona giuridica indicare: Denominazione, partita IVA, Sede sociale
Se gli interventi riguardano parti comuni condominiali indicare: il codice fiscale del condominio e se il soggetto che trasmette la scheda informativa è l'amministratore o un condomino.

2. Dati identificativi della struttura oggetto dell'intervento:

Indicare l'ubicazione (denominazione COMUNE, sigla PROV, via con numero civico, interno, CAP o dati catastali: cod. comune catasto, foglio, mappale, subalterno);

3. Identificazione della tipologia di intervento eseguito:

Comma 344 345 346 347

Pareti verticali
- Superficie m^2.
- Trasmittanza precedente - attuale W/m^{2}K
- verso esterno o parti non riscaldate Si No

Pareti orizzontali o inclinate
- Tipo (Pavimenti, solai, falde tetto)
- Superficie m^2.
- Trasmittanza precedente - attuale W/m^{2}K
- verso esterno o parti non riscaldate Si No

Infissi
- Tipologia esistente (Legno, alluminio, acciaio, materiali plastici, misto; tipo di vetro singolo, doppio, a bassa emissione …..)
- Sostituzione infisso Si No se "si" indicare la nuova tipologia del telaio e del vetro
- Sostituzione vetro Si No se "si" indicare la nuova tipologia del vetro
- Superficie mq. totale vetro e telaio
- Trasmittanza attuale W/m^{2}K

Solare Termico
- Superficie netta m^2.
- Tipo installazione (tetto piano, falda….)
- Inclinazione %
- Orientamento N S E O NE NO SE SO
- Accumulo (litri) Accumulo sanitario (litri)
- Integrazione con riscaldamento Si No
- Integrazione con produzione di acqua calda sanitaria Si No
- Fluido di scambio (acqua, glicole, altro)

Climatizzazione invernale
- Caldaia a condensazione e distribuzione a bassa temperatura/caldaia tradizionale/ *pompa di calore/impianto geotermico*
- Potenza nominale al focolare del nuovo generatore termico kW/ *potenza elettrica assorbita/potenza termica nominale*
- Potenza nominale al focolare del generatore termico sostituito kW
- Integrazione con accumulo di calore Si No
- Tipo di accumulo calore: Solare termico, cogenerativo, pompa di calore
- Trasformazione di impianti centralizzati per rendere applicabile la contabilizzazione del calore
- Tipologia di contabilizzazione del calore prevista.

4. Risparmio annuo di energia in fonti primarie previsto con l'intervento (kWh)

5. Costo dell'intervento di qualificazione energetica al netto delle spese professionali (Euro):

6. Importo utilizzato per il calcolo della detrazione (Euro):

7. Costo delle spese professionali (Euro):

Data e firma del richiedente

Data e Firma del tecnico compilatore

Fig. 4.4-b Example of one of the main documents to be delivered to Enea in order to join the tax cut facilities (source ENEA)

All the assessments were carried out through excel, hand cost-benefit calculations and spreadsheets and were developed basing such analyses on those which should be the most suitable **lifespan values** for the different kinds of intervention.
Thence, after a global review of the current European Standardization and of the Regulations related to this topic, different adjustment factors were introduced: due to the statistical nature of all the data processed and being the typological range of such renovations so wide and general, such factors were assumed rather "widespread and global-fitting".

Hence, the following **reference intervals** were adopted:

50 years both for vertical and horizontal surfaces insulation (i.e. walls, floors and roofs), **30 years** for windows replacement and **25 years** both for solar thermal collectors installation and heating plants replacement.

2007						
	INTERVENTIONS	**NORTH-WEST**	**NORTH-EAST**	**CENTER**	**SOUTH**	**ISLANDS**
	OPAQUE HORIZONTAL SURFACES	413	472	280	119	52
	OPAQUE VERTICAL SURFACES	674	932	379	188	53
	WINDOWS REPLACEMENT	13.868	10.263	5.410	2.863	935
	SOLAR PANEL INSTALLATION	3.341	8.899	3.180	978	2.661
	THERMAL PLANT REPLACEMENT	9.620	9.564	5.756	2.068	563
2008						
	INTERVENTIONS	**NORTH-WEST**	**NORTH-EAST**	**CENTER**	**SOUTH**	**ISLANDS**
	OPAQUE HORIZONTAL SURFACES	2.339	2.518	916	341	139
	OPAQUE VERTICAL SURFACES	1.221	1.690	285	227	62
	WINDOWS REPLACEMENT	42.915	28.484	16.972	9.731	3.306
	SOLAR PANEL INSTALLATION	6.691	16.525	6.484	2.480	4.417
	THERMAL PLANT REPLACEMENT	21.563	21.999	12.543	4.124	1.487
2009						
	INTERVENTIONS	**NORTH-WEST**	**NORTH-EAST**	**CENTER**	**SOUTH**	**ISLANDS**
	OPAQUE HORIZONTAL SURFACES	4.331	3.440	1.481	407	179
	OPAQUE VERTICAL SURFACES	2.133,00	2.283	438	385	138
	WINDOWS REPLACEMENT	48.735	32.777	18.741	10.632	3.921
	SOLAR PANEL INSTALLATION	9.383	15.771	5.664	2.079	3.042
	THERMAL PLANT REPLACEMENT	25.120	23.800	13.209	5.983	2.650
2010						
	INTERVENTIONS	**NORTH-WEST**	**NORTH-EAST**	**CENTER**	**SOUTH**	**ISLANDS**
	OPAQUE HORIZONTAL SURFACES	2.338	2.555	880	316	145
	OPAQUE VERTICAL SURFACES	1.570	2.067	493	347	113
	WINDOWS FRAME REPLACEMENT	94.503	62.986	36.208	20.058	7.654
	SOLAR PANEL INSTALLATION	14.527	19.542	7.494	3.088	3.060
	THERMAL PLANT REPLACEMENT	48.079	43.890	20.232	9.429	4.053

Fig. 4.5 Number of renovations registered by Enea in the several Italian macroareas during the time-span 2007-2010

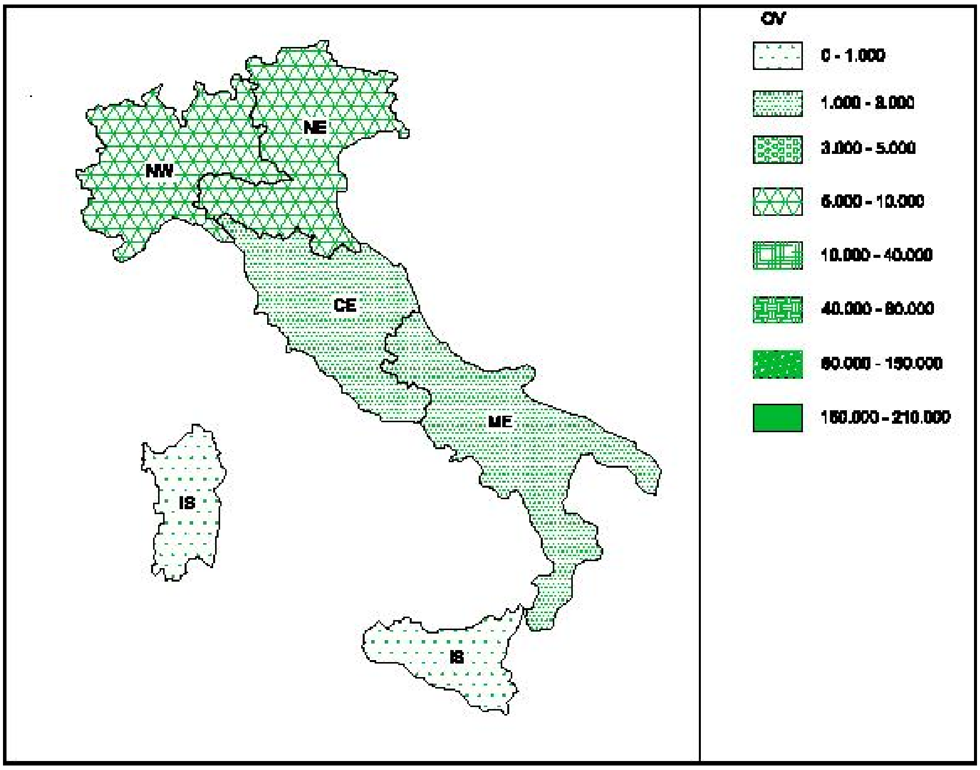


Fig. 4.6-a

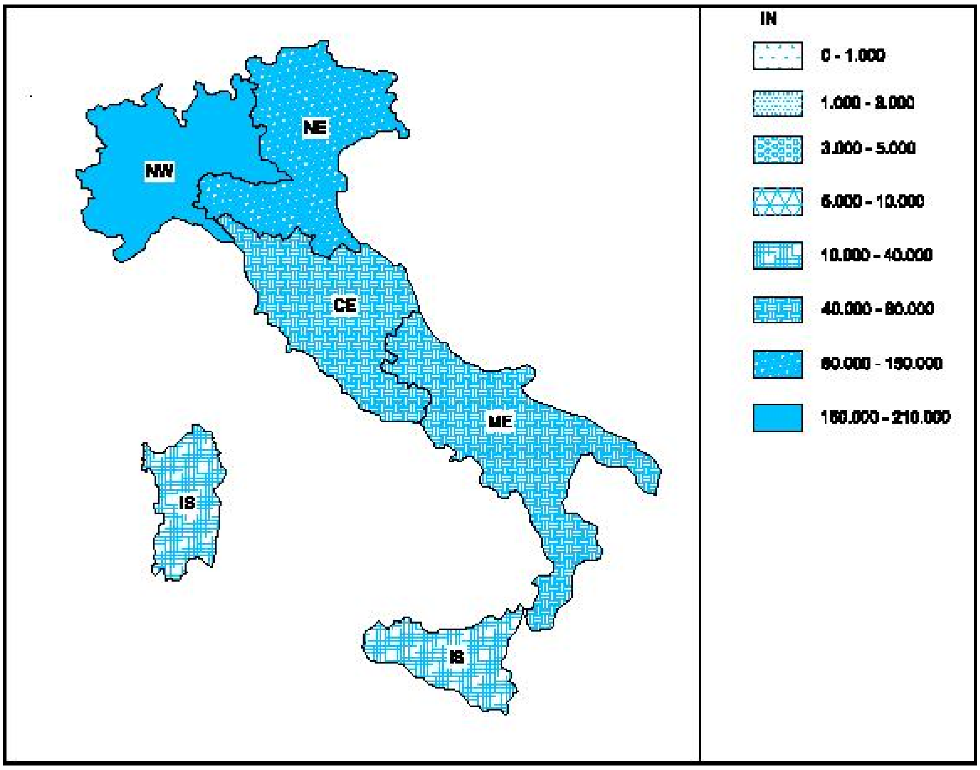


Fig. 4.6-b

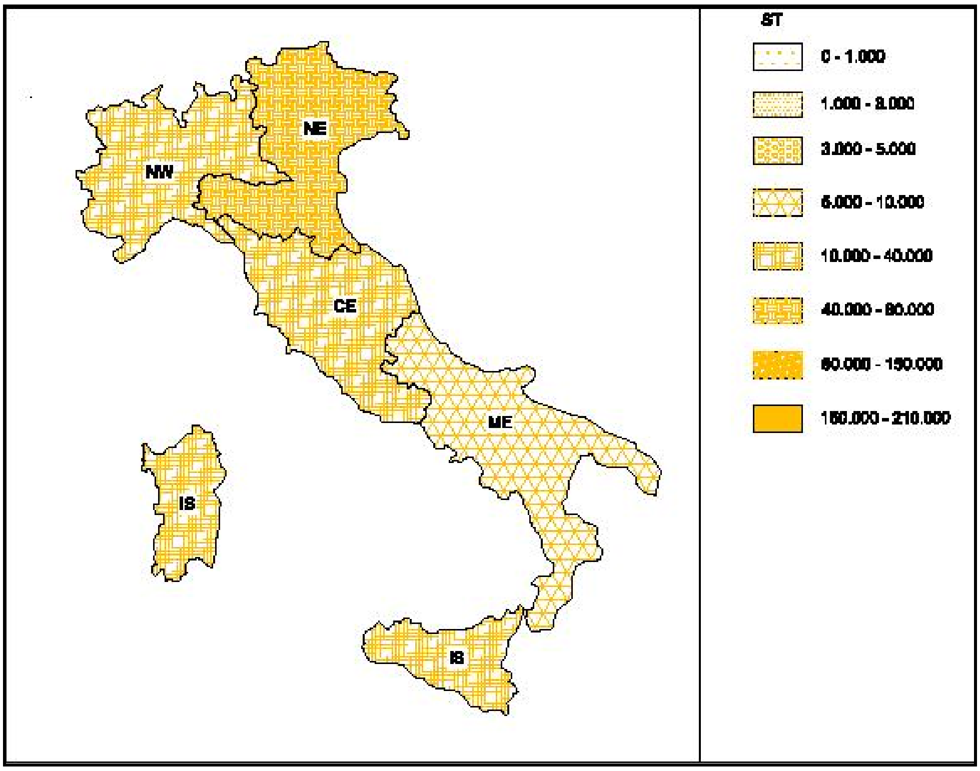


Fig. 4.6-c

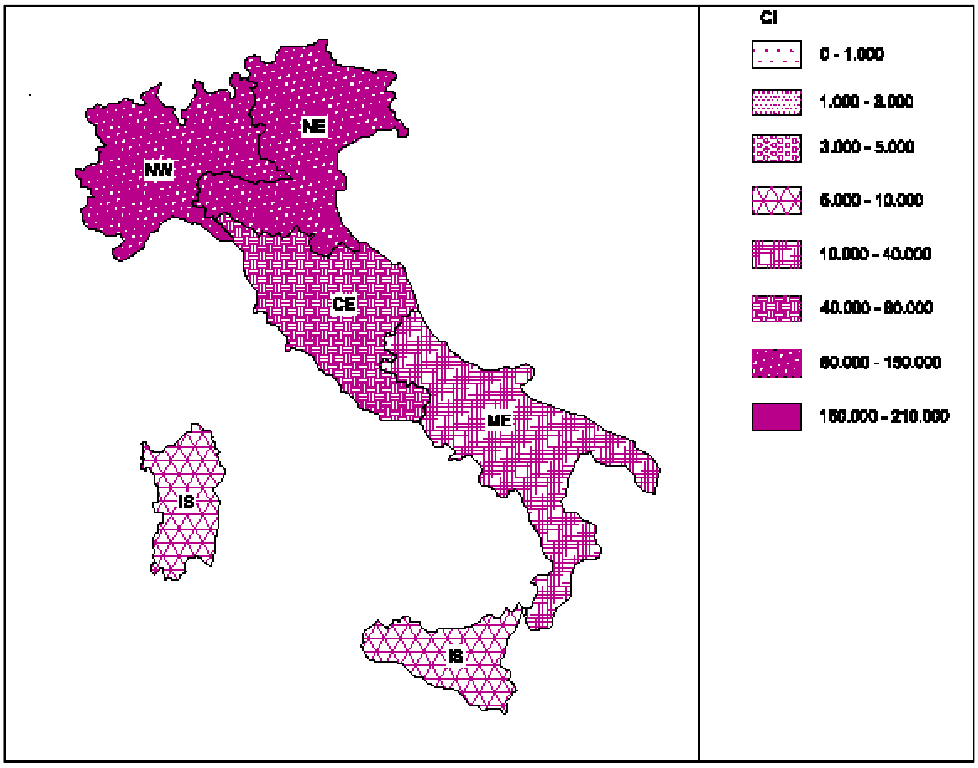


Fig. 4.6-d

Fig. 4.4 a,b,c,d Time-span 2007 – 2010:
cumulative overall renovations' distribution along the whole Italy

As it's easy to note, a lot of differences and discrepancies among the several resume tables and figures of above are detectable: they are both related to the number of renovations registered along the entire country, as well as to their respective distribution.

First of all, an evident gap is recognized between the global number of renovations reported during the first campaign year and the successive ones. And such a statistical phenomenon is essentially ascribable to the following main reasons:

- on the one hand, it is due to the first venture's year being a bit like a sort of "initial, testing experience". Thence, despite the awareness campaign and the Enea helpdesk and informative venture, people hadn't enough experience with such an investment plan yet;
- on the other hand an error had occurred in the earliest version of the Budget Law issued in 2007 (and hence in the consequent so-called "*Decreto Edifici – Buildings Decree*"): due to an editing and drafting mistake, the U-Value (thermal transmittance limits) to be respected into realizing the different kinds of opaque horizontal renovations (roofs vs. floors), were in fact reversed. Thence, one more reason that made even fewer the already low rate of such a quite expensive kind of building retrofit.

4.4 A further assessment and evaluation criterion: refurbishment's lifespan versus analysis period

As before mentioned, a systematic review of all the available documents and most significant materials about such a topic area has been performed in order to make the global investigation and assessment the most reliable possible.
The literature review also involved the analysis of Life Cycle Cost methodologies, guidelines and tools already in force or under development in the European Union, as well as in the U.S.
Among all the data and information provided by the huge body of literature related to sustainability assessment on a life cycle basis, the assessment criteria which have been recognized as the most reliable and worthwhile were adopted.

In particular, the ***Life-Cycle Costing Manual for the Federal Energy Management Program*** (carried out by the U.S. Department of Energy) represented a wide and complete source of data and evaluation methods.
Besides, the most reliable lifespan to be assumed for the appliances and energy systems in buildings was gathered by the ***European Standards*** currently in force and/or under evaluation (e.g. the prEN 15459:2007).

The spreadsheet and cost/saving evaluation performed in the first section of the present research (i.e. through the adoption of a "Top Down" approach) has temporarily deferred until the second part of research (with its "Bottom Up" approach) the inclusion of the entire assessment period to be investigated after the refurbishments.

Actually there isn't any relation with the time-span (2007-2010) considered in the first step of survey, since it is based on a completely different kind of analysis and approach.

As before mentioned, the current investigation adopted the following lifetime refurbishments.

INTERVENTION	OPAQUE HORIZONTAL SURFACES	OPAQUE VERTICAL SURFACES	WINDOWS REPLACEMENT	SOLAR PANEL INSTALLATION	THERMAL PLANT REPLACEMENT
LIFE SPAN (SERVICE LIFE in YEARS)	50	50	30	25	25

Fig. 4.7 The different lifetimes respectively assumed by the present research for the main building retrofit typologies

This research has then developed its own evaluation criteria, adopting an assessment approach widely different than the one reported by ENEA Agency (and its document "*ERS - Energy ReStyling degli edifici residenziali e del terziario*").
Actually, under a methodological point of view, it reveals quite difficult to deal with the possibility of univocally defining any single refurbishment lifetime: they are strongly related to the high technologies' variability, as well as to the different kinds of building systems nowadays available.
In any case, to be thorough, the following table reports the reference values quoted by the ENEA.

INTERVENTION	OPAQUE HORIZONTAL SURFACES	OPAQUE VERTICAL SURFACES	WINDOWS REPLACEMENT	SOLAR PANEL INSTALLATION	THERMAL PLANT REPLACEMENT
LIFE SPAN (SERVICE LIFE in YEARS)	20	15	20	20	12

Fig. 4.8 The different lifetimes respectively assigned by Enea to the main building retrofit typologies

4.5 Description of the method used for the analysis: Excel spreadsheet assessment versus Linear Programming and Optimization tools

After an all-embracing review of the available ENEA documents and with reference to the time interval 2007-2010 before selected, several *ad hoc* assessment excel spreadsheets and calculation files were filled up.
This process was developed in order to gather key fact about the main building refurbishments already performed, dealing with the final purpose to define the best and most cost-effective energy saving measures combination.
Clearly, the above balance should also be founded on a properly climatic area distinction.

Besides, according to the main aim of the present research, on the one hand the excel spreadsheet assessment was followed by a manual cost/saving ratio assessment, and on the other hand it is designed to be involved in a successive linear programming script definition.

4.6 Spreadsheet calculations

Also in the light of the above considerations it's important to underline the difficulty of globally implementing a meaningful, exhaustive and fair comparison among all the different yearly reports analyzed. Beside that, a further alteration and data corruption that affects this global trend overlooking is made up by the sensible differences in the population amount - and thence in the dwellings number – detected among the different macroareas carefully analyzed (and above of all, in the case of Islands Macroarea).

COST-BENEFIT BALANCE SUMMARY 2007 [€/MWh*yr]	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES	42,43	**35,82**	45,47	79,35	52,18
OPAQUE VERTICAL SURFACES	54,10	47,15	57,56	72,34	126,02
WINDOWS REPLACEMENT	95,54	92,94	115,68	163,54	172,33
SOLAR PANEL INSTALLATION	78,90	68,70	59,72	37,93	37,79
THERMAL PLANT REPLACEMENT	35,92	45,72	46,98	60,93	73,45

COST-BENEFIT BALANCE SUMMARY 2008 [€/MWh*yr]	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES	32,53	32,13	49,72	71,83	99,82
OPAQUE VERTICAL SURFACES	42,11	38,22	54,62	62,86	98,72
WINDOWS REPLACEMENT	113,64	103,33	153,81	243,47	232,14
SOLAR PANEL INSTALLATION	44,95	50,72	30,24	**14,04**	15,72
THERMAL PLANT REPLACEMENT	34,97	46,82	42,31	43,12	57,45

COST-BENEFIT BALANCE SUMMARY 2009 [€/MWh*yr]	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES	32,22	35,53	44,37	61,92	80,96
OPAQUE VERTICAL SURFACES	42,50	37,27	59,12	58,75	108,55
WINDOWS REPLACEMENT	116,72	105,23	142,66	188,65	214,81
SOLAR PANEL INSTALLATION	52,24	52,37	31,01	**23,34**	24,49
THERMAL PLANT REPLACEMENT	42,89	52,19	44,55	68,82	68,58

COST-BENEFIT BALANCE SUMMARY 2010 [€/MWh*yr]	NORTH-WEST	NORTH-EAST	CENTER	SOUTH	ISLANDS
OPAQUE HORIZONTAL SURFACES	33,12	41,46	58,70	79,35	85,56
OPAQUE VERTICAL SURFACES	46,86	53,71	76,63	88,99	103,15
WINDOWS REPLACEMENT	106,19	98,06	136,33	167,53	197,53
SOLAR PANEL INSTALLATION	67,79	60,93	54,09	28,42	**23,58**
THERMAL PLANT REPLACEMENT	55,93	74,93	86,59	94,45	108,35

Fig. 4.9 Cost-Benefit balance values reckoned for the several Italian macroareas (time-span 2007-2010): as it's quite easy to observe and rather reasonable, according to the Enea data-processing southern zones reveal solar panel installation being the most profitable type of building retrofit (in particular with reference to the 2008, 2009 and 2010 campaign); while instead the northern (and also colder) macroareas depict opaque surfaces insulation as the most cost-effective kind of renovation

Hence, the overall frame depicted by the above table confirms what right now outlined and provides much further, interesting food for thought and research questions to delve into: first of all, it's important to appreciate the big effort required by such a survey and data gathering.
Beside that, also the main aim and intentions which have led this global campaign play a strategic role into realizing the broad sweep and the weight of such financial and energetic policies, with the final target of improving and refining them.
And even though the trends analyses and data-processing performed by the above cost-saving ratio values actually don't directly supply a clear indication about how addressing and developing a future, worthwhile financial policy and investment plan, they reveal however themselves fairly meaningful.

The cost-benefit balances were assessed, year by year and for all the several Italian macroareas, through the evaluation of the ratio between the **weighed average cost** (i.e. the actual average cost, given in €) and the **weighed average energy saving** (expressed in MWh per year) calculated for any kind of renovation, also considering the respective life-time factors previously introduced.
Actually such data provide a global frame quite patchy and uneven and, at first sight, it could be seem affected by some such of mistakes and/or evaluating errors.

But a deeper analysis and a careful examination of the main boundary conditions and global background which lay behind it, will lead us to some reasonable comments and observations:

- beside the already highlighted appreciable differences into population amount and dwellings number for all the several macroareas involved in the survey, another reason of such a relevant results gap and mismatching is ascribable to the substantially different economic conditions which make the northern areas more active and resourceful;
- a further element which doesn't help the overall assessment into gathering a global, common analyzing criterion - and which therefore concurs to such results - is closely connected to the distinct weather patterns that concern the entire Italy: actually, the whole nation involves a quite wide range of different Climatic Zones: exactly 6 (from the *A Zone* until the *F Zone*) and thence 6 distinct weather contexts and environmental backgrounds;
- but, despite all the above considerations, such a huge amount of data and information however plays a very important role: although the earliest results till now outlined reveal themselves so much heterogeneous, it would reveal possible and quite worthwhile to base on them a final knowledge and an overall comprehension of which and why should be the most cost-effective kinds of renovation for any Italian macroarea;
- thence, it would also be easier gathering the most profitable adjustments and amendments to be applied for the already issued financial strategies.

It should be however remarked that, since all the previous years' analyses didn't allow detecting any significant and reliable prediction or trend to base on and to develop the future steps of research, it's only possible to work out some few, very rough assumptions in order to lead the work:

- for instance (according to the current assessment) it's possible to argue that, in the future and with some such further technical development, average costs for the different energy saving solutions and technologies would decrease;
- but, on the other hand, some new technologies are going to be probably developed and also the inflation rate, the interest rate and the price of money should increase and vary afterwards;
- moreover, although the ongoing global climate changes, southern Italian areas are actually in general warmer and with a wider solar radiation than the rest of the country.

But, ultimately, beside the above considerations it isn't possible holding any mathematical certainty about the future occurrences, unless the information and the data already collected.

Also the latest, lowest cost/benefit ratio value registered in the Islands macroarea for solar panel installations (**23,58**) confirms the appropriateness of such an already registered trend, while it should be strongly recommended enhancing and encouraging solar thermal collector equipments in the south of Italy (due to the other two lowest ratio values of **23,34** and **14,04** there reckoned).

But actually other fundamental and more precise information are needed about the already issued financial strategies and - most of all - in relation both to the current and to the incoming tax reduction criteria too.

While it would be necessary adopting a far-sighted policy to allow - in the future - such facilitations during a wider time-span, a lot of care is however needed in order to plan them avoiding any unfruitful investment.

Restrictive upper limits should be settled, also exploiting all the earliest cost-effective information already performed. Moreover, turning towards both the latest, urgent European statements and Regulations and towards the overall economic crisis too, the standard-range to be respected in order to obtain such fiscal reliefs should be stiffened.

Thence, just related to the above last topic, hardening the U-value limit ranges which must be respected along the different macro-areas clearly turns out as being a suitable decision.
While instead it should be avoided the incoming resolution to make no more binding energy efficiency certification proofs for some kinds of renovation, i.e. with reference to solar panel installation, thermal plant replacement and windows replacement (ref. "*Le agevolazioni fiscali per il risparmio energetico*" published in September 2013 by the *Italian Revenue Agency*).
On the other hand it has to be recognized that, right this latest kind of building retrofit - despite its higher cost-benefit ratio value and thence its flimsiness - is also the most affordable renovation measure (from an economic point of view), besides its most quick and easy feasibility.
Hence, recalling that a National Policy and a fruitful Energy Strategy could be really worthwhile if enough balanced and widely exploitable by a large users' bracket, a reasonable and fairly-weighed financial support should be preserved also into boosting such an outwardly fruitless type of energy-saving intervention.

PART III

5 Linear Programming assessment

A deeper and more detailed comprehension of the main elements and key-factors which lay behind the previous results (also determining such an unfair distribution) could be provided by exploiting and implementing the great potentialities provided by linear programming tools.
Actually, a stronger and more powerful assessment criterion should be applied in order to achieve the final goal of understanding and balancing the most cost-effective kinds of building retrofit.
Indeed, the main objective for such an investigation would be the comparison between the already assessed trend for the current incentives program and the one achievable through an "optimal" configuration and distribution.
This process would also point the way towards a more adequate future policies development, depicting an energy retrofit strategy more suitable to the different, specific local realities.

The excel spreadsheets, along with the previous calculations developed during the first step of analysis, were then adopted and implemented in order to define the different complete scripts to be uploaded and launched through an optimization software called *"**Lindo**"*.
Actually, the above programming tool is able to implement the mathematical optimization ***Simplex Method*** in order to work out a multifactorial optimization analysis which, using the manual application of such an algorithm, wouldn't be feasible, or at least would be too much complex to be developed.

More precisely, the Simplex optimization method is fruitfully applied to solve complex linear programming problems and consists in a mathematical technique - also implemented into computer modelling (simulation) - aimed to find out the best possible solution in allocating limited resources (e.g. energy, machines, materials, space, time etc - and, as in this case, also money), also achieving the maximum profit or the minimum cost.
Developed by the Russian economist L.V. Kantorovich (1912-86) and the Dutch economist T.C. Koopmans (1910-85) on the basis of the studies worked out by the Russian mathematician A.N. Kolmogorov (1903-87), it was refined and improved by the American, mathematician G.B. Dantzig (1914-2005).

Actually, the ***Simplex Optimization Method*** is a search procedure which sifts through the set of basic feasible solutions for a linear programming (*LP*) problem, one a time, until the optimal basic feasible solution - whenever it exists - is identified.
Since the simplex method consists in a particular kind of algorithm, it involves an iterative procedure for solving a wide class of problems. Moreover, it guarantees the generation of a solution for any problem instance by mean of a finite iterations' number: thence it reveals quite useful and profitable.

5.1 Linear programming and simplex optimization algorithm: previous applications in the energy retrofit assessment field

As shown by a significant literary review about this particular issue, several studies and researches were already carried out implementing linear programming and performance optimization tools, along with several mixed integer programming techniques for building retrofit and energy saving refurbishment in the residential sector.
Furthermore, analogous algorithms and mathematical techniques were implemented to optimize insulation measures on existing buildings, also evaluating economically optimal retrofit investment options and solutions for energy savings in buildings.

Moreover, linear programming approaches - also exploiting the Life-Cycle Cost concept - were already adopted to assess and perform household energy conservation and heating-systems, as well as to simulate building energy systems, with the final aim of reaching a consequent efficient allocation for the required budget.
At this reference, the studies illustrated by Stig-Inge Gustafsson in his article entitled "*Mixed integer linear programming and building retrofits*" along with the papers "*Optimisation of insulation measures on existing buildings*" and "*Optimisation and simulation of building energy systems*" provide interesting fruit for thought about such a task.
Also the overall researches "*Optimization methods applied to renewable and sustainable energy: A review*" (Baños, Manzano-Agugliaro, Montoya, Gil, Alcayde, Gómez) and "*Linear programming models for measuring economy-wide energy efficiency performance*" (Zhou, Ang) contain a wide range of important points to be considered while dealing with this issue.

Nevertheless, none of the previous studies attempted to evaluate energy efficient retrofit solutions within a joined planning and balancing framework of both financial government subsidies and their respective linear programming optimization outputs too (see, at this reference the article "*A linear programming approach to household energy conservation: Efficient allocation of budget*" by F. G. Üçtug, E. Yükseltan).

Hence, one of the main purposes for this part of research is to fill up such a gap, by showing how adequate mathematical tools could be fruitfully applied into developing linear programming models (solving them, as in this case, by mean of the Simplex algorithm), in order to assess political, economic and energetic building retrofit policies implications under an all-embracing perspective.

Actually, the possible combination of such multiple benefits makes the building sector a crucial field for policy makers also at EU and National levels. Hence it's strongly needed a policy framework that supports the National markets in unlocking these potentials.
Furthermore, it's rather important finding out how to foster and encourage energy efficient improvements and energy saving measures in private dwellings, in order to achieve the double advantage of reducing the global energy consumption level within the private sector, also increasing investments and favouring the creation of additional cash flows too.

5.2 The linear programming key topics, focus on the method primarily implemented in the research: the *Dantzig Simplex Algorithm*

Coming back to the specific topic of this part of study and focusing the attention on the particular algorithm model to be adopted and implemented in order to define the linear programming problem of interest, it's necessary to recall the fundamental basis of such a method.

Actually, any kind of linear problem is configured as a problem of maximizing (or minimizing) a linear function, subject to such linear constraints of inequality (and/or equality) type.
The general model to be adopted and then properly calibrated is characterized by the following expression:

$$\textbf{Maximize} \quad s_1 x_1 + s_2 x_2 + s_3 x_3 + \dots\dots\dots + s_n x_n$$

Subject to the following restrictions:

$$a_{11} x_1 + a_{12} x_2 + a_{13} x_3 + + \dots\dots\dots + a_{1n} x_n \leq c_1$$
$$a_{21} x_1 + a_{22} x_2 + a_{23} x_3 + + \dots\dots\dots + a_{2n} x_n \leq c_2$$
$$a_{31} x_1 + a_{32} x_2 + a_{33} x_3 + + \dots\dots\dots + a_{3n} x_n \leq c_3$$

$$\begin{array}{ccc} \ldots\ldots & \ldots\ldots & \ldots\ldots \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \end{array}$$

$$a_{m1}\, x_1 + a_{m2}\, x_2 + a_{m3}\, x_3 + + \ldots\ldots + a_{mn}\, x_n \leq c_m$$

$$x_1 , \quad x_2 , \quad x_3 , \quad \ldots\ldots\ldots \; x_n \geq 0$$

where:

- $(s_1 x_1 + s_2 x_2 + s_3 x_3 + \ldots\ldots + s_n x_n)$ is the ***objective function*** (or *criterion function*) to be optimized (in this case maximized) and which will be denoted by **y**;
- the terms $(s_1 , s_2 , s_3 , \ldots . s_n)$ are the (known) coefficients generally defined as ***cost coefficients***;
- $x_1 , \; x_2 , \; x_3 , \ldots\ldots\ldots \; x_n$ are those variables or activity levels (a.k.a. ***decision variables)*** to be determined;
- the coefficients a_{ij} (for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$) are called ***technological coefficients*** and are globally included in the ***Constraint Matrix "A"*** - as below summed up - by means of the introduction of the ***General Linear Programming Problem Form***:

$$\textbf{Max yx}$$

$$\text{s.t.} \qquad \mathbf{Ax \leq c}$$

$$\mathbf{x \geq 0}$$

In first instance, referring to those data and information before introduced and recalling the earliest results before achieved, it's necessary to specify the different factors involved in the current problem:

$\mathbf{x_{ij}}$ = number of the possible refurbishments to be planned;
$\mathbf{s_{ij}}$ = row vector associated to the different energy saving factors referable to any specific kind of building energy retrofit;
$\mathbf{A_{ij}}$ = matrix of the average building energy retrofit costs;
$\mathbf{c_{ij}}$ = constant term vector (as hereinafter further specified).

Finally, recalling that the simplex method is designed to solve linear programs where the variables are non-negative (since they represent such physical quantities) the last restriction imposes that:
$\mathbf{x_{ij} \geq 0}$.

Applying the above modelling criteria to the current problem it's then possible to formulate the several scripts (entirely reported in the Annex section of the present work) uploading and launching them by mean of the *Lindo* software.

5.3 The *Lindo* tool

In order to analyse and examine the different retrofit scenarios to be assessed through the simplex method application, ***Lindo Software - Release 6.1*** has been primarily used.
Actually the several scripts initially only manually drawn up, were previously uploaded and then launched through such an optimization software - developed by the U.S. society ***LINDO Systems, Inc***.

5.4 Linear programming assessment and simplex optimization application in the present research: the different scenarios drawn up and investigated - focus on the Italian Energy Efficiency Campaign - the Enea Reports Year 2007

The analysis started from the first report issued by Enea in 2008, but referred to the first 2007 campaign.
Thence, by picking out the data from the report available and downloadable from the web-page http://efficienzaenergetica.acs.enea.it/doc/rapporto_2007.pdf, such information were applied and processed also in the light of other additional data provided by *ISTAT*.
Actually, the above public research organization (namely the ***National Institute of Statistics***, established in Italy in 1926) is the main producer of official statistics at the service of citizens and policy-makers.
In particular, it carries out (every 10 years) a global survey and census of inhabitants and dwellings along the entire Italian Country and thence it reveals an important source of information also for the present job.
Despite the latest 15° ISTAT Census (referred to year 2011) has been recently completed and published, the current investigation is focused on the previous one (i.e. the 14° Census performed in 2001) also in order to fully exploit its more articulated structure by means of different synoptic tables.
Before going through the first scenario here analyzed, it is useful recalling and highlighting that the first Enea report (issued for the "*2007 energy efficiency campaign*") referred such "initial and still testing results" (as before noticed, see par. 4.3) and hence the final output provided should be consequentially considered.

The first^{07} Scenario and its main assumptions:

The first scenario drawn up and here investigated (as reported by the Annex section – script 1^{07}) attempted to carry out an incentives distribution different than the one registered during year 2007: such a choice was done with the purpose of finding out the optimal configuration to be assigned to the public financial support for energy efficient building retrofits.
A unique economic budget was imposed for the entire country (without any distinction nor with reference to the specific kind of intervention, neither regarding the single Italian macroarea of interest) and an all-involving maximum interventions constraints block was also fixed.
Such this latest upper-limit block was gathered from the 14° Istat Census and consists in the total number of dwellings respectively registered in the several Italian macroareas.
Furthermore it must be highlighted that such a restriction doesn't require (as an additional constraint) the exclusiveness of any kind of building retrofit on a single dwelling: actually - according to the respective guidelines issued both by Enea and by the Italian Revenue Agency - any building (i.e. any tax reductions' recipient) may exploit the financial reliefs also for more than a single kind of renovation (as long as the maximum amounts of below are respected).

MAXIMUM TAX RELIEF AMOUNTS ALLOWED FOR ANY SINGLE KIND OF BUILDING RETROFIT	
KIND OF BUILDING RETROFIT	MAXIMUM TAX RELIEF ALLOWED
OPAQUE HORIZONTAL SURFACES INSULATION	60.000 €
OPAQUE VERTICAL SURFACES INSULATION	60.000 €
WINDOWS AND WINDOWS FRAMES REPLACEMENT	60.000 €
SOLAR PANELS INSTALLATION	60.000 €
HEATING PLANTS REPLACEMENT	30.000 €
GLOBAL MAXIMUM AMOUNT ALLOWED FOR THE ENTIRE BUILDING'S RETROFIT	100.000 €

Fig. 5.1 Main guidelines and limits required by the Italian Revenue Agency for exploiting the building retrofit tax relief (cross-reference Fig. 4.2)

The inequality imposed by the first restrictions row required instead the total refurbishments costs to be supported not higher than the maximum amount assumed (in this case the total financial budget registered for any single year analyzed and hence used to support such building retrofits).

Actually, the different coefficients belonging to this row were calculated through the global weighed assessment performed by mean of excel spreadsheets (similarly to what also done with reference to the objective function coefficients).

The superior (financial) limit to be admitted was instead defined (as above prefigured) as the total cost (financial budget) allocated in 2007 by government in order to support those interventions registered during the specific year of interest. This latest choice was made in order to allow an effective economic feasibility.

N.B.
Since the variables scanned by such an algorithm consist into building interventions and they must be therefore considered as "entire", discrete and not continuous entities, a further condition must be introduced in the script to be launched: by adding after the "*END*" instruction the statement "***GIN***" followed by the number of variables to be assessed, any rounding and approximation error can be avoided.
Actually, the process of simply rounding algorithm outputs to the nearest integer numbers might lead to the following problems:

a) the rounded solution may be infeasible;
b) rounding may not give the optimal solution.

Thence, the first scene-setting sketched out, uploaded and finally launched through the optimization engine, was developed with the main purpose of maximizing an objective function obtained by summing up all the weighed average values of energy savings [MWh] registered along the different Italian macroareas (by doing all the different kinds of renovation analyzed in the Enea report) and restricting their respective numbers to a set of non-negative integers.

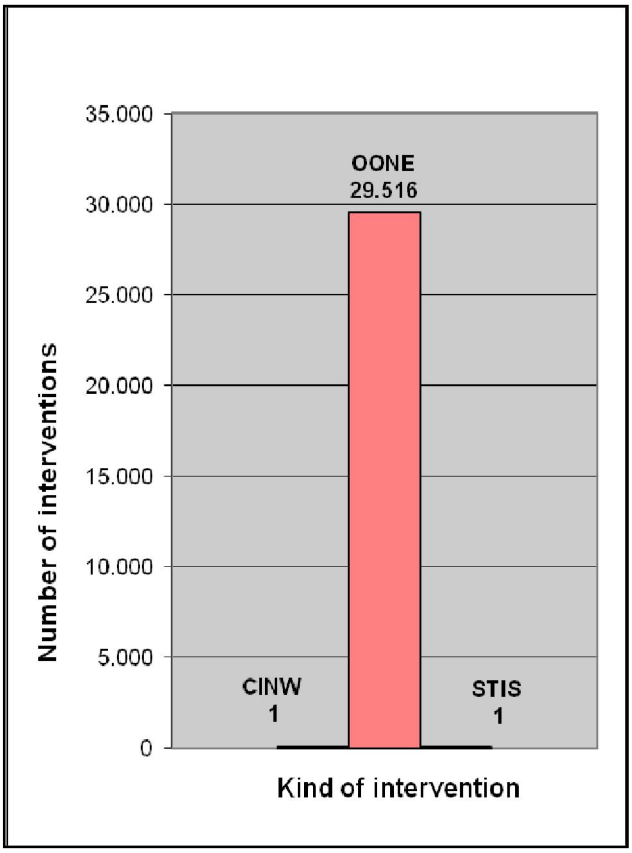
More precisely, the analysis was developed in order to know how many of such energy building retrofits should be done to reach the maximum level of energy saving possible, but without exceeding the total number of dwellings registered in the different Italian macroareas and without crossing the financial budget assumed (i.e. the total amount of spending carried out by considering the average cost registered in any macroarea for the different kinds of renovation).

In brief (after having previously introduced appropriate adjusting-factors in order to consider also the lifetime assumed for different renovations) the main aim of such an initial analysis scenario was that "***to find out the best way of spending money (i.e. which kind of renovation should be promoted and supported by the Italian Government in the different macroareas) with the main purpose of knowing how to address in the most proper way the Italians regulations and politicians decisions***".

The first[07] Results and main observations: Tab. 5.1[07]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	29.516	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	0	0	1
CI		1	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	23.985.470				
	CONSEQUENT RENOVATION COSTS [€]	636.751.952				
COST/BENEFITS BALANCE SUMMARY [€/MWh*yr]		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
NUMBER OF OPAQUE HORIZONTAL SURFACES INTERVENTION		42,43	35,82	45,47	79,35	52,18
NUMBER OF OPAQUE VERTICAL SURFACES INTERVENTION		54,10	47,15	57,56	72,34	126,02
NUMBER OF WINDOWS FRAME REPLACEMENT		95,54	92,94	115,68	163,54	172,33
NUMBER OF SOLAR PANEL INSTALLATION		78,90	68,70	59,72	37,93	37,79
NUMBER OF THERMAL PLANT REPLACEMENT		35,92	45,72	46,98	60,93	73,45

As it's possible to notice looking at the so uneven and unfair results provided by the above resume table and by the following histograms, actually such a configuration guaranties a savings level higher than the one globally registered by Enea (23.985.470 MWh against the Enea 14.220.045 MWh) with a total expenditure of 636.751.952 € (thence markedly lower than the 840.241.834 € registered by Enea).



But it must be also highlighted that, beside the outward quite foreseeable and unsurprising results (actually completely coherent with the cost/saving ratio assessment before manually performed) this output is directly derived from such a complex and multifactor algorithm implemented by the optimization software.
And if on the one hand the only goal which addressed the iterative searching engine was that to maximize the energy savings level achievable, on the other hand it should be also highlighted that any fair energy policy couldn't be developed only adopting such an incentive criterion.
Besides, a more complex and well-structured script should be developed, also in order to fully exploit the huge potentialities provided by such a powerful and complete investigation algorithm (i.e. without any unfruitful "over-killing" and in order to avoid to "under-use" it).

Fig. 5.1[07]

Hence it turns quite clear and evident the need of a deeper understanding of the role played by the different terms of the scripts, along with their adjustment and balance within an overall investigation scenario. And that, in order to achieve a fairly balanced and realistic solution to be involved in a global investment plan.
At this reference, it would be also quite useful and worthwhile considering the additional information provided by the software through some particular, further output variables, also in order to properly exploit all the Lindo's potentialities.
Actually, beside the global results summed up by the above table and graph, the first[07] script detailed by the Annex section also returned the following overall output data:

OBJECTIVE FUNCTION VALUE

1) 0.2398547E+08

VARIABLE	VALUE	REDUCED COST
OONW	0.000000	-855.450012
OVNW	0.000000	-399.850006
INNW	0.000000	-113.070000
STNW	0.000000	-128.949997
CINW	1.000000	-359.190002
OONE	29516.000000	-812.609985
OVNE	0.000000	-465.670013
INNE	0.000000	-113.500000
STNE	0.000000	-103.250000
CINE	0.000000	-224.339996
OOCE	0.000000	-544.289978
OVCE	0.000000	-255.279999
INCE	0.000000	-83.290001
STCE	0.000000	-103.980003
CICE	0.000000	-173.399994

OOME	**0.000000**	**-260.920013**
OVME	**0.000000**	**-193.350006**
INME	**0.000000**	**-71.660004**
STME	**0.000000**	**-174.539993**
CIME	**0.000000**	**-100.639999**
OOIS	**0.000000**	**-200.000000**
OVIS	**0.000000**	**-112.260002**
INIS	**0.000000**	**-60.000000**
STIS	**1.000000**	**-113.379997**
CIIS	**0.000000**	**-75.000000**

ROW	**SLACK OR SURPLUS**	**DUAL PRICES**
2)	**515.402344**	**0.000000**
3)	**7444761.000000**	**0.000000**
4)	**7444761.000000**	**0.000000**
5)	**7444761.000000**	**0.000000**
6)	**7444761.000000**	**0.000000**
7)	**7444760.000000**	**0.000000**
8)	**5046322.000000**	**0.000000**
9)	**5075838.000000**	**0.000000**
10)	**5075838.000000**	**0.000000**
11)	**5075838.000000**	**0.000000**
12)	**5075838.000000**	**0.000000**
13)	**5137694.000000**	**0.000000**
14)	**5137694.000000**	**0.000000**
15)	**5137694.000000**	**0.000000**
16)	**5137694.000000**	**0.000000**
17)	**5137694.000000**	**0.000000**
18)	**6260594.000000**	**0.000000**
19)	**6260594.000000**	**0.000000**
20)	**6260594.000000**	**0.000000**
21)	**6260594.000000**	**0.000000**
22)	**6260594.000000**	**0.000000**
23)	**3349993.000000**	**0.000000**
24)	**3349993.000000**	**0.000000**
25)	**3349993.000000**	**0.000000**
26)	**3349992.000000**	**0.000000**
27)	**3349993.000000**	**0.000000**

NO. ITERATIONS = 88

As it's possible to observe, beside the bold and underlined outputs of above there are a lot of further values and information which could help the end user to balance the results accordingly to his purposes and requirements.
For instance, knowing that the optimal value achievable by the current objective function could be **0.2398547E+08 MWh**, the numbers related to the "***REDUCED COST***" column report how much this value would decrease (since this is a Maximum Problem) by simply doing just one of those interventions which aren't recognized by the software as feasible solutions.

In other words, according to the main principles and rules of the *Simplex Method*, such a phenomenon will occur if a non-basic variable is "forced to enter into the basis".

Thence, if the decision-maker decides to carry out just only one Opaque Horizontal renovation in the North-West Macroarea, it will determine a final lower objective function value output (in terms of MWh saved).

It's therefore useful to highlight that formally (for a maximization problem), the *Reduced Cost* for a non-basic variable could be defined as the amount by which the objective function's value will decrease if the value of that non-basic variable is increased by 1 (while holding at 0 all the other non-basic variables).

Furthermore (with reference to the values belonging to the "***SLACK OR SURPLUS***" column) they are related to the overall restrictions imposed by the script: each row is related to its respective constrictions and in fact, in this case, for 26 required conditions, the software has returned 26 output slack rows.
Since the numbering of rows starts with the number 1, as opposed to 0, thus the ROW 1 refers (as above seen) to the objective-function row; while instead ROW 2 is referred to the first functional constraint and so on….
Correspondingly, the slack variables are also numbered according to such a criterion and hence - for instance - the first budget constraint is linked to the second row " *2) 515.402344* ".

If - instead of a non-null value - a zero output has been reported, it would have meant that the above inequality was strictly satisfied (i.e. the slack values that should be added to the solution were null).
However, since the "*GIN-INTEGER*" requirement here imposed has also introduced a complex series of rounding off and approximations, an identically null slack-value should be quite difficult to be obtained and hence the above shown 515.402344 value (still quite low) means that the suggested optimal configuration has almost completely absorbed the entire financial budget available.

Clearly, an analogous enlightenment could be also done with reference to those other inequalities linked to the total number of dwellings existing in the same Macroarea (e.g. OONW < 7444761, OVNW < 7444761, INNW < 7444761 etc.…).
Actually, for instance the third row "*3) 7444761.000000*" (related to the OONW < 7444761 restriction) tells that – obviously, since the results for Opaque Horizontal interventions in the North-West must be null - the number which should be used to "turn" the inequality into an equality is identically the same of the restriction value.

Hence, the only cases in which such a value will be different are for instance related to the Thermal Plants for the Northwest (in this case in fact, the value of *7) 7444760* is given by the difference [7444761 - 1]), and so on also for the row *8) 5046322* (i.e. the difference [5075838 – 29516]) etc…

In other terms, the *slack or surplus values* are those values which should be introduced into an optimization linear programming problem to turn it from the *canonical form* given at the beginning (i.e. with inequality relations), to a *standard format* (which only contains equalities).
It's indeed important to recall that the *Simplex Method* (i.e. the same method implemented within the *Lindo Software* to solve an optimization problem) is designed to be applied only after the problem is put in the standard form.
Besides, it's also possible to observe that the *slack or surplus* column variables show how much the relative terms are "far" from their respective limits (i.e. this gap is called "*surplus*" in case of $\geq$ relations, while otherwise - in case of $\leq$ inequalities as for the current problem - is called "*slack*").

About those values reported by the "*DUAL PRICES*" column, it's instead possible to notice that they are related to the so-called *Shadow Prices or Accounting Prices*, which reveal how much the objective function value could be improved (in this case how could increase) if the constant terms of the inequalities (i.e. the RHS-Right Hand Side terms) are increased by 1 unit.
The term "dual" is used because, since every linear program has got an associated dual linear problem, the concept of dual prices exactly originates just from the dual linear program.
Also for the Dual Prices Column, each row is related to the respective constriction: thence, for 26 constraints, there will be 26 rows (as above shown).

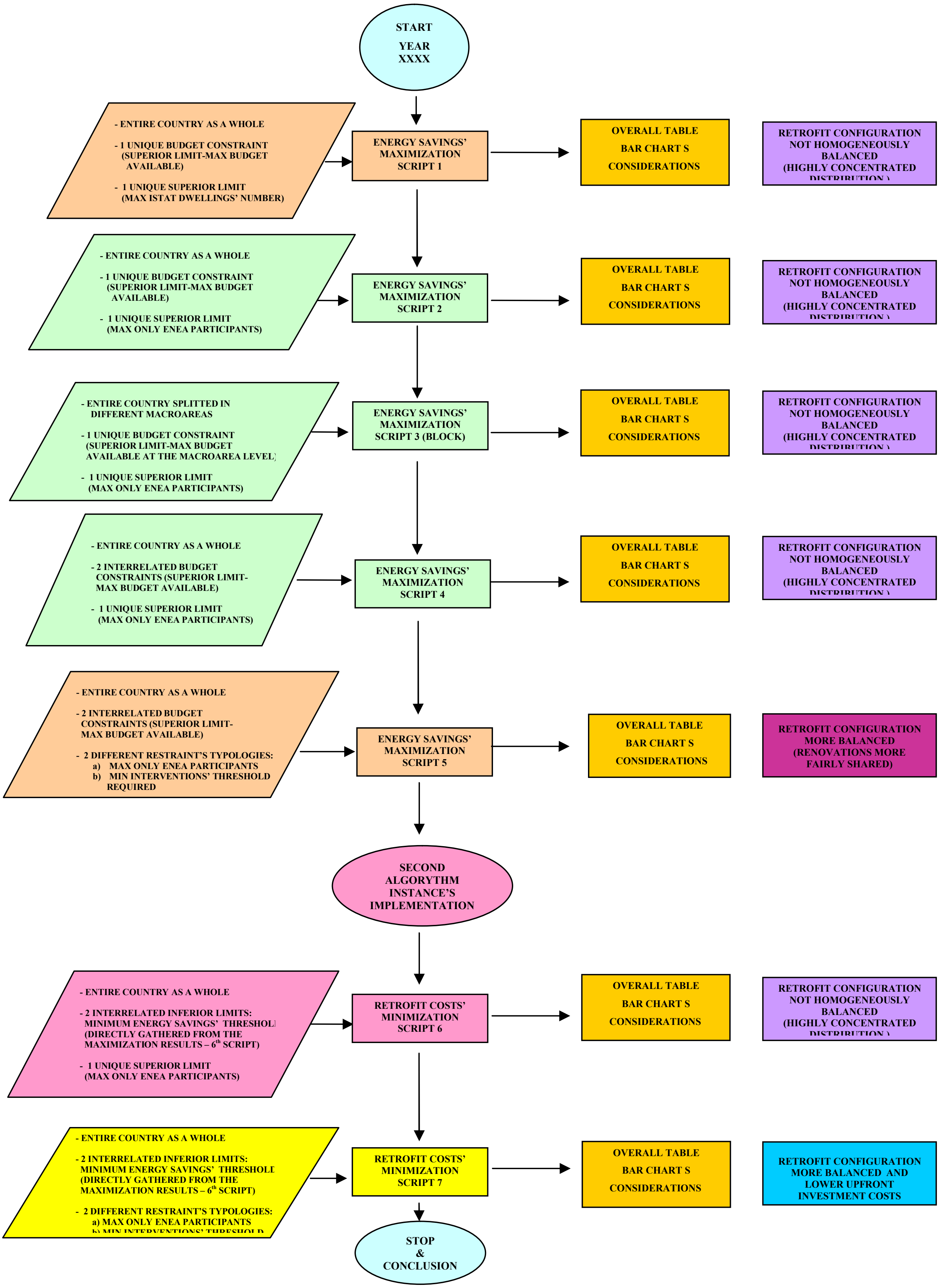
The shadow price associated to the RHS constant of an original constraint (or with the availability of a resource, as in this case) is defined as the amount by which the optimal objective-function value will improve if the value of that constant is increased by 1 (and it is important to notice that such a 1-unit increment is, as in the case of the Reduced Cost Column too, merely nominal).

Actually, in the current problem, the first row of the Dual Prices Column - related to the financial budget condition - reports for instance that, if the settled budget of 840.241.834 € is increased by 1 unit, the optimal objective function value will not be increased in any case (since this value is not enough in order to allow any kind of intervention "jumping" to a higher entire value).
On the other hand (as it's easy to expect) it's possible to gather that, if the total number of dwellings related to the respective 25 conditions will be increased (but without a concurrent growth in the available budget), the optimal value shouldn't be affected: and in fact all the other values of this column are also null.

By the last line *NO.ITERATIONS = 88* the programme reports how many times it was necessary to repeat the optimization process before the optimal solution is reached (since the Simplex method is an iterative optimization method). In this case, it's easy to notice that the Simplex algorithm has gone through a total of 88 iterations in order to achieve such an optimality level.

Finally, before going on with the analysis of all the other further scenes year by year analyzed, it would be quite useful and worthwhile providing an overall frame of them by mean of the global flow-chart hereinafter reported.

OVERALL METHOD ADOPTED: DESCRIPTIVE FLOW-CHART



N.B.

An additional discriminating factor has also been adopted, year by year, as a distinguishing homogeneousness criterion for all the several output distributions to be assessed: actually, the respective ***Gini coefficient*** (a.k.a. ***Gini index*** or ***Gini ratio***) was introduced and calculated for all the different scenarios step by step performed.
Actually, such an index provides a worthwhile measure for the statistical dispersion of a generic distribution of variables and could be useful into balancing and developing a fair and fruitful energy strategy.

The ***coefficient*** was developed by the Italian statistician Corrado Gini in 1912 and is commonly used as a measure for comparative income or wealth: in this case, it's going to be assessed for the distribution of those 25 variables made up by all the 5 different kinds of building renovation which is possible to carry out in the 5 main Italian macroareas.
The Gini value is computed as follows:

$$G(S) = 1 - \frac{2}{n-1}\left(n - \frac{\sum_{i=1}^{n} i y_i}{\sum_{i=1}^{n} y_i}\right)$$

Where: $\mathbf{y_1, y_2, \ldots y_n}$ are distribution of individual income of **n** samples (in this case n=25), arranged in descending order, so that $\mathbf{y_i \leq y_{i+1}}$

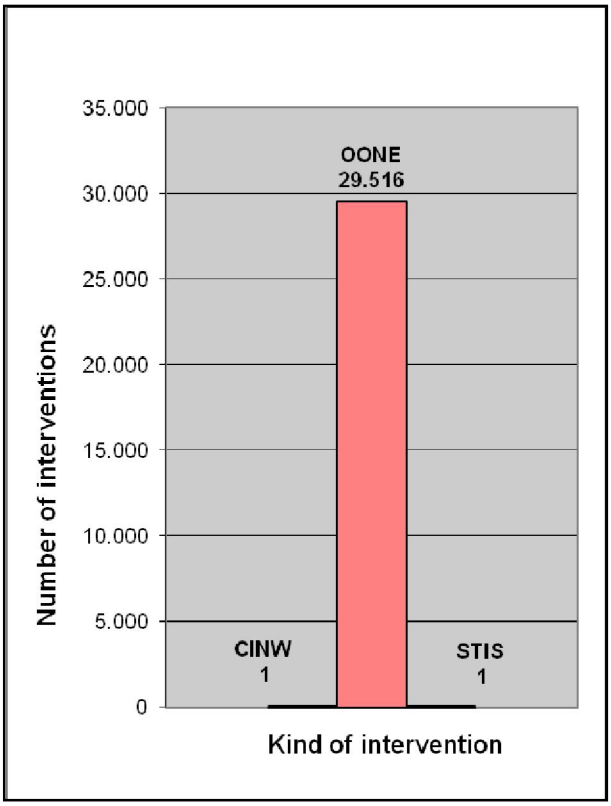
In particular it must be highlighted that, while high Gini coefficients indicate unequal distributions, a lower Gini value implies a more equal distribution: hence a value equal to 1 corresponds to the complete inequality, i.e. to a highly concentrated distribution.

According to the main aim of the current part of research - addressed to find out a proper balance between the energy savings level achievable and the building retrofits to be supported along the entire Italian country (within a global policy framework fair enough) - an arbitrary value was adopted as a discriminating factor.
Such a value, year by year calculated for all the different scenarios step by step defined, was assessed and implemented in order to lead and track the entire energy policy's development according to a more cost-effective criterion.

The <u>second</u>[07] Scenario and its main assumptions (Script n.2[07]):
In order to reach a final configuration more scattered and distributed (and without a so high concentration, i.e. a too much low index of dispersion) also assessing an investment scenario more adherent to the real scenario effectively reported by Enea, the current scene setting was defined as follows.
Coming back to the first "overall Italian scenario" (but now adopting a different approach) this step of analysis only considered the effective number of "Enea participants" (i.e. the actual incentives' recipients) involved in the global survey.
Actually, the superior limit to be considered became now the real number of Italian citizens which had fulfilled all the necessary procedures required to benefit the public financial support.
Such a new investigation scenario is once again available in the Annex section – script 2[07].

The second^{07} Results and main observations: Tab. 5.2^{07}

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	29.516	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	0	0	1
CI		1	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	23.985.470				
	CONSEQUENT RENOVATION COSTS [€]	636.751.952				



The main information provided by these latest (unchanged) results, besides confirming the inconsistence of the first scene's maximum dwellings limit, provide a further proof about the too low financial budget "available" compared to the building stock to be refurbished.
Actually, the economic budget to be properly allocated shouldn't allow any further intervention in addition to those ones reported, and even though is entirely used only for funding the most cost-effective kinds of building retrofit (in this case Opaque Horizontal Surfaces Insulation), it doesn't allow reaching and covering the so wide building stock registered, neither by ISTAT, nor by the *ENEA 2007 Energy Efficiency Campaign* (in this case indeed, in the North-East area 30.130 subscription were registered, and hence a number > than the 29.516 of output).

Fig. 5.2^{07} *(Gini Ratio = 1,000)*

Finally, it's also interesting to notice that those only other kinds of intervention suggested (*CINW* and *STIS*, even though just in a merely unit value amount) are respectively the "second classified" and the "third place" of the above cost-effectiveness table (with the respective ratio value of 35,92 and 37,79).

In the light of such overall considerations, the current job has been therefore addressed to only focus on the so called "Enea participants" (i.e. those only dwellings which were joined in the 55% tax deduction), in order to allow answering the hypothetic question: "*This was the financial budget available and it has been spent according to such a distribution: was this money well-spent, or it should has been used in a different and more effective way?*".

Hence, also all the other years of interest hereinafter analyzed (i.e. those other annual reports issued by Enea at this reference after 2007) are going to be assessed reminding such enlightenments.

The third[07] Scenario and its main assumptions (Script n.3[07]):

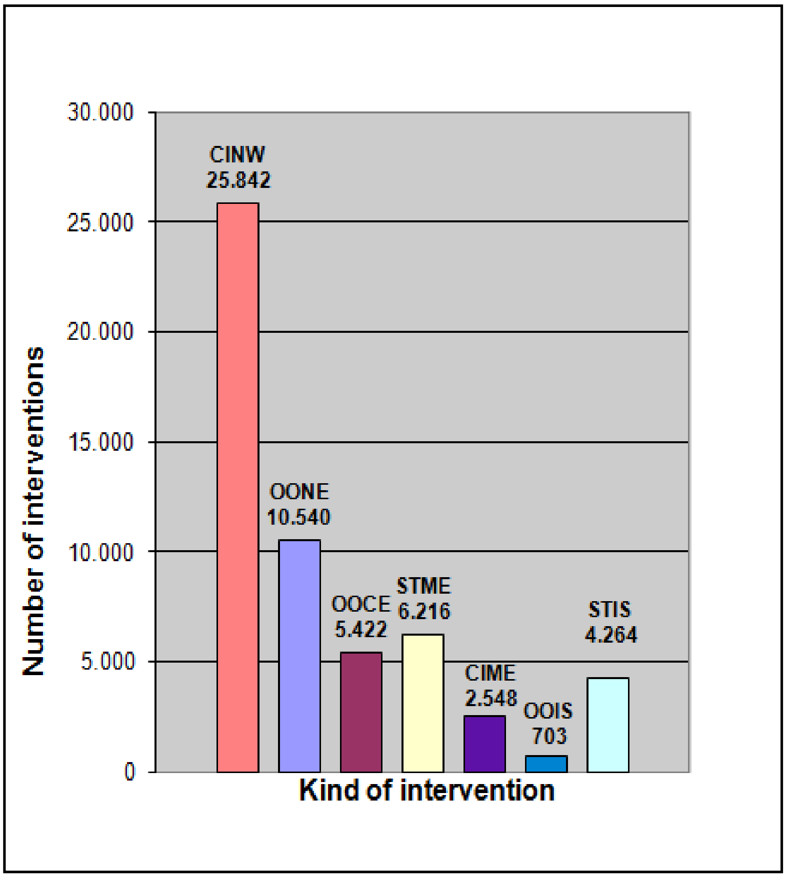
The application of the same investigation criteria adopted by the previous, third analysis scheme - but now distinguishing among all the different Italian macroareas - has led to a further study framework (as shown in the Annex section – script 4[07] - Block).

Actually, several more simple and homogeneous configurations were assumed by this latest investigation scenario: a set of different scenes has been developed, each one focused onto any single macroarea and involving the total number of Enea participants.

The respective constraints were then consequentially adjusted, leading to the scenarios depicted by the Annexes Section – script 3[07] (block).

The third[07] Results (cumulated block's results) and main observations: Tab. 5.3[07]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	10.540	5.422	0	703
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	0	6.216	4.264
CI		25.842	0	0	2.548	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	22.764.632 (cumulated)				
	CONSEQUENT RENOVATION COSTS [€]	840.161.444 (cumulated)				



In this case, despite such an outward more varied configuration and interventions' distribution, it must be highlighted that the shown results consist in the cumulated values resultant from the several scripts reported by the annexes. Actually, any single script only returned one kind of renovation for the single macroarea (except the two southern zones).

Moreover (and once again) for each one of them only the most cost-effective kinds of building retrofit (i.e. those ones with the lowest cost/saving ratio value) were suggested. And if on the one hand the cumulated level of energy saving achievable is higher than the one reported by Enea (even though lower than the scenarios before assessed), on the other hand a total retrofit cost sensibly higher than the one ascribable to the previous asset-scenes must be highlighted (despite still compliant with the maximum acceptable value).

Fig. 5.3[07] ***(Gini Ratio = 0,890)***

However, as it's possible to notice looking at the above results and observing the respective bar charts, a slightly more differentiated retrofits distribution is now detectable for the southern macroareas, i.e. the South and the Islands.

Actually, such a distribution is ascribable to the tighter maximum limits now settled for the current scenario, and particularly with reference to the southern zones: after the maximum limit allowed for the "most cost-effective" kinds of building retrofit had been reached, the lower admitted values imposed have in fact assigned the "remainders" – the places still available - to the "second most performing ones" (i.e. thermal plants for the south and opaque horizontal surfaces for the islands). Hence it turns even clearer the need for a better and more proper limits' definition in order to fully exploit the linear programming potentialities, also achieving a properly calibrated model.

The fourth[07] Scenario and its main assumptions (Script n.4[07]):

By means of a successive refinement and introducing the further restrictions depicted by the annexes (script 4[07]), the financial budget assumed became more binding and was split up in two different blocks: the first one was defined keeping fixed the macroarea and varying the specific kind of building retrofit, while the second one was established maintaining any single macroregion unchanged and exploring all the five different retrofit typologies. A mutual interdependence was therefore introduced, while the building stock to be assessed was kept limited to those only "Enea participants" and the investigation involved, once again, the entire Italian country as a whole.

The consequent results are below summed up.

The fourth[07] Results and main observations: Tab. 5.4[07]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	1.320	0	0	2
OV		0	2.075	0	0	0
IN		4.799	21.178	5.741	1.179	707
ST		0	0	12.219	6.216	4.264
CI		21.915	0	0	1	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	16.301.390				
	CONSEQUENT RENOVATION COSTS [€]	840.216.625				

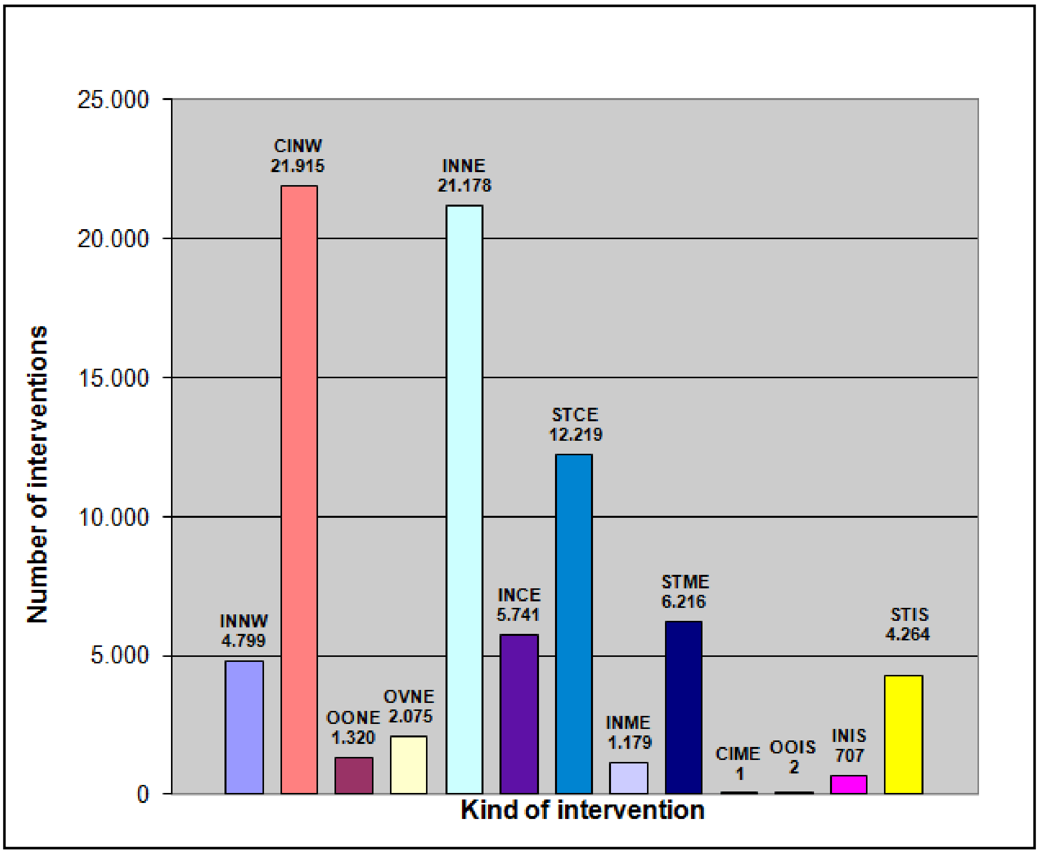


Fig. 5.4[07]
(Gini Ratio = 0,817)

It's now quite clear that such a more varied and balanced configuration had got a consistent negative effect upon the global energy saving level achievable: actually, the more scattered distribution "has cost" more than 6.000.000 MWh in terms of MWh saved. However, against such a "bleak side", a "bright aspect" can be highlighted under a decision-making process perspective (fairer). Furthermore, the latest distribution here suggested doesn't appear as directly inferable by mean of simple cost-effectiveness arguments and hence it turns even more significant the role played by a proper linear programming assessment into analyzing such a class of problems.

The <u>fifth</u>^{07} Scenario and its main assumptions (Script n.5^{07}):

By adopting an analogous approach and hence adding up some even more restrictive constraints (still considering the entire Italian Country as a whole) a further investigation scenario was defined: actually, observing that any decision and policy evaluation should involve a lot of different aspects (an economic feasibility, a balanced and fair incentives' distribution, as well as some necessary budget and weather forecasts and - generally speaking - also unavoidable compromises), several lower, minimum required values were settled.

These values were defined requiring, for the "worst" and least cost-effective kind of building retrofit (i.e. the one characterized by the highest cost/saving ratio value), a minimum number of interventions to be carried out and thence gradually increasing such a required minimum value for all the other retrofit measures by adopting a direct proportionality criterion and consequentially adjusting and calculating once again all the respective contributions.

A further specification is needed with regard to the lowest-minimum value to be imposed: such a threshold must indeed take into account the global budget available (i.e. the total cost assessed by Enea for all the several kinds of building retrofit registered during the year of reference) and hence this "arbitrary" value can't be high too much in order to avoid any infeasibility and capability problem.

The current minimization became thence even more restrictive.

The results consequently achieved (after the respective fifth^{07} script of the Annexes has been launched), may be summed up as follows:

The <u>fifth</u>^{07} Results and main observations: Tab. 5.5^{07}

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		156	765	154	137	389
OV		150	1.641	150	136	114
IN		4.241	23.312	5.232	719	88
ST		137	142	11.835	6.216	4.264
CI		21.580	154	153	146	136
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	16.151.180				
	CONSEQUENT RENOVATION COSTS [€]	840.195.277				

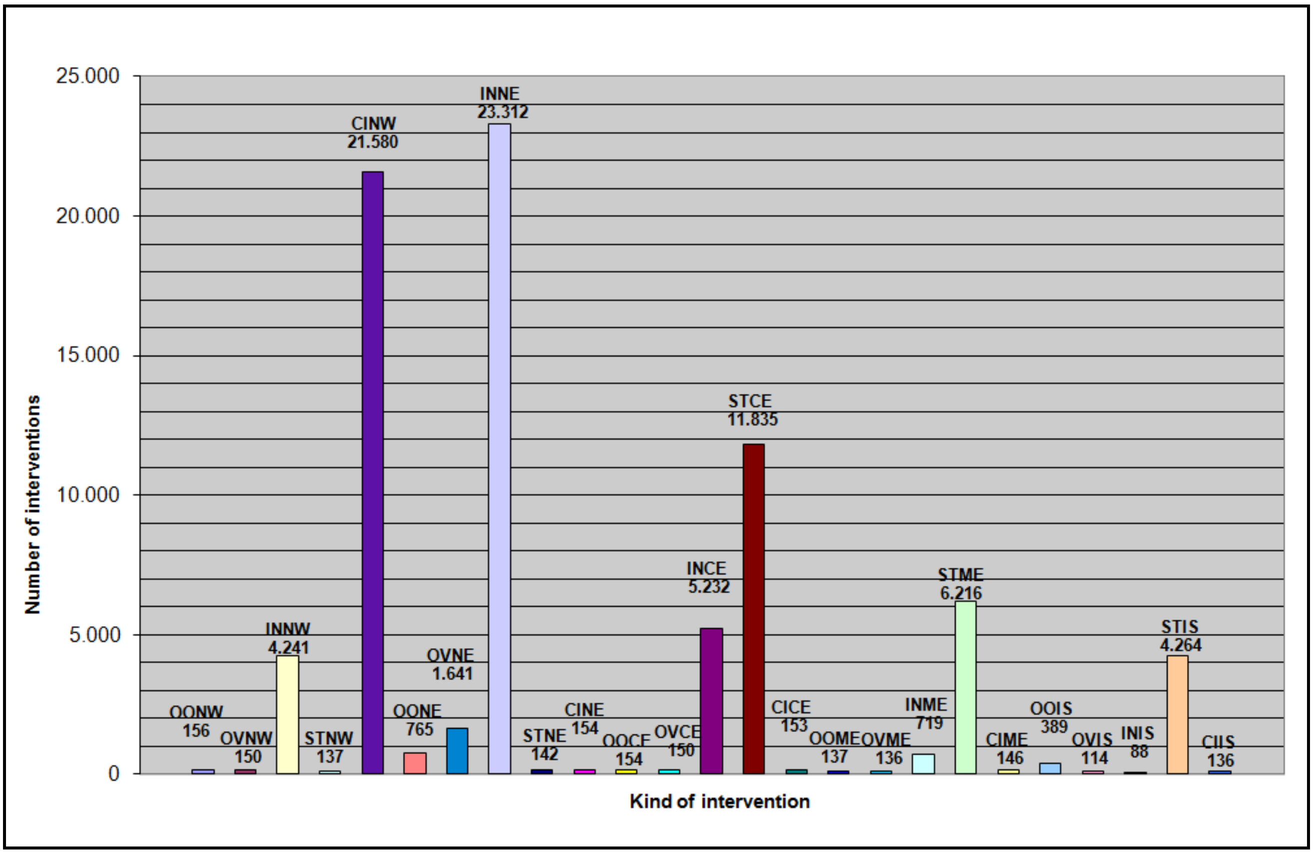


Fig. 5.5[07] ***(Gini Ratio = 0,804)***

As expected, a more spread and slightly more homogeneous distribution can be noticed and no building retrofit has been now neglected in any macroarea.

However, it must be also noticed that (with reference to those interventions before not exploited) not only they are now not null anymore, but they don't always coincide with their respective minimum required thresholds: and such a phenomenon is for the majority ascribable to the "integer requirement" introduced by means of the "*GIN*" statement, along with the particular specific algorithm of linear programming here implemented.

For instance, on the one hand it's possible to observe that the value of "88" assigned to the "worst" cost-effectiveness ratio value renovation (*IN-IS* with a cost/saving ratio of 172,33) coincides with the minimum threshold imposed by the script, but on the other hand the value suggested by such a distribution for one of the other less cost-effective kinds of building retrofit (e.g. *IN-ME* with got a cost/saving ratio of 163,54), is not only sensibly higher than its respective threshold (719 > 93), but is also higher than the value assigned to other kinds of building retrofit outwardly more cost-effective (e.g. *ST-NE* → 142 which has got a cost/saving ratio of 68,70 and whose value 142 coincides with the minimum limit here imposed).

As a **counter-check** (see Annexes, *SCRIPT 5[07] COUNTER-CHECK*), it's for instance possible to assess the infeasibility for the script launched after having imposed to such a kind of building retrofit its minimum threshold (i.e. by imposing *INME=93*), while leaving all the other variables free to vary according to the same restrictions before settled.

Moreover, as a further **counter-check** (see Annexes, *SCRIPT 5[07] COUNTER-CHECK- BIS*), it's possible to assess the slightly lower energy saving level achievable by the objective function after having imposed the acceptable value for *INME* variable between the values of 93 and 719, while leaving all the other interventions still free to vary: actually, the final objective function's value resulted in **16.151.160 MWh** (with the respective *INME* value identically equal to its upper limit 719) and hence **<16.151.180 MWh**.

Furthermore it turns once again even clearer the fundamental key-role played, at a policy level, by decision-makers into addressing such global incentives plans, as well as the importance of linear programming tools.
And if on the one hand such a forcing action artificially stretches the entire subsidies mechanism, on the other hand it must be recalled that any political decision should introduce unavoidable compromises and arbitrary settlements.
A complex and multifactor cluster of stakeholders is indeed involved in any policy decision and therefore a rigid and just one-sided approach mustn't be adopted.

Finally, a confirmation of such above remarks may be detected into the markedly lower energy saving level achievable: the latest fifth result to be considered as a point of reference for the further scenarios hereinafter analyzed (i.e. **16.151.180** MWh) is a global value still higher than the overall energy savings registered by Enea during the 2007 Energy Efficiency Campaign (14.220.045 MWh), even though is also sensibly lower compared to the starting output scenarios previously assessed.

Maximization results' exploitation and consequent implementation of the Minimization script (Script n.6[07]):

In order to achieve a more balanced and weighed distribution (optimizing both energy savings and retrofit costs) a further investigation scenario has been now developed, by mean of a respective investment's assessment.
A minimization script was therefore launched imposing the global energy saving level reached by the previous maximization as the minimum target of energy savings to be reached.
Furthermore, in order to maintain the same distinction and grouping criterion based onto any single macroarea and its respective kinds of intervention, analogous contributes and proportional "weights" were supposed for them within the current assessment scenario too.

The sixth[07] Results and main observations: Tab. 5.6[07]

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	3	2.470	0	530
OV		0	1.935	1	2	0
IN		3.895	27.994	3	0	0
ST		0	0	4.502	6.216	4.264
CI		22.276	0	1	1.280	1
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 16.100.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	814.826.200				

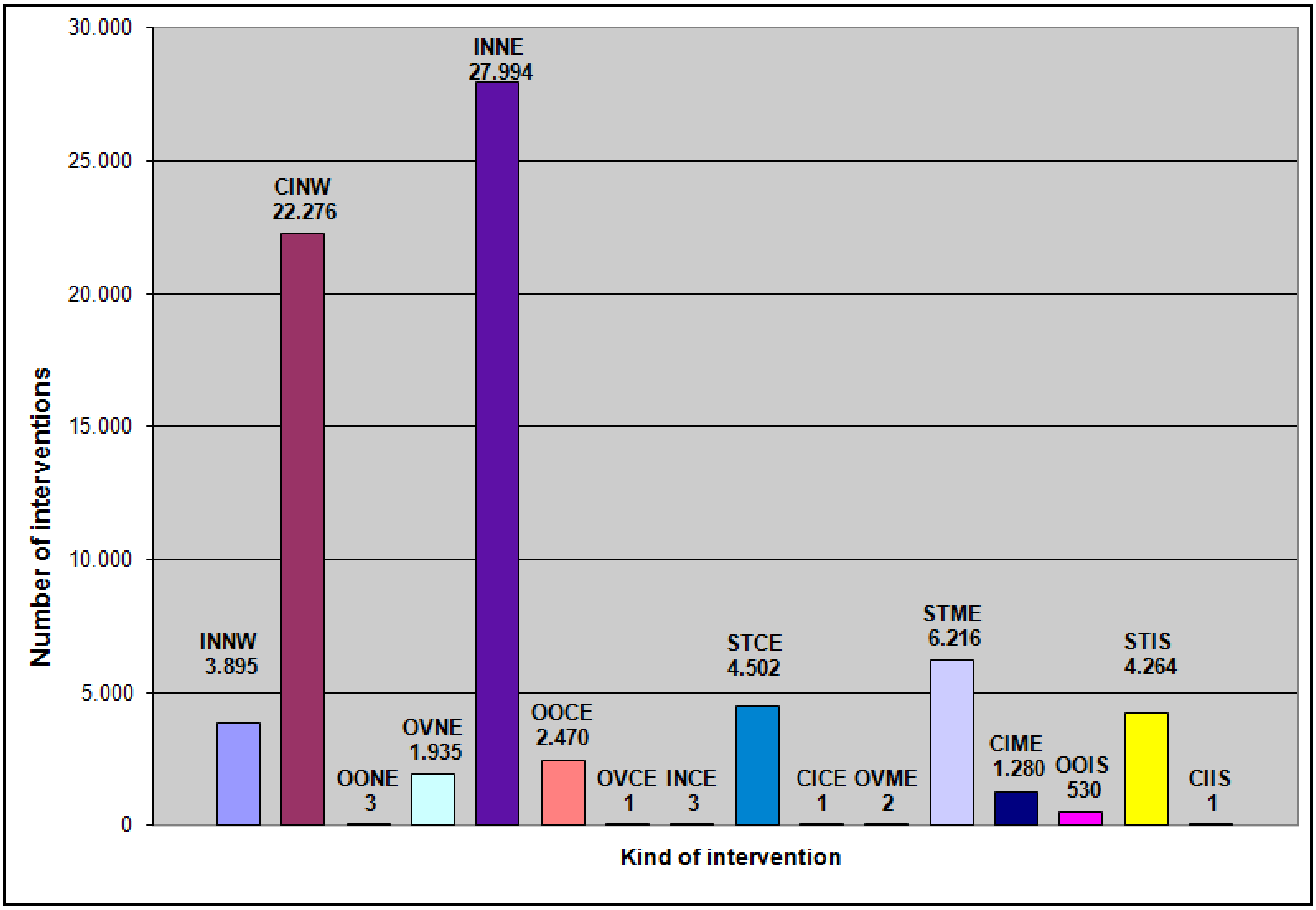


Fig. 5.6[07] ***(Gini Ratio = 0,858)***

As it's possible to observe, by allowing the simplex algorithm to allocate the financial budget according to the less expensive distribution criterion (still guarantying the energy savings threshold required) an overall incentive scheme not fair enough has been reached.

However, it's also quite interesting to notice that, as not expectable looking at the global cost/saving ratio assessment, those most expensive kinds of renovation (compared to the respective energy savings level achievable) hadn't been avoided in all the different Italian macroareas (e.g. windows frame in the North-West zone).

The global minimum budget at least necessary to reach the energy savings required has been assessed in 814.826.200 € and hence is lower than the total cost registered by Enea (840.241.834 €).

In conclusion, it's possible to assess that such a combined optimization process has led to a global energy savings level ≈ 1.900.000 MWh higher (≈ 16.140.000 MWh against 14.220.045 MWh) with a public incentive budget lower (814.826.200 € against 840.163.056 €), but without a building retrofit distribution fair and homogeneous enough.

<u>Maximization</u> results' exploitation, consequent implementation of the <u>Minimization</u> script plus bottom minimum values requirement (Script n.7[07]):

Adding a further lower constraint (analogously to what already done in the fifth[07] maximization script) the current minimization became thence even more restrictive.

The <u>seventh</u>[07] Results and main observations: Tab. 5.7[07]

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		156	159	2.393	137	389
OV		150	1.641	150	137	114
IN		4.050	27.650	118	93	88
ST		137	142	4.193	6.216	4.264
CI		21.640	154	153	594	136
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 16.100.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	820.298.900				

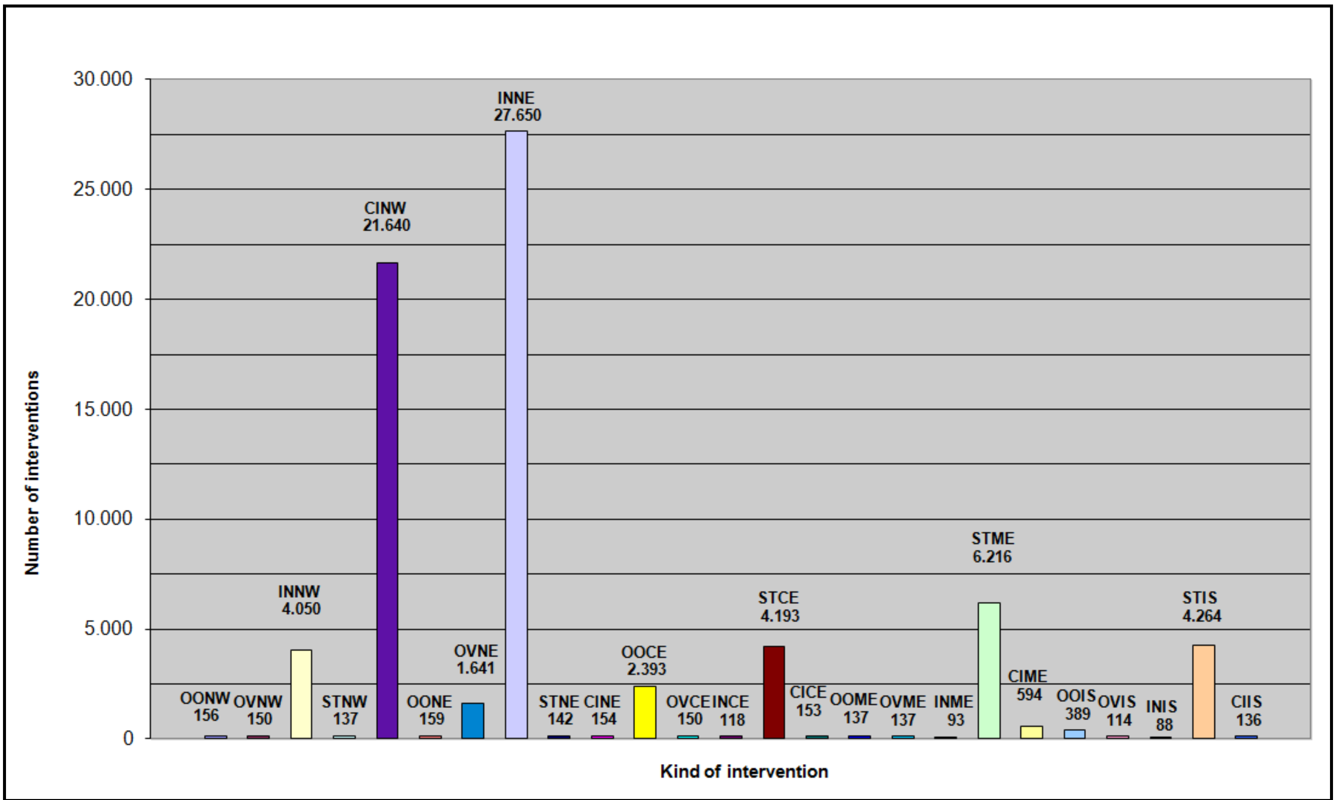


Fig. 5.7[07] ***(Gini Ratio = 0,832)***

This latest scenario has finally led to a global energy savings level ≈ 1.900.000 MWh higher than the one registered by Enea, with a public incentive budget slightly lower (820.298.900 € against 840.163.056 €) and a building retrofit distribution addressed and "moulded" according to a discretionary, political criterion.

Hence it's possible to gather that, while according to the Enea 2007 results each one MWh of energy saved has cost on the average ≈ **59,08 €**, the latest configuration here assumed led to a "unit cost" evaluated at **≈ 50,79 €/MWh.**

Actually, the lower value of *Gini* coefficient analogously assessed for the building retrofits distribution registered by Enea (i.e. **G = 0,621**), on the one hand allowed a more varied and mixed configuration along the entire Italian country, but on the other hand has provided, as a bleak side of such a phenomenon, a sensibly lower final energy savings level.

The above results therefore confirm what before highlighted regarding the strategic role to be recognized - at a global policy level - to such a mathematical algorithm.
Actually, they provide a clear proof of how much powerful and strategic such a decisional optimization method could be if properly handled by the most relevant decision-makers, also addressing their future incentives' policies, along with the overall energy-financial plans (nowadays particularly urgent).

Moreover, all the previous analyses (as well as the further scenarios hereinafter carried out and analyzed) also provide a worthwhile demonstration about the importance of a proper implementation and exploitation for such linear programming tools.
Actually, as proved by the results step by step reached in the current research, the simplex algorithm application could be particularly useful into addressing policies' resolutions and into directing towards the application of a fairer distributing criterion, also restoring the balance of public subsidies in a better way.

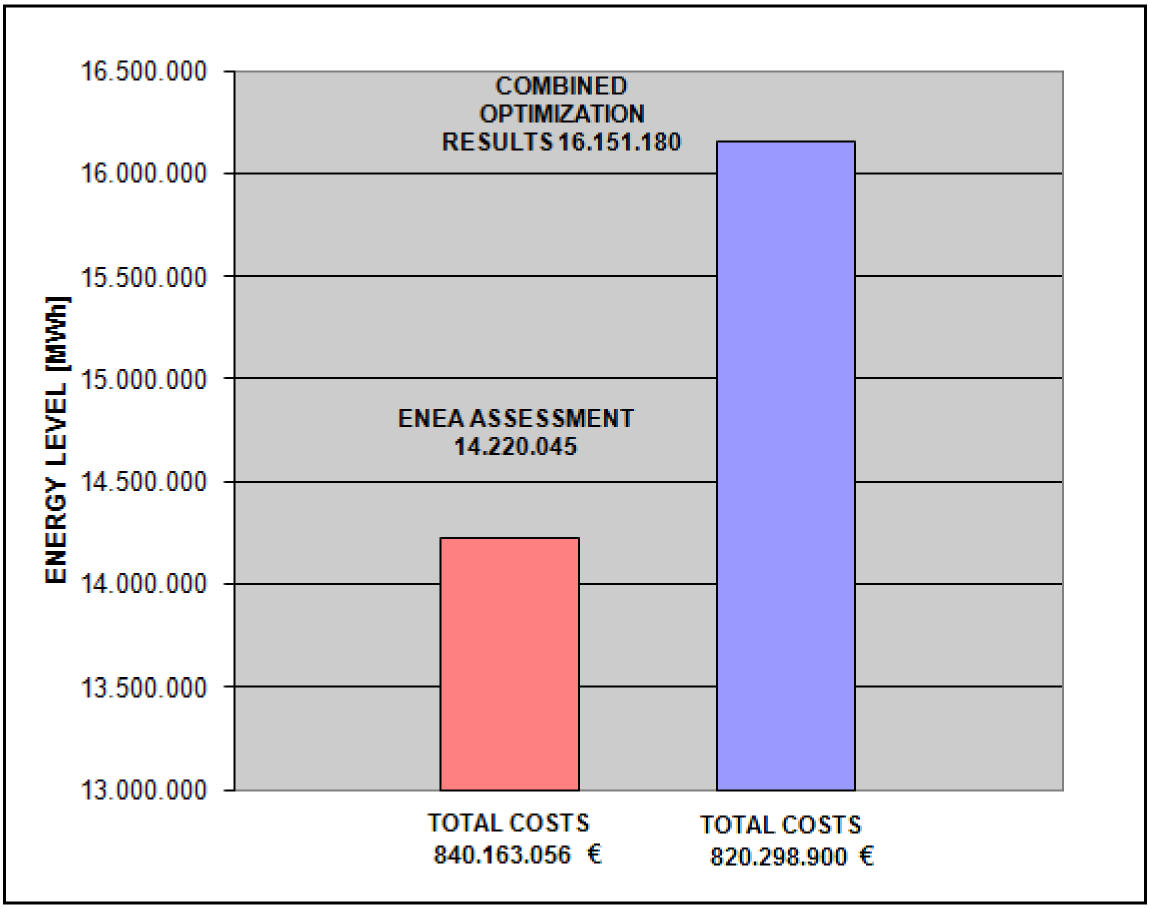


Fig. 5.8[07] GLOBAL COMPARISON TABLE

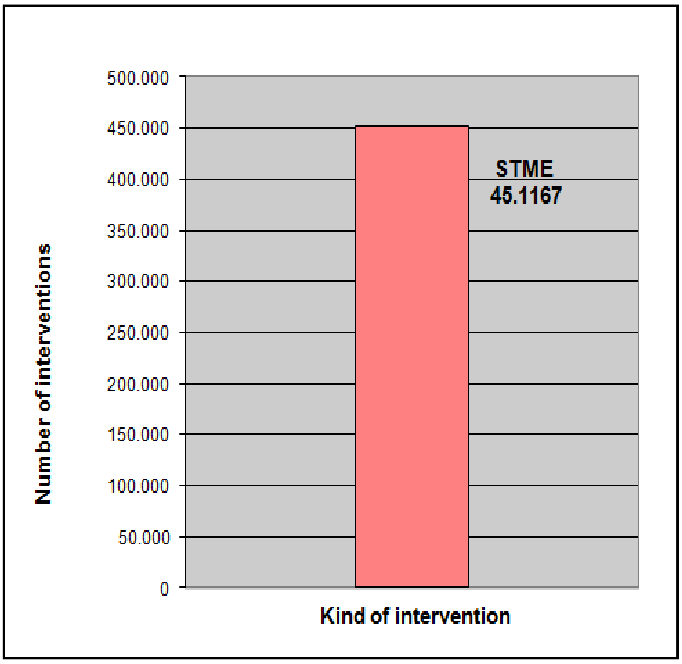
5.5 Linear programming assessment and simplex optimization application in the present research: the different scenarios drawn up and investigated - focus on the Italian Energy Efficiency Campaign - the Enea Reports Year 2008

By adopting the same investigation criterion already implemented for the previous 2007 data analysis (and still keeping valid the same assumptions and working hypotheses before declared) the current assessment was performed using all the information provided by the second Enea report.
Despite the report has been issued in December 2009, it's referred to the energy efficiency campaign carried out during year 2008 and can be downloaded from the following link: *http://efficienzaenergetica.acs.enea.it/doc/rapporto_2008.pdf*

The first^{08} Scenario and its main assumptions (Script n.1^{08}):
The current scenario has investigated (as reported by the Annex section – script 1^{08}) the incentives distribution registered during year 2008, in order to define the optimal configuration to be assigned to the public financial support for energy efficient building retrofits.
A unique economic budget has been imposed for the entire country (without any distinction neither with reference to the specific kind of intervention, nor regarding the single Italian macroarea of interest), as well as an all-involving maximum interventions constraints block.
Once again, such this latest upper-limit block was gathered from the 14° Istat Census and consists in the total number of dwellings respectively registered in the several Italian macroareas.
If on the one hand (as before observed while analyzing year 2007) the above first constraint is still too much weak and hence not able to return results significant enough, on the other hand it could be useful to better track the output retrofit distributions, following their respective development when gradually adjusting the different restrictions. Therefore, such a first test is going to be carried out also in the successive years hereinafter analyzed. The inequality imposed by the first restrictions row required instead the total refurbishments costs to be supported not higher than the maximum amount assumed. Through the development of another set of *ad hoc* excel spreadsheets (in order to calculate the new coefficients to be applied and implemented within the current objective function, as well as all the other several constraints) the **first^{08} script** of the Annex section has been defined and then launched. Also in this case, such a scenario was directed to maximize an objective function obtained by summing up all the weighed average values of energy saving [MWh] achieved along the several Italian macroareas, by doing all the different kinds of renovation analyzed by the Enea Report.

The first^{08} Results and main observations: Tab. 5.1^{08}

MAXIMIZATION	NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO	0	0	0	0	0
OV	0	0	0	0	0
IN	0	0	0	0	0
ST	0	0	0	451.167	0
CI	0	0	0	0	0
GLOBAL RESULTS – ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	170.636.100				
GLOBAL RESULTS – CONSEQUENT RENOVATION COSTS [€]	2.225.401.057				
COST/BENEFITS BALANCE SUMMARY [€/MWh*yr]	NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
NUMBER OF OPAQUE HORIZONTAL SURFACES INTERVENTION	32.53	32.13	49.72	71.83	99.82
NUMBER OF OPAQUE VERTICAL SURFACES INTERVENTION	42.11	38.22	54.62	62.86	98.72
NUMBER OF WINDOWS FRAME REPLACEMENT	113.64	103.33	153.81	243.47	232.14
NUMBER OF SOLAR PANEL INSTALLATION	44.95	50.72	30.24	14.04	15.72
NUMBER OF THERMAL PLANT REPLACEMENT	34.97	46.82	42.31	43.12	57.45



As it's possible to notice looking at the above results, once again the too much weak restrictions imposed by the current script only allowed the most cost-effective kind of building retrofit to absorb all the available financial budget (without any typological, neither geographical differentiation).

Furthermore, a huge difference can be noticed between the current and the previous year's global investment (along with the consequent energy saving level registered). Such a phenomenon can be directly justified (as already previously observed) recalling the particular boundary conditions and the overall frame which had characterized the first-testing and "start-up phase" ascribable to the 2007 Energy Efficiency Campaign.

Fig. 5.1^{08} ***(Gini Ratio = 1,000)***

The <u>second</u>^{08} Scenario and its main assumptions (Script n.2^{08}):

Coming back to the first "overall Italian scenario" - but now adopting a different approach - this step of analysis has only considered the real number of those "Enea participants" (i.e. those incentives' recipients) involved in the global survey.

Such a new investigation scenario is once again available in the Annexes Section – script 2^{08}.

The <u>second</u>^{08} Results and main observations: Tab. 5.2^{08}

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		48.121	0	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	37.196	16.903	9.411
CI		0	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	80.526.160				
	CONSEQUENT RENOVATION COSTS [€]	2.225.372.470				

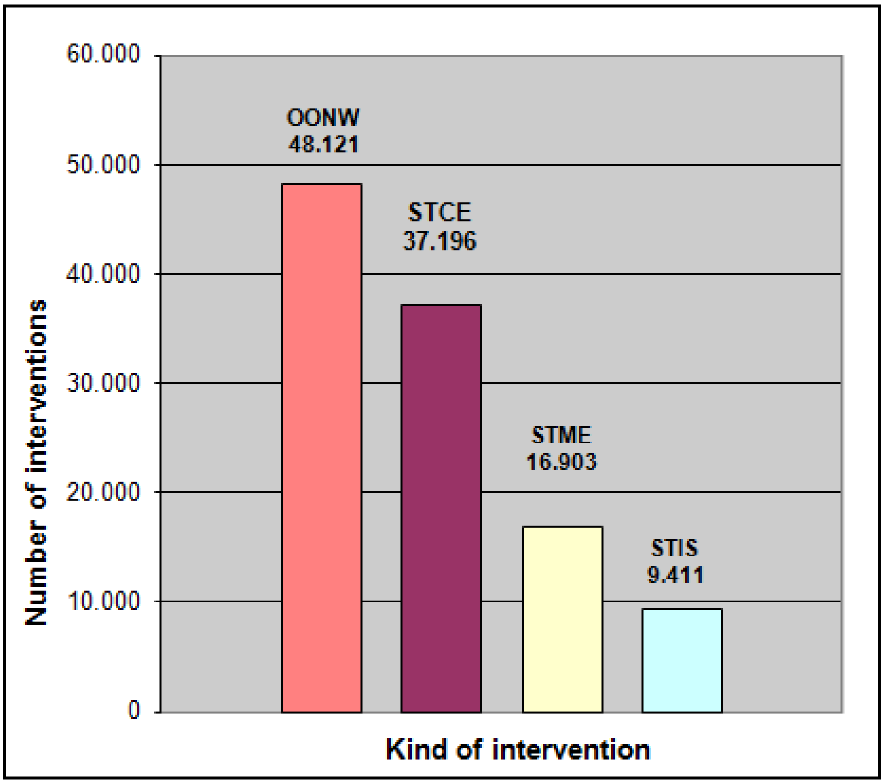


Fig. 5.2[08] ***(Gini Ratio = 0,926)***

This latest result just confirms the inconsistence of the first scene's maximum dwellings limit: actually, the available financial budget shouldn't allow any further intervention in addition to the ones already reported. And even though such a budget is entirely used only for funding the most cost-effective kinds of building retrofit, it doesn't allow reaching and covering the so wide building stock reported by ISTAT.

Therefore, also the current assessment involving year 2008 is going to be focused on those only "*Enea participants*" (as previously mentioned - see the above "second 2007 results" observations).

Furthermore, such a slightly more varied and distinguished configuration once again confirms, on the one hand the uniqueness of the first 2007 results (i.e. a lower available budget and hence consequent identical results for the first and the second scenario), and on the other hand reveals a more consistent building stock of reference, made up of those only Enea participants (compared to the entire Italian building complex of the first scene setting).

Actually, the higher financial budget available in 2008 allows covering a wider building stock, also leading to a possible retrofitting scenario more differentiated along the entire country.

The <u>third</u>[08] Scenario and its main assumptions (Script n.3[08]):

Once again, only focusing on the number of dwellings really involved in the incentives scheme, the current scenario was developed distinguishing among all the different Italian macroareas (ref. Annex section – script 3[08] - Block).

The third[08] Results (cumulated block's results) and main observations: Tab. 5.3[08]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		23.021	24.008	3	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	37.200	16.903	9.411
CI		0	0	12.184	14.199	4.193
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	76.489.150 (cumulated)				
	CONSEQUENT RENOVATION COSTS [€]	2.225.363.594 (cumulated)				

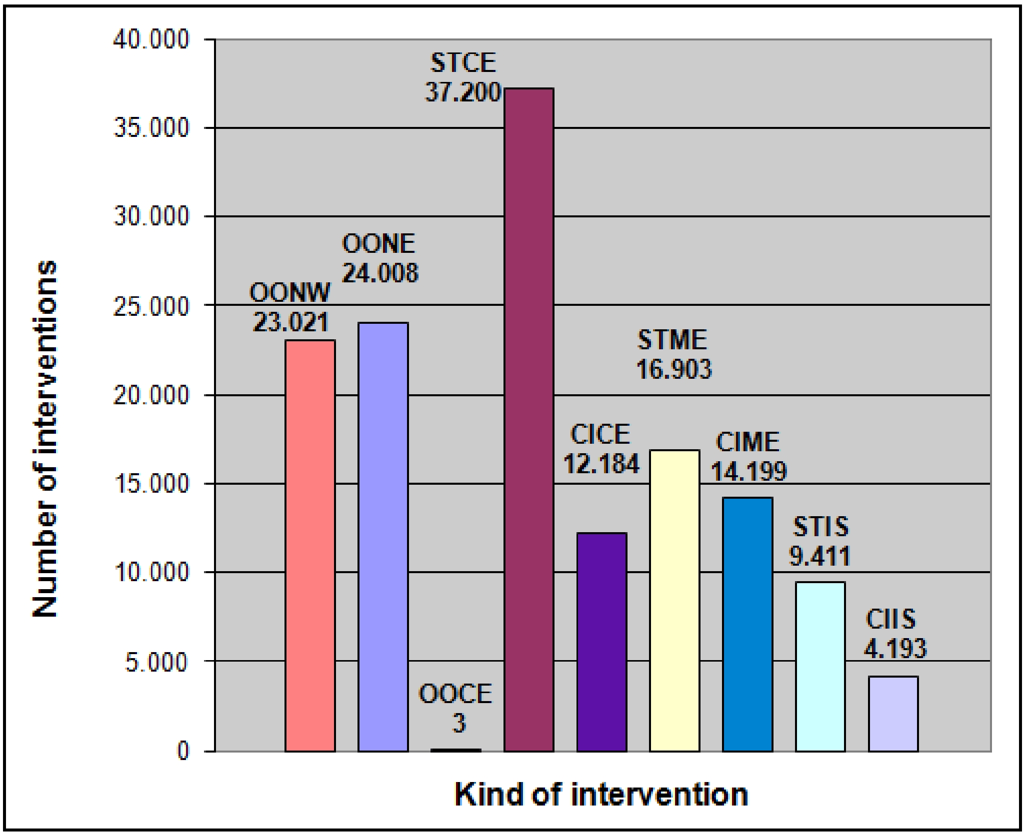


Fig. 5.3[08] ***(Gini Ratio=0,809)***

Also in this case it must be recalled that such an outward more varied configuration and interventions distribution is made up of a cumulated results collection and juxtaposition. Any single script only returned the most cost-effective kinds of building retrofit for any single macroarea (once again, for each zone only the ones with the lowest cost/saving ratio value).

Furthermore, as shown by these latest results' bar charts, a slightly more differentiated retrofit distribution is now detectable for the Center, South and the Islands of Italy while instead, for the other two Italian macroregions, an output configuration different than the previous asset-scene should be highlighted (unlikely what has happened for year 2007 and, once again, due to the higher financial budget available). However, also in this case such a distribution is ascribable to the tighter maximum limits settled for the current scenario, and particularly with reference to the latest three areas: after the maximum limit allowed for the "most cost-effective" kinds of building retrofit had been reached, the lower admitted values now settled have in fact assigned the "remainders" (i.e. the places still available) to the "second most performing ones" (i.e. thermal plants both for the South and the Islands, as well as for the Center of Italy).

Clearly, also the *Gini* coefficient is now sensibly lower compared to the scenario previously assessed.

Finally, it's also possible to observe that now the cumulated level of achievable energy savings is still higher than the one reported by Enea (despite lower than the previous scenario), while instead the total retrofit cost required is almost the same as the one ascribable to the second asset-scene.

The fourth[08] Scenario and its main assumptions (Script n.4[08]):

By means of a successive refinement and introducing the further restrictions depicted by the Annex, the allowed financial budget became now more binding and was "split" in two different blocks (analogously to what already done for the previous year).
A mutual interdependence was therefore introduced, while the building stock to be assessed has been kept limited to those only "Enea participants" registered along the entire Italian country.

The fourth[08] Results and main observations: Tab. 5.4[08]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		4.607	1.038	0	0	0
OV		0	3.550	0	0	0
IN		1	71.215	24.526	5.923	2.670
ST		0	0	21.776	16.903	9.411
CI		47.508	3	0	2.636	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	51.586.300				
	CONSEQUENT RENOVATION COSTS [€]	2.225.381.128				

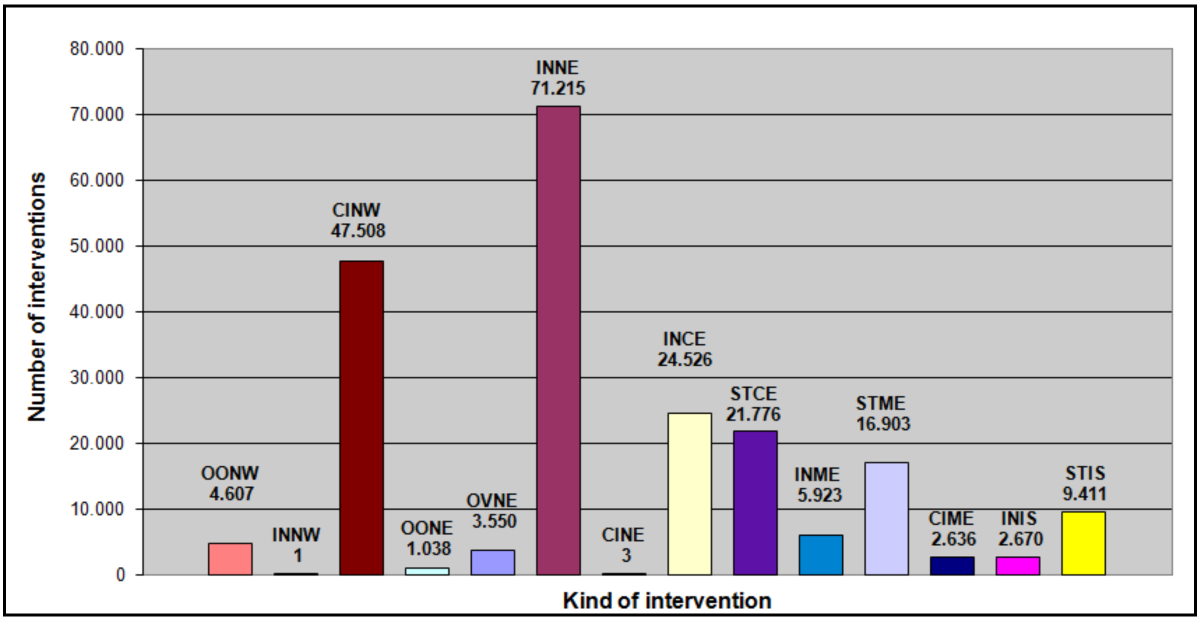


Fig. 5.4[08] ***(Gini Ratio = 0,829)***

As highlighted by the global results, such a more varied and well balanced configuration had a consistent negative effect upon the global energy saving level achievable: actually, the more scattered distribution "has cost" more than 24.900.000 MWh in terms of MWh saved.
However, once again, a positive effect may be noticed under a policy and decision-making perspective.

It's indeed interesting to notice the higher values registered for windows replacement, i.e. for the "worst" kind of building retrofit under a cost-effectiveness aspect (which, on the other hand, are also the most affordable ones and the most easy to be carried out): such renovations shouldn't be therefore neglected within a fairy energy policy, even though they appear the least efficient into achieving higher energy saving performances.

Finally, it must be also highlighted the higher value registered for the *Gini* coefficient with reference to the current asset-scene: actually, it's possible to observe that, on the one hand the above configuration appears more spread and distributed along the entire country (involving a wider range of interventions), but on the other hand a concentration rate sensibly higher can be noticed with reference to the thermal plants installations to be carried out in the North-West area (as well as for the windows frame replacements suggested in the North-East zone).

The fifth^{08} Scenario and its main assumptions (Script n.5^{08}):

Also the current scenario - as already done while dealing with year 2007 - considers the entire Italian Country as a whole introducing different bottom limits through a direct proportionality criterion. Actually, after a minimum required value had been settled for the highest cost/saving ratio referred to a single kind of building retrofit for a certain macroarea (hence, in this particular case, for window frames in the south of Italy), all the other inferior values were step by step evaluated end settled according to their respective higher feasibility.
With reference to such a lowest-minimum threshold, it must be once more recalled (as already done while processing the 2007 data) that a proper "*limes*" should be met into fixing its value, in order to avoid any infeasibility and capability problem due to the algorithm iterative searching engine.

The results consequently achieved (by launching the respective fifth^{08} script of the Annex) may be summed up as follows:

The fifth^{08} Results and main observations: Tab. 5.5^{08}

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		4.089	1.286	152	144	135
OV		157	2.981	150	147	135
IN		393	71.215	23.730	6.713	1.926
ST		153	152	21.358	16.903	9.411
CI		48.306	153	155	160	152
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	51.281.330				
	CONSEQUENT RENOVATION COSTS [€]	2.222.591.799				

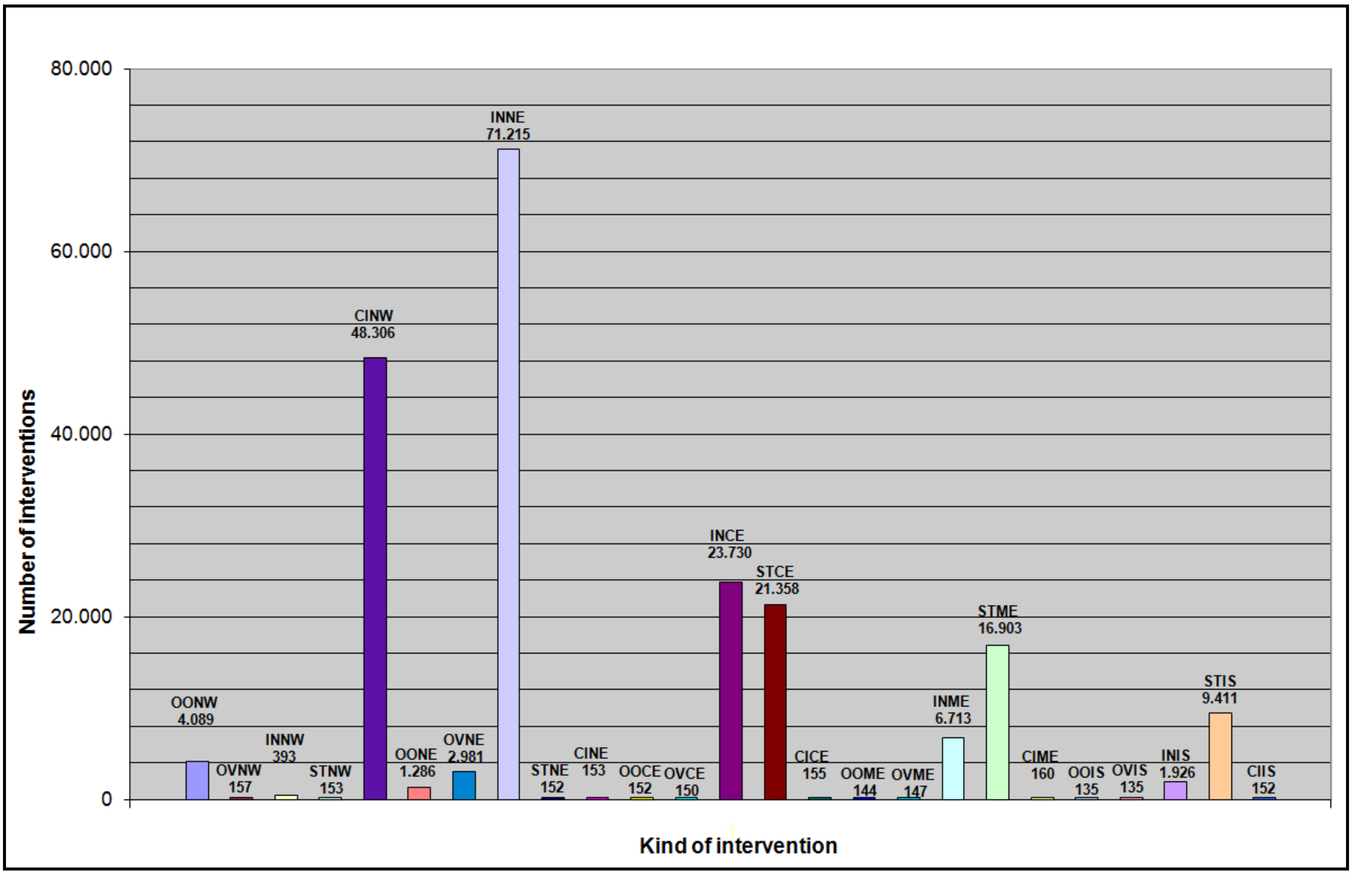


Fig. 5.5[08] ***(Gini Ratio = 0,827)***

As expected, also in this case the bottom minimum thresholds introduced by the current script have led to a new distribution more spread along the entire country.
Furthermore, by analyzing such a latest building retrofit configuration, it's possible to notice that the lower values now settled aren't identically coinciding with the respective output provided by the algorithm here implemented.
For instance, if on the one hand the value assigned to the opaque vertical surfaces in the South of Italy coincides with its respective minimum threshold (***OVME*** ≡ ***147***), on the other hand the kind of renovation outwardly "worst" and least cost-effective (i.e. windows replacement for the Italian Islands - ***INIS***) has reached the higher value of ***1.926*** (while instead, according to the script launched in the current session and reported by the Annex section, its minimum threshold had been fixed in only ***89*** interventions).

<u>Maximization</u> results' exploitation and consequent implementation of the <u>Minimization</u> script (Script n.6[08]):

As previously carried out with reference to the year 2007, also for the current assessment a minimization script was filled up in order to achieve a more balanced and weighed retrofit distribution (optimizing both energy savings and retrofit costs and exploiting the global results achieved by means of the latest, and most complete, fifth[08] scenario).
The same distinction and grouping criterion were maintained, as well as the proportionality factors and the several "weights" to be considered for the new assessment of all the different retrofit typologies.

The <u>sixth</u>^{08} Results and main observations: Tab. 5.6^{08}

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		4.345	1.149	0	0	0
OV		0	3.374	0	0	0
IN		21.484	71.216	2	0	0
ST		1	0	21.607	16.903	9.411
CI		43.652	2	6.555	3.175	1.435
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 51.200.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	2.121.822.000				

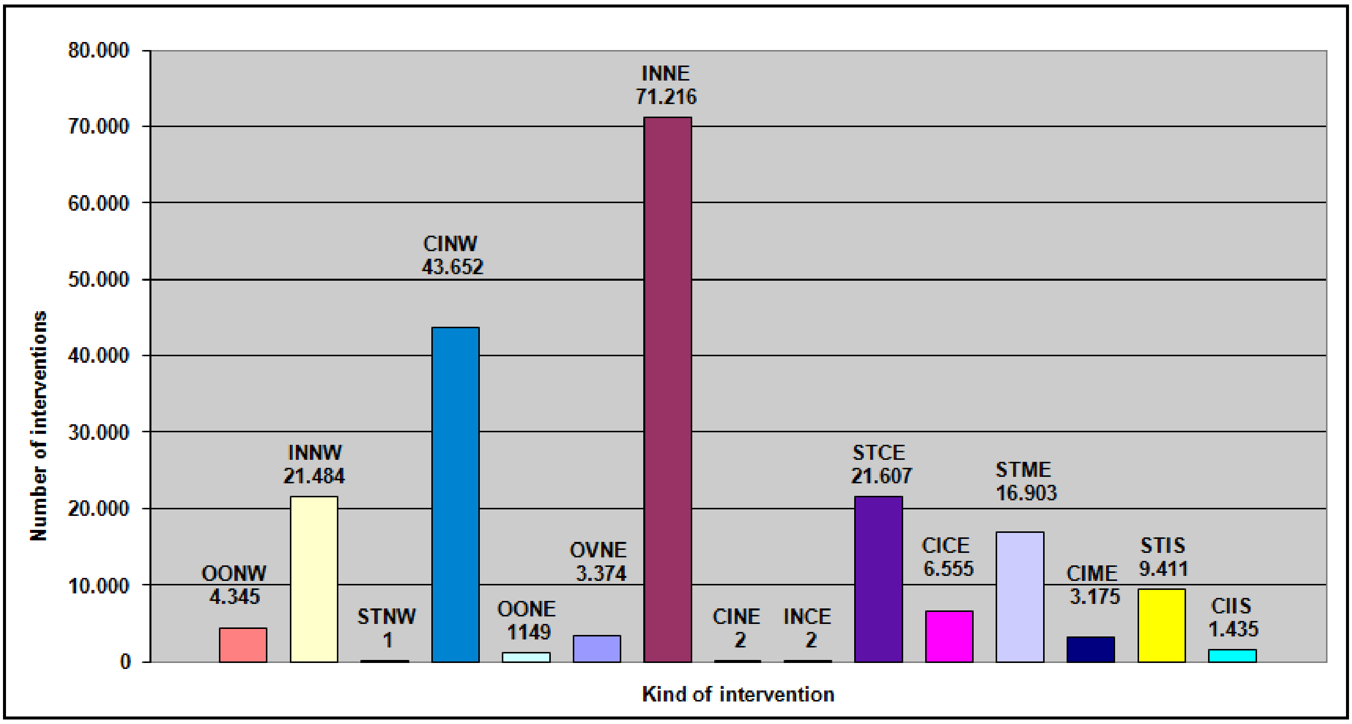


Fig. 5.6^{08} ***(Gini Ratio = 0,829)***

<u>Maximization</u> results' exploitation, consequent implementation of the <u>Minimization</u> script plus bottom minimum value requirement (Script n.7^{08}):

Adding a further lower constraint (analogously to what already done in the fifth^{08} maximization script) the current minimization became even more restrictive.

The <u>seventh</u>^{08} Results and main observations: Tab. 5.7^{08}

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		4.088	1.286	154	144	135
OV		158	2.980	150	147	135
IN		21.309	71.216	117	85	89
ST		153	152	21.358	16.903	9.411
CI		44.215	153	6.030	2.547	833
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 51.200.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	2.131.751.000				

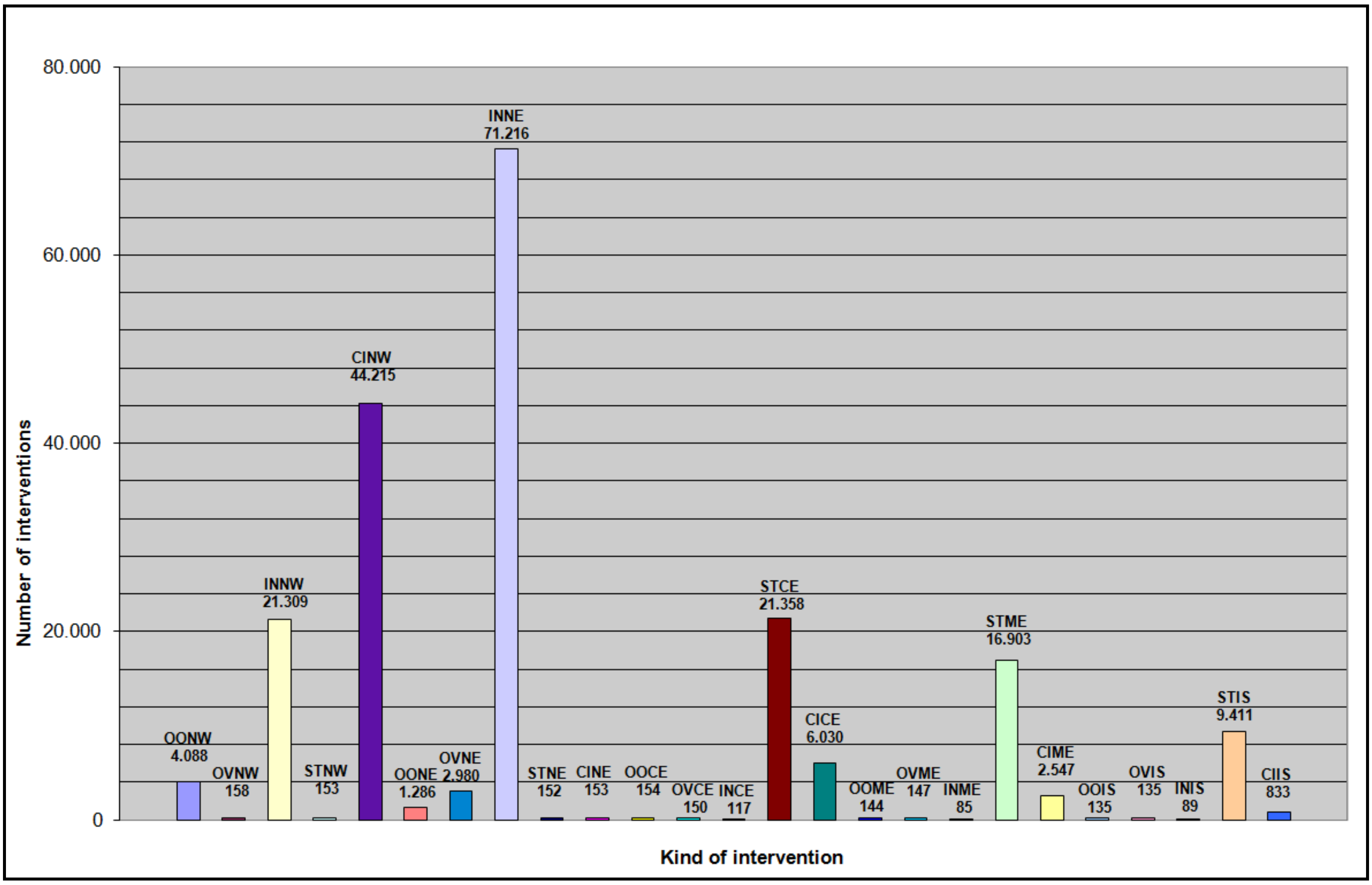


Fig. 5.7[08] ***(Gini Ratio = 0,824)***

Compared with the Enea 2008 assessment, such a latest scenario has finally led to a global energy savings level ≈ 9.600.000 MWh higher (≈51.200.000 MWh against 41.615.338 MWh) with a public incentive budget slightly lower (2.131.751.000 € against 2.225.404.392 €) and a building retrofit distribution addressed according to a more discretionary, political criterion.

Hence it's possible to gather that, while according to the Enea 2008 results each one MWh of energy saved has cost on the average ≈ **53,48 €**, the latest configuration now assumed has led to a "unit cost" evaluated in **≈ 41,64 €/MWh.**

Also in this case, the lower value assessed for the *Gini* coefficient ascribable to the "Enea 2008 building retrofit distribution" (i.e. **G= 0,646**) is directly connected with the lower energy efficiency framework registered for the Enea scenario.
Also the current year's assessment has therefore provided a further confirmation about the strategic key-role played (under a policy and decisional point of view) by linear programming resources.

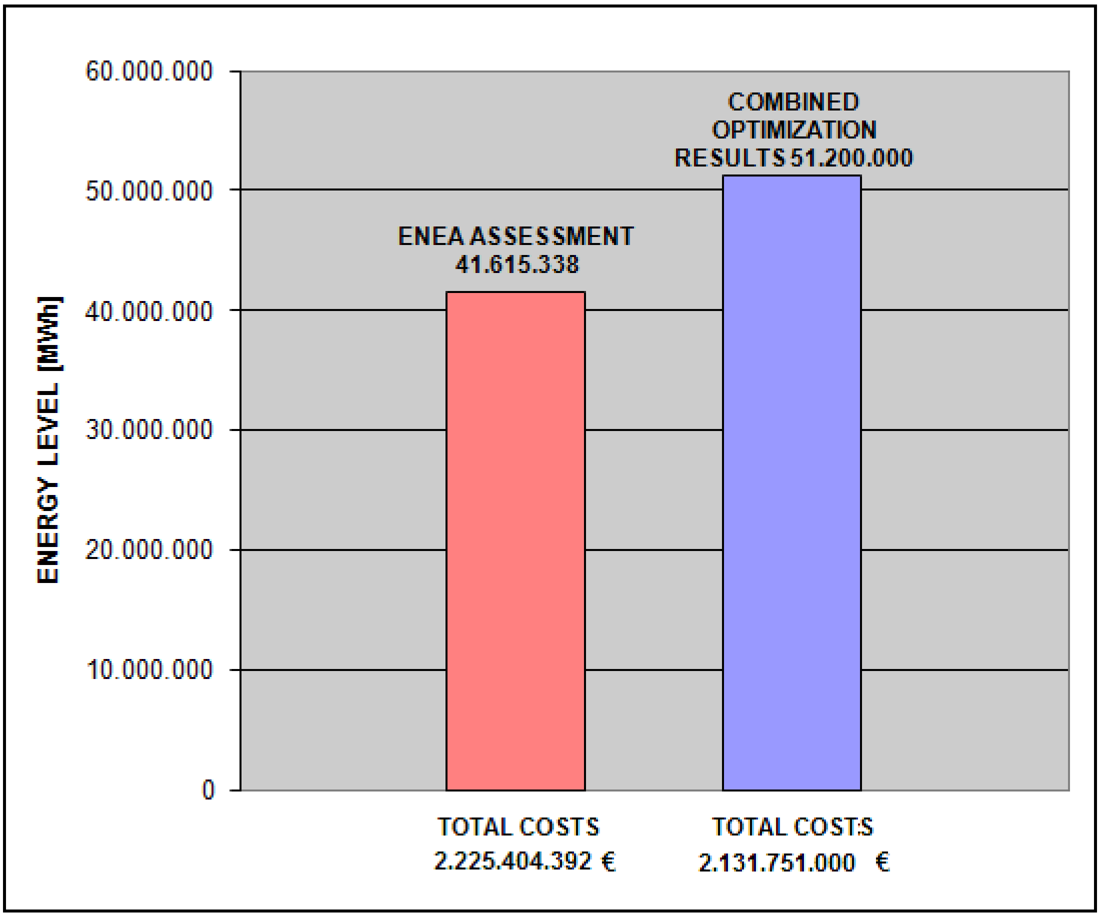


Fig. 5.8[08] GLOBAL COMPARISON TABLE

5.6 Linear programming assessment and simplex optimization application in the present research: the different scenarios drawn up and investigated - focus on the Italian Energy Efficiency Campaign - the Enea Reports Year 2009

Once again, by adopting the same investigation's approach before applied both for the year 2007 (as well as for year 2008), the current assessment has been performed processing all the information and data provided by the third Enea report.
Despite such a report has been issued in December 2010, it is referred to the energy efficiency campaign carried out during year 2008 and it can be downloaded from the following link: *http://efficienzaenergetica.acs.enea.it/doc/rapporto_2009.pdf*

The first[09] Scenario and its main assumptions (Script n.1[09]):

The current scenario has investigated (as reported by the Annex section – script 1[09]) the incentives distribution registered during year 2009, in order to find out the optimal configuration to be defined for the public financial support to energy efficient building retrofits.
Still maintaining a unique economic budget for the entire country and after having developed a further multifactor group of excel spreadsheets, the **first[09] script** was filled up and then launched.

Also in this case, the main goal was the maximization of an *ad hoc* objective function obtained by summing up all the weighed average values of energy saving [MWh] registered in the different Italian macroareas.

The first[09] Results and main observations: Tab. 5.1[09]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	0	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	405.375	0	0
CI		0	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]- LINDO RES	115.167.900				
	CONSEQUENT RENOVATION COSTS [€]	2.563.270.796				
COST/BENEFITS BALANCE SUMMARY [€/MWh*yr]		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
NUMBER OF OPAQUE HORIZONTAL SURFACES INTERVENTION		32,22	35,53	44,37	61,92	80,96
NUMBER OF OPAQUE VERTICAL SURFACES INTERVENTION		42,50	37,27	59,12	58,75	108,55
NUMBER OF WINDOWS FRAME REPLACEMENT		116,72	105,23	142,66	188,65	214,81
NUMBER OF SOLAR PANEL INSTALLATION		52,24	52,37	31,01	23,34	24.49
NUMBER OF THERMAL PLANT REPLACEMENT		42,89	52,19	44,55	68,82	68,58

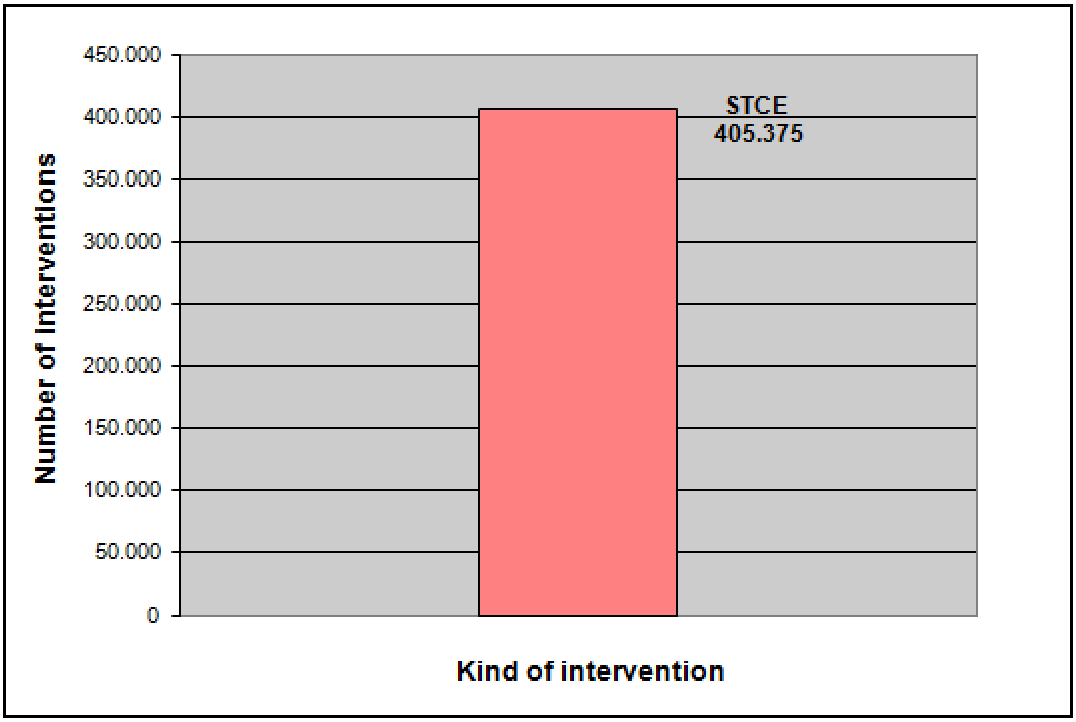


Fig. 5.1[09] ***(Gini Ratio = 1,000)***

Once again, despite the available budget slightly higher than the previous year (2.563.271.161 € > 2.225.404.392 €), it must be notice that such an amount was still too low compared with the building stock to be covered (i.e. the Italian building stock registered by ISTAT).
Furthermore, as it's possible to observe looking at the above results, also in this case the too weak restrictions imposed by the current script have entirely funnelled the available funds into only doing one kind of building retrofit without any typological, neither geographical distinction.
It has to be also highlighted that, considering the overall cost/saving ratio assessment, no apparent reason seems to be recognizable behind such a distribution.
Actually, even though the lowest cost/saving ratio assessed is associated to solar panel installation for the South macroarea (23,34 value), the simplex method implementation has given, as unique output result, only solar panel installations for the Centre of Italy (i.e. "the third place" in the cost-effectiveness ranking, with a value of 31,01). However, the main reason for the above outwardly incongruous result is directly derived from the complex and multifactor calculation developed and performed by such an algorithm.

The second[09] Scenario and its main assumptions (Script n.2[09]):

By only focusing the analysis on the whole Italian country through an all-embracing assessment and narrowing down the investigation field to those only dwellings involved in the Enea Reports, the second[09] step of analysis has led to the script 2[09] reported by the Annex section.

The second[09] Results and main observations: Tab. 5.2[09]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		74.651	0	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	39.532	19.486	9.927
CI		0	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	92.471.060				
	CONSEQUENT RENOVATION COSTS [€]	2.563.270.056				

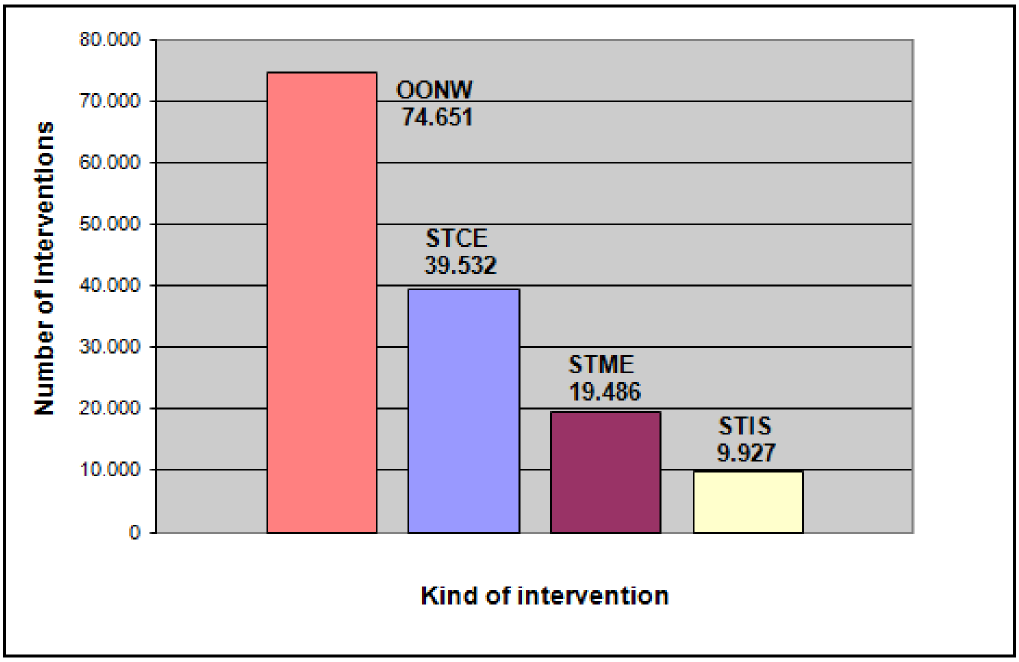


Fig. 5.2[09] ***(Gini Ratio=0,937)***

The above results now suggest a different investment plan and retrofit configuration, which involves more Italian macro-areas and extends the feasible kinds of renovation to a wider range.
Actually, according to this latest output, the only building retrofits to be carried out should be the four ones with the lowest (i.e. the best) cost/saving ratio values.
No interventions are in fact funded by the available budget in the North East macroarea, which has shown, as the best "cost-effectiveness ratio value", the number of **35,53** (i.e. the highest one among the five most performing interventions detected along the entire country).

The <u>third</u>[09] Scenario and its main assumptions (Script n.3[09]):

Once again, by only considering the so called "Enea participants", the current scenario was developed keeping now distinguished all the different Italian macroareas (ref. Annex section – script 3[09] - Block).

The <u>third</u>[09] Results (cumulated block's results) and main observations: Tab. 5.3[09]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		37.989	32.779	5.369	1	0
OV		0	2	0	6.569	0
IN		0	0	0	0	0
ST		0	0	39.533	19.486	9.930
CI		0	0	3	0	4.465
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	84.423.266 (cumulated)				
	CONSEQUENT RENOVATION COSTS [€]	2.563.252.373 (cumulated)				

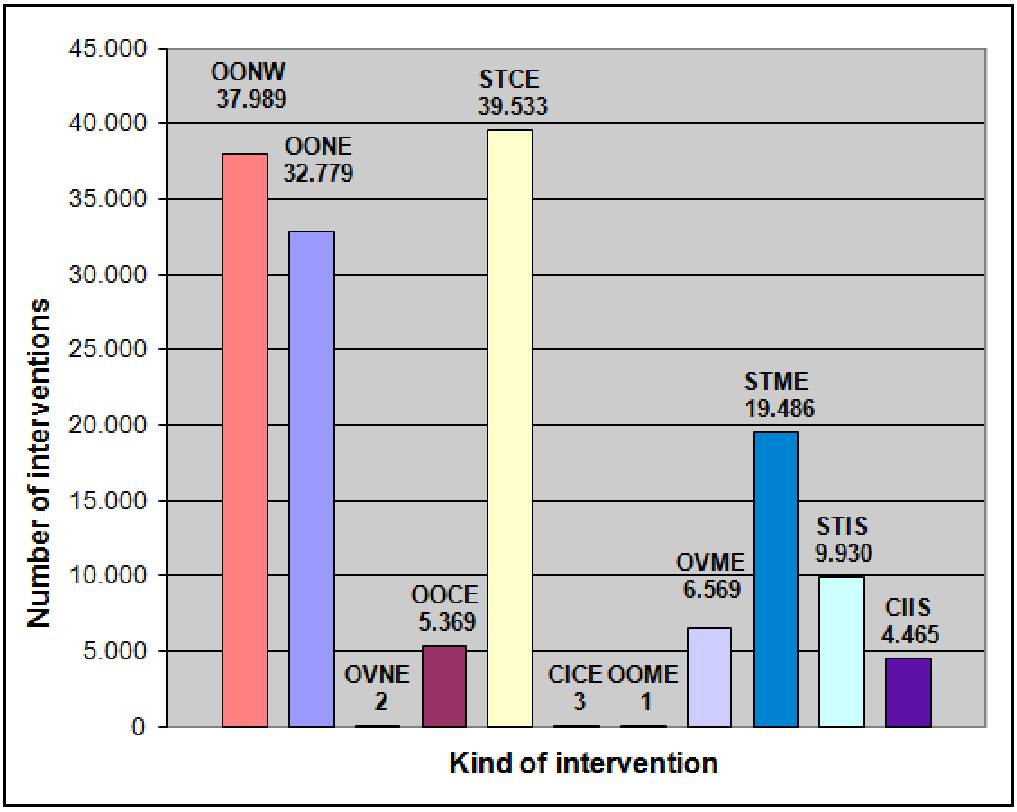


Fig. 5.3[09] ***(Gini Ratio = 0,841)***

In this case, despite the above outwardly more varied configuration and retrofit distribution, it must be highlighted that (once more) the shown results consist in the cumulated values resultant from the several scripts reported by the annex. Such a cumulated level of achievable energy savings is higher than the one referred by Enea (once again, and even though also lower than the previous scenarios), but now the total retrofit cost required is almost the same than the other ones before assessed.
Furthermore, as shown by the latest results bar charts, a slightly more differentiated retrofits distribution is now detectable for the Center, South and for the Islands of Italy.
With reference to the northern zones, while in the North-West the same kind of building retrofit has been kept (but with a number of interventions lower than the previous one), in the North-East may be now detected the "arrival" and the appearance of the most-cost effective kind of building renovation at this single macroarea level (i.e. the opaque horizontal surfaces retrofit).
However, also in this case it's possible to notice that, after the maximum limit allowed for the "most cost-effective" kinds of building retrofit had been reached (in the three southern areas), the lower admitted values now settled have assigned the "remainders" (the places still available) to the "second most performing ones".
Also the current sensibly lower value assessed for the *Gini* ratio coefficient provides a further confirmation about the higher distribution level now recognizable.

The <u>fourth</u>[09] Scenario and its main assumptions (Script n.4[09]):
Once again, by means of a further constraints refinement and introducing a mutual interdependence among the different kinds of building retrofit (as well as among the several Italian macroareas) a more complex script was sketched out (ref. Annexes - script 4[09]).

The <u>fourth</u> [09] Results and main observations: Tab. 5.4[09]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		8.870	0	0	0	0
OV		0	5688	0	0	0
IN		24.866	78071	1	8218	3483
ST		0	0	17393	19.482	9.927
CI		38.633	277	25943	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	50.844.310				
	CONSEQUENT RENOVATION COSTS [€]	2.551.785.702				

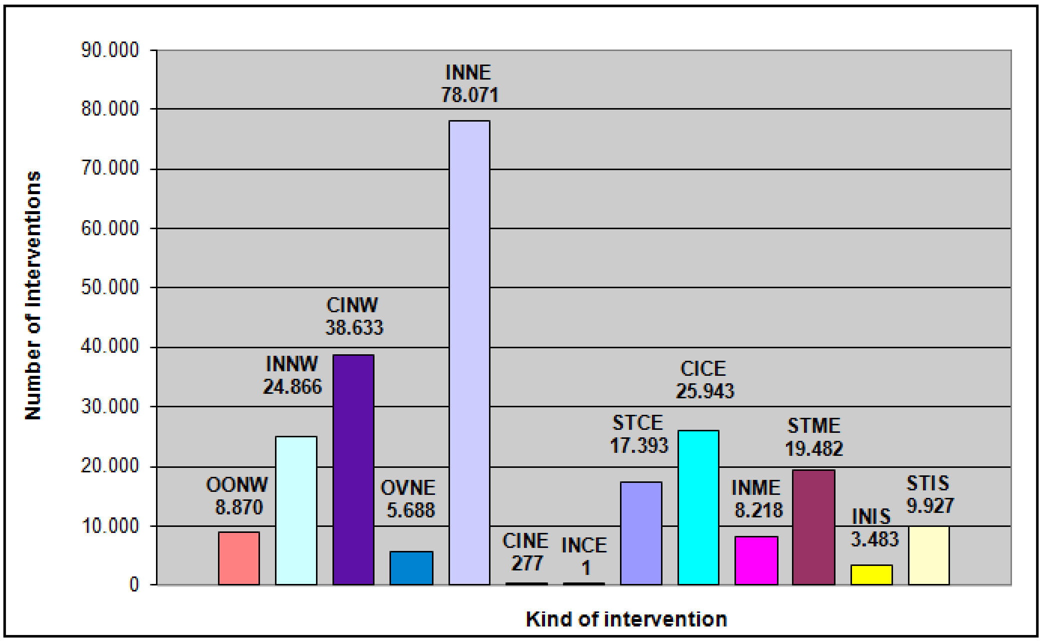


Fig. 5.4[09]
(Gini Ratio = 0,790)

As highlighted by the global results, such a more varied and well balanced configuration (also confirmed by the current *Gini* Ratio value) had a consistent negative effect upon the global energy saving level achievable: actually, the more scattered distribution "has cost" more than 30.000.000 MWh in terms of MWh saved.
However (once again) a positive effect may be noticed under a policy and decision-making process perspective.

Furthermore it must be highlighted that, for instance in the North-West macroarea, the imposed restrictions have yielded to such results not completely adherent with the respective "cost-effectiveness" ranking: actually, after the kind of building retrofit not most cost-effective (i.e. the "third place", that is thermal plant interventions) has reached the maximum number allowed, the algorithm has favoured windows' renovations (the "worst" one according to the cost/saving ratio assessment) rather than the "first classified" in the ranking chart (i.e. opaque horizontal surfaces retrofit).

And analogous remarks can be mentioned with reference to the North-East zone, where even the highest ratio value (i.e. the least cost-effective kind of retrofit) has been particularly privileged.
A partially different approach was instead adopted into dealing with the southern areas: here (according to the final results) the interventions to be mainly favoured are the solar panels, i.e. the first place in the cost-effectiveness ranking both for the South, as well as for the Islands.

Such a phenomenon can be directly connected with the so stronger influence due to the higher insolation detectable in these areas, which has made solar panels installations particularly fruitful and cost-effective.
Once again, it should be however registered a consistent number of windows frame replacements (actually not cost-effective, but easier and cheaper to be carried out).

The <u>fifth</u>^{09} Scenario and its main assumptions (Script n.5^{09}):

Also the current scenario, as already done for the previous years, considers the entire Italian Country as a whole introducing different bottom limits through a direct proportionality criterion.
Actually, after the minimum required value had been settled for the highest cost/saving ratio associated to a single kind of building retrofit for a certain macroarea (hence, in this particular case, for windows renovation in the Islands of Italy), all the other inferior values were step by step calculated according to their respective higher feasibility (ref. Annex - fifth^{09} script).

The <u>fifth</u>^{09} Results and main observations: Tab. 5.5^{09}

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		8.434	156	152	145	137
OV		153	5.115	146	147	127
IN		25.911	78.068	113	7.657	2.957
ST		148	148	17.044	19.486	9.910
CI		38.546	626	25.464	142	142
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	50.562.780				
	CONSEQUENT RENOVATION COSTS [€]	2.563.258.868				

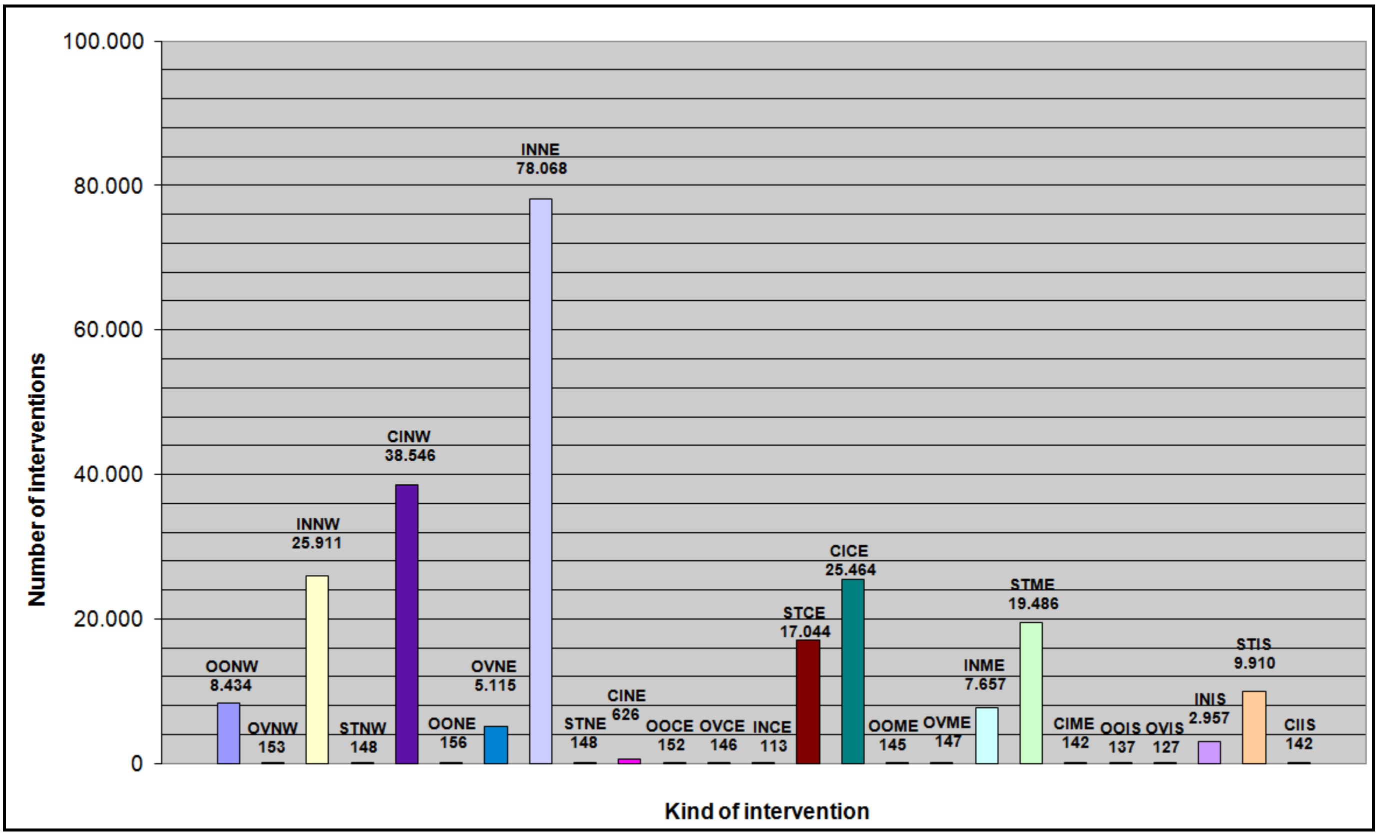


Fig. 5.5[09] ***(Gini Ratio = 0,784)***

Such a final distribution (more scattered along the entire country and which actually involves all the different kinds of intervention) provides a further confirmation for the main results previously obtained.

Beside the "arrival" of those interventions before not involved in the distribution (whose required values are exactly the same than the minimum settled thresholds, and with the only exception of OVME → 147 > 146), it must be noticed that all the other building renovations weren't assigned according to their respective cost-effectiveness ratio value.

Furthermore, while such a configuration (along with the new minimum thresholds now required) seems to "sacrifice" the most performing interventions (favouring instead the other ones), the huge potentialities provided by the iterative simplex method here implemented must be once again highlighted.
Actually, the optimal solution suggested for the current scenario wasn't directly inferable, neither by means of a plain cost-effectiveness assessment, nor through any simple convenience argument.

Moreover, no logical reason seems to lay behind the retrofit output distribution above reported.

Anyway, it's also possible to gather how much powerful should be, in the southern areas, the "worth" to be assigned to the solar panels installations, so far that they are able to strongly defend their cost-effectiveness primary role, therefore maintaining their respective "supremacy".

Maximization results' exploitation and consequent implementation of the Minimization script (Script n.6[09]):

The current investigation scenario was filled up in order to achieve a more balanced and weighed retrofit distribution, optimizing both energy savings and retrofit costs and exploiting the global results achieved by means of the latest, previous assessment.
The same distinction and grouping criteria were maintained, as well as the proportionality factors and the several contributions to be considered for all the different kinds of renovation.
A new calculation of the respective weights to be considered for the several building retrofits has been developed and a new group of *ad hoc* excel spreadsheets was filled up in order to define the new variable coefficients for the scripts to be launched.

The sixth[09] Results and main observations: Tab. 5.6[09]

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		8.069	914	0	0	0
OV		0	4.232	0	2.171	0
IN		32.663	78.070	0	0	0
ST		0	0	17.187	19.486	9.930
CI		38.218	0	25.918	3	1.672
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 52.000.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	2.524.547.000				

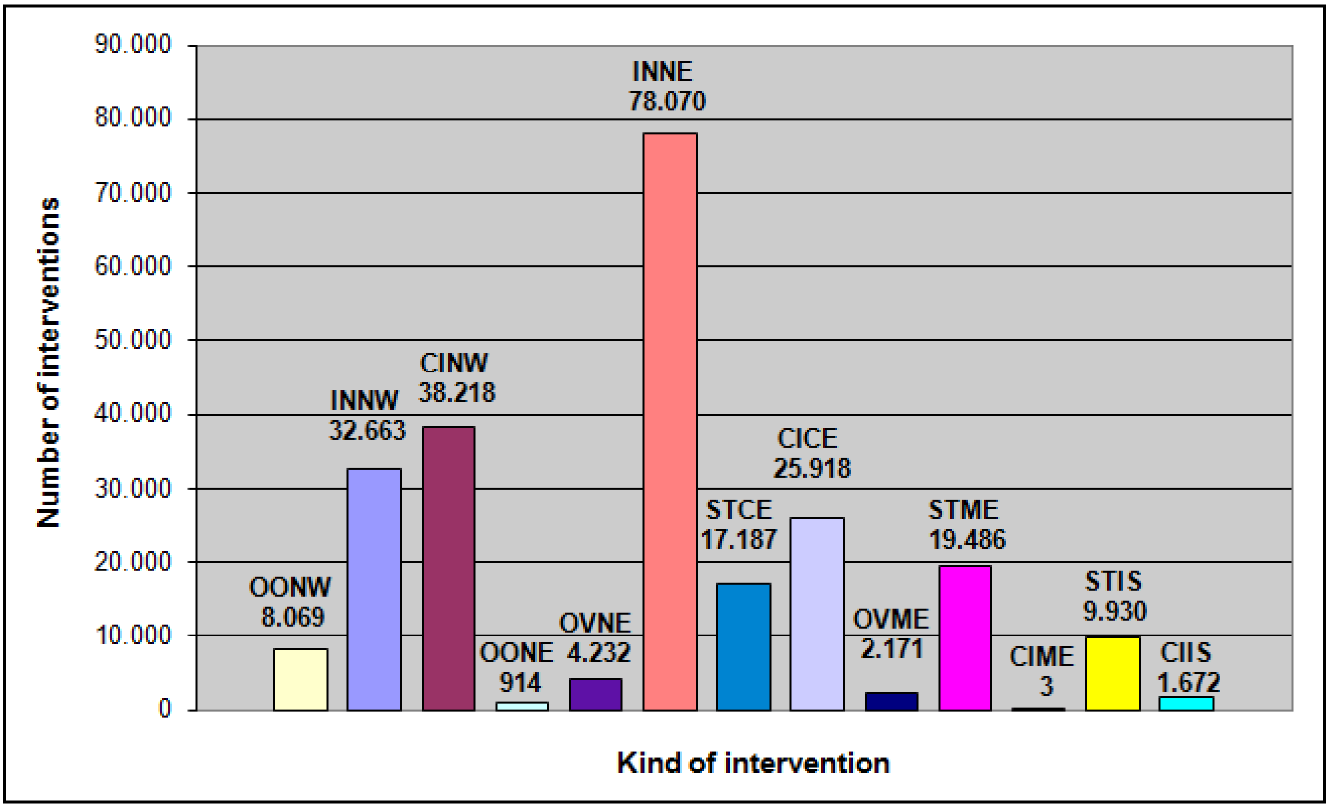


Fig. 5.6[09] ***(Gini Ratio = 0,811)***

Looking at these latest results and analyzing the respective configuration it's possible to observe an overall distribution globally in line with the correspondent sixth[08] script's output (see Fig. 5.6[08]).
Actually, once again, the windows replacements have gained the highest weight in the North-East macroarea, as well as the thermal plant replacements in the North-West.
Furthermore (as expected) the solar thermal panels have instead registered their supremacy in the southern areas while, on the average, a floating variability may be observed with reference to the other retrofit typologies.

Also the *Gini* ratio value (now evaluated as **0,811** compared with the previous **0,829**) confirms such an overall similarity, mainly ascribable to the criterion which lays behind the respective boundary conditions' definition, as well as directly connected to the available budget (registered both for year 2008 and 2009) to deal with.

<u>Maximization</u> results' exploitation, consequent implementation of the <u>Minimization</u> script plus bottom minimum value requirement (Script n.7[09]):

Adding a further lower constraint (analogously to what already done in the fifth[09] maximization script), the current minimization became even more restrictive.

The <u>seventh</u>[09] Results and main observations: Tab. 5.7[09]

MINIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		7.894	919	152	146	137
OV		153	4.093	146	1891	127
IN		32.473	78.070	114	95	85
ST		148	148	17.032	19.486	9.930
CI		38.494	149	25.479	147	1.240
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]	> 52.000.000 (as estimated)				
	CONSEQUENT RENOVATION COSTS [€] - LINDO RES	2.531.344.000				

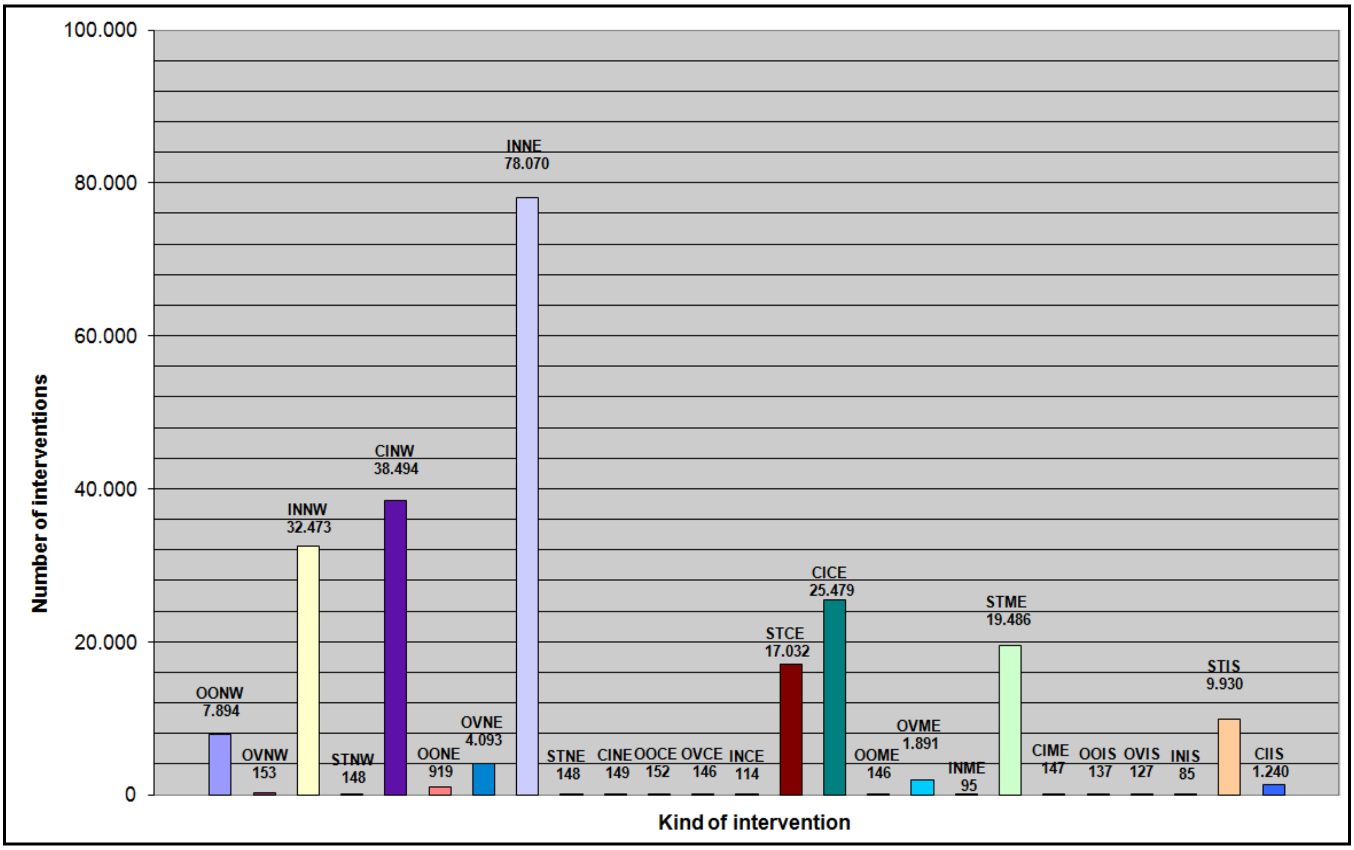


Fig. 5.7[09] ***(Gini Ratio = 0,804)***

Compared to the Enea assessment, this latest scenario has finally led to a global energy savings level ≈ 7.700.000 MWh higher (≈52.000.000 MWh against 44.300.000 MWh) with a public incentive budget slightly lower (2.531.344.000 € against 2.563.271.161 €) and a building retrofit distribution addressed according to a more discretionary, distributed criterion.

Hence it's possible to gather that, while according to the Enea 2009 results each one MWh of energy saved has cost on the average **≈ 57,86 €**, the latest configuration now assumed has led to a "unit cost per MWh saved" evaluated in **≈ 48,68 €.**

Also in this case, the lower value assessed for the *Gini* coefficient ascribable to the "Enea building retrofit distribution" (i.e. **G= 0,634**) is directly linked to the lower energy efficiency framework registered for such a scenario.

Moreover it must be highlighted that, if on the one hand this latest configuration still depicts a quite unequal distribution (picking out and showing several evident peaks), it has also provided a more cost-effective and convenient incentives' distribution, strategically addressed by means of such a linear programming assessment.

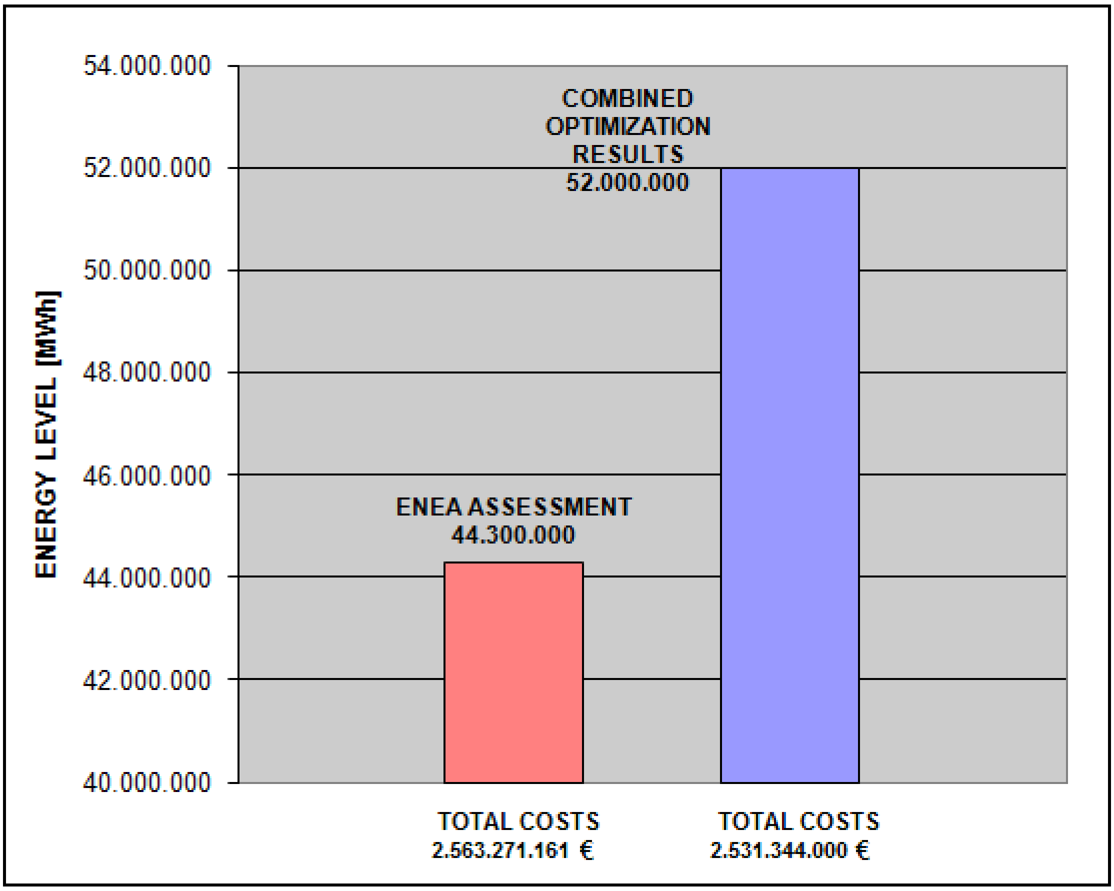


Fig. 5.8[09] GLOBAL COMPARISON TABLE

5.7 Linear programming assessment and simplex optimization application in the present research: the different scenarios drawn up and investigated - focus on the Italian Energy Efficiency Campaign - the Enea Reports Year 2010

By applying the same assessment criterion adopted till now, the current investigation considered all the main information and data provided by the fourth Energy Efficiency Incentives Report issued by Enea. Even though such a document has been published during year 2012, it's referred to the energy efficiency campaign carried out during 2010 and can be downloaded from the following link: *http://www.acs.enea.it/doc/rapporto_2010_pubblicato.pdf*

The first[10] Scenario and its main assumptions (Script n.1[10]):

The current analysis has investigated (as reported by the Annex section – script 1[10]) the incentives distribution registered during year 2010, with the final purpose of defining the optimal configuration which should be assigned to the public financial support for energy efficient building retrofits.

The **first**[10] **script** of the Annex has been consequently filled up and then launched (also in this case after having carried out the respective group of excel spreadsheets). Once again, the main goal linked to such a scenario was the maximization of an *ad hoc* objective function obtained by summing up all the weighed average values of energy saving [MWh] registered in all the different Italian macroareas.

The first[10]-Results and main observations: Tab. 5.1[10]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		0	0	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	0	0	1.013.957
CI		0	0	0	0	2
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	202.406.400				
	CONSEQUENT RENOVATION COSTS [€]	4.607.732.397				
COST/BENEFITS BALANCE SUMMARY [€/MWh*yr]		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
NUMBER OF OPAQUE HORIZONTAL SURFACES INTERVENTION		<u>33,12</u>	<u>41,46</u>	58,70	79,35	85,56
NUMBER OF OPAQUE VERTICAL SURFACES INTERVENTION		46,86	53,71	76,63	88,99	103,15
NUMBER OF WINDOWS FRAME REPLACEMENT		106,19	98,06	136,33	167,53	197,53
NUMBER OF SOLAR PANEL INSTALLATION		67,79	60,93	<u>54,09</u>	<u>28,42</u>	23,58
NUMBER OF THERMAL PLANT REPLACEMENT		55,93	74,93	86,59	94,45	108,35

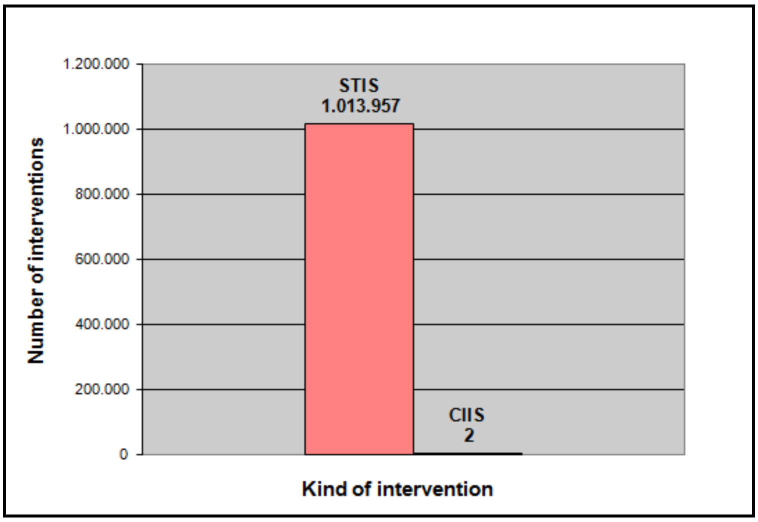


Fig. 5.1[10] ***(Gini Ratio = 1,000)***

Also in this case, according to the too weak restrictions imposed by the current script, only one kind of building renovation was picked out (and thence should be financially supported).
Actually, once again, just the most cost effective kind of intervention (i.e. solar thermal panel installation for the Islands macroarea, which has shown the lowest cost/savings ratio value) was detected and selected.
Besides, the only 2 thermal plant replacements suggested for this same macroarea are mainly ascribable to the integer ("*GIN 25*") restriction introduced in the simplex script: they could therefore be neglected.
Indeed, as verified after having launched the same first[10] script without the integer requirement statement, the linear programming algorithm here implemented has univocally addressed the entire building retrofit process only towards the solar panel installation.

The second[10] Scenario and its main assumptions (Script n.2[10]):

The current analysis was carried out involving once again the entire Italian country by means of an all-embracing assessment and narrowing down the investigation field to those only "Enea participants" (as referred by the script 2[10] of the Annex section).

The second[10] Results and main observations: Tab. 5.2[10]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		87.101	0	0	0	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		0	0	1	33.236	15.025
CI		0	0	0	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	142.342.500				
	CONSEQUENT RENOVATION COSTS [€]	4.607.732.979				

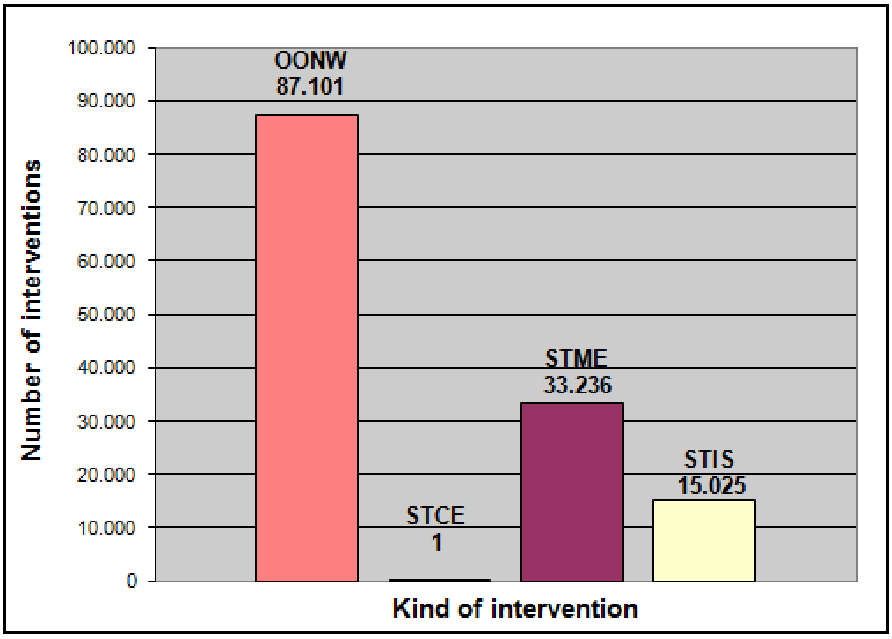


Fig. 5.2[10] ***(Gini Ratio = 0,961)***

The consequent, slightly different investment plan here suggested involves now two further Italian macro-areas and introduces a second kind of building-renovation (i.e. the opaque horizontal surfaces retrofit).Hence, those only interventions now selected by the simplex algorithm were the "first three classified" (i.e. those first ones with the respective three lowest cost/saving ratio values along the entire country) and any further indication hasn't been currently provided beside the ones just gathered by a simple cost-effectiveness assessment.

The <u>third</u>[10] Scenario and its main assumptions (Script n.3[10]):

Still considering only the "Enea participants", the new scenario now developed has introduced once again a distinction at the single macroarea level (ref. Annex section, script 3[10] – Block).

The <u>third</u>[10] Results (cumulated block's results) and main observations: Tab. 5.3[10]

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		38.761	32.167	4.180	3596	0
OV		0	0	0	0	0
IN		0	0	0	0	0
ST		1	3	65.307	33.238	15.025
CI		0	0	1	2	8.073
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	120.884.469 (cumulated)				
	CONSEQUENT RENOVATION COSTS [€]	4.607.716.500 (cumulated)				

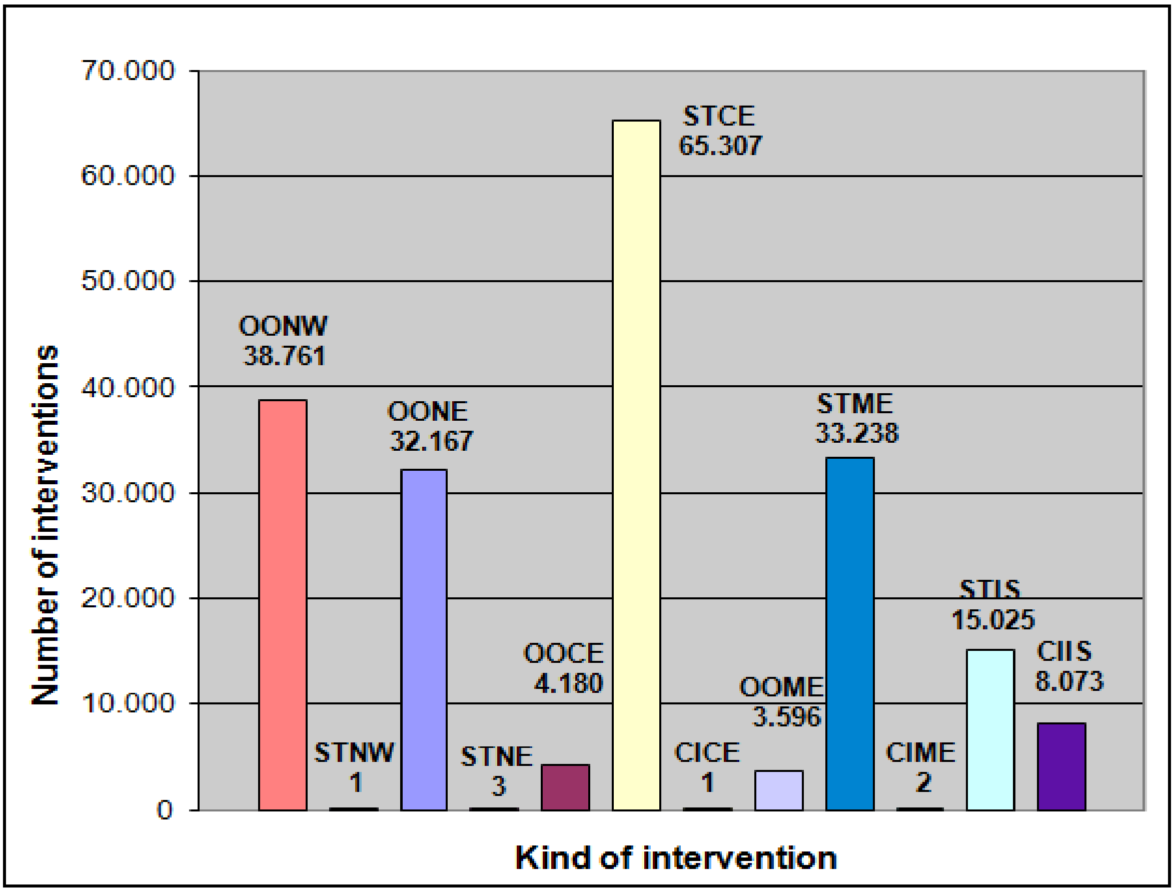


Fig. 5.3[10] ***(Gini Ratio = 0,853)***

A more differentiated retrofit distribution is now detectable mainly for the Center, the South and the Islands. For the northern zones instead, the opaque horizontal surfaces' supremacy may be observed (except the few interventions assigned to solar thermal panels, once again due to the "GIN" restriction). However, also in this case, it's possible to notice that, after the maximum limit allowed for the "most cost-effective" kinds of building retrofit had been reached (in the three southern areas), the lower admitted values now settled have assigned the "remainders" (the places still available) to the "second most performing ones".

The fourth[10] Scenario and its main assumptions (Script n.4[10]):

As already done while dealing with the previous years until now analyzed, a further constraints' refinement and a mutual interdependence among the different kinds of building retrofits (as well as among the several Italian macroareas) was now introduced (ref. Annex - script 4[10]).
With reference to this latest scenario it must be however highlighted an **infeasibility** problem due to the more stringent "crossed-budget" restrictions now imposed.
Actually, according to the boundary conditions here required (and as deducible by the software debugging process), the only building retrofit which should be possible to carry out in the islands macroarea consists in the solar thermal panel installation (i.e. the most cost-effective kind of renovation and the cheapest one too). Hence, by exploiting the main **Lindo-Debug** information, the script 4[10] was emended and modified according to what depicted by the successive script 4[10-bis] (see Annex).
Such a script has therefore left free to vary only solar panel interventions into the islands (by deleting their upper limit and hence allowing them to absorb the entire available budget).
As expected, the respective results (below depicted) only addressed islands' building retrofits towards this latest kind of intervention, proving once again the key-role played by the main "political" and discretional statements into orienting and balancing such a decision-making process.

The fourth[10-bis] Results and main observations (Script n.4[10-bis] and respective Tab. 5.4[10-bis]):

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		5.981	0	0	0	0
OV		5	4.451	0	0	0
IN		15.990	131.040	65.307	14.804	0
ST		0	1	6.318	33.238	28.842
CI		100.594	5.823	4.462	0	0
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	73.755.680				
	CONSEQUENT RENOVATION COSTS [€]	4.607.688.162				

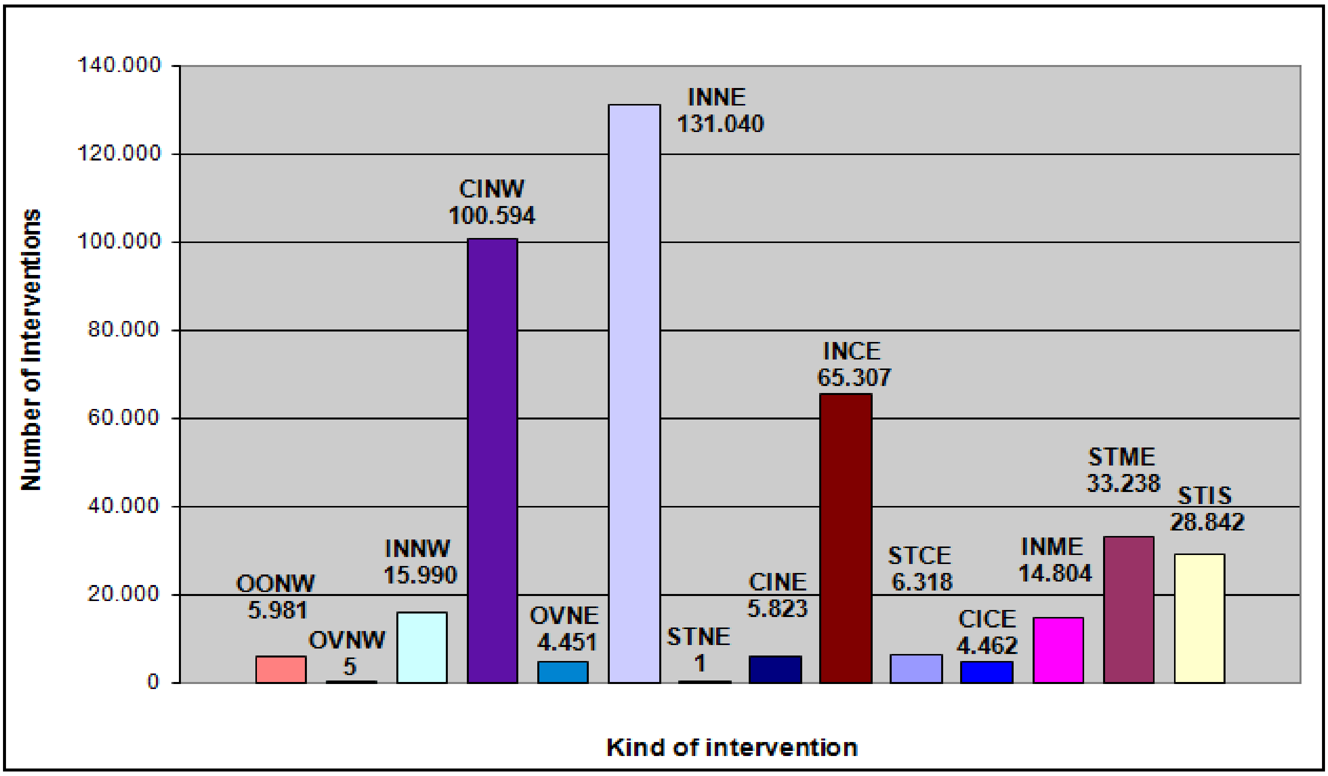


Fig. 5.4[10-bis] ***(Gini Ratio = 0,829)***

Also in this case, such a more varied and well balanced configuration had a consistent negative effect upon the final energy saving level globally achievable (this more scattered distribution "has cost" more than 47.000.000 MWh in terms of MWh saved).
However, if on the one hand (and once again) a positive effect may be noticed under a policy and decision-making perspective (slightly more homogeneous balance), on the other hand it must be recalled that such results are sensibly skewed by the upper limits' release above introduced for "*STIS*".
Nevertheless, an energy level still higher than the one registered by Enea is detectable (**73.755.680 MWh > 61.675.900 MWh**) and a global investment cost that, with **4.607.688.162 €** is slightly lower than the one reported by ENEA (evaluated in **4.607.733.288 €**) may be assessed.

The fourth[10-ter] **Results and main observations (Script n.4**[10-ter] **and respective Tab. 5.4**[10-ter]**):**
In the light of these latest remarks, and **recalling once again the wide discretional potentialities which such a linear programming assessment and financial allocating process could offer to decision-makers and policy-planners**, a further scenario has been now sketched out.
In this case it doesn't show any upper constraints' alteration, but its respective two budget restrictions' blocks were now modified: actually, the economic amount available has been now evenly distributed among all the respective several rows (as depicted by the Annex section - script 4[10-ter]) in order to assess a new possible distributing criterion, still exploiting the same financial resources .

MAXIMIZATION		NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH	ISLANDS
OO		18.392	0	0	1	0
OV		0	4.442	0	3.242	12.031
IN		0	43.645	3	33.238	15.023
ST		5	26.065	65.307	33.238	15.025
CI		0	7.685	38.460	33.238	15.025
GLOBAL RESULTS	ENERG. SAV. ACHIEVABLE [MWH]-LINDO RES	9.510.750				
	CONSEQUENT RENOVATION COSTS [€]	4.607.668.515				

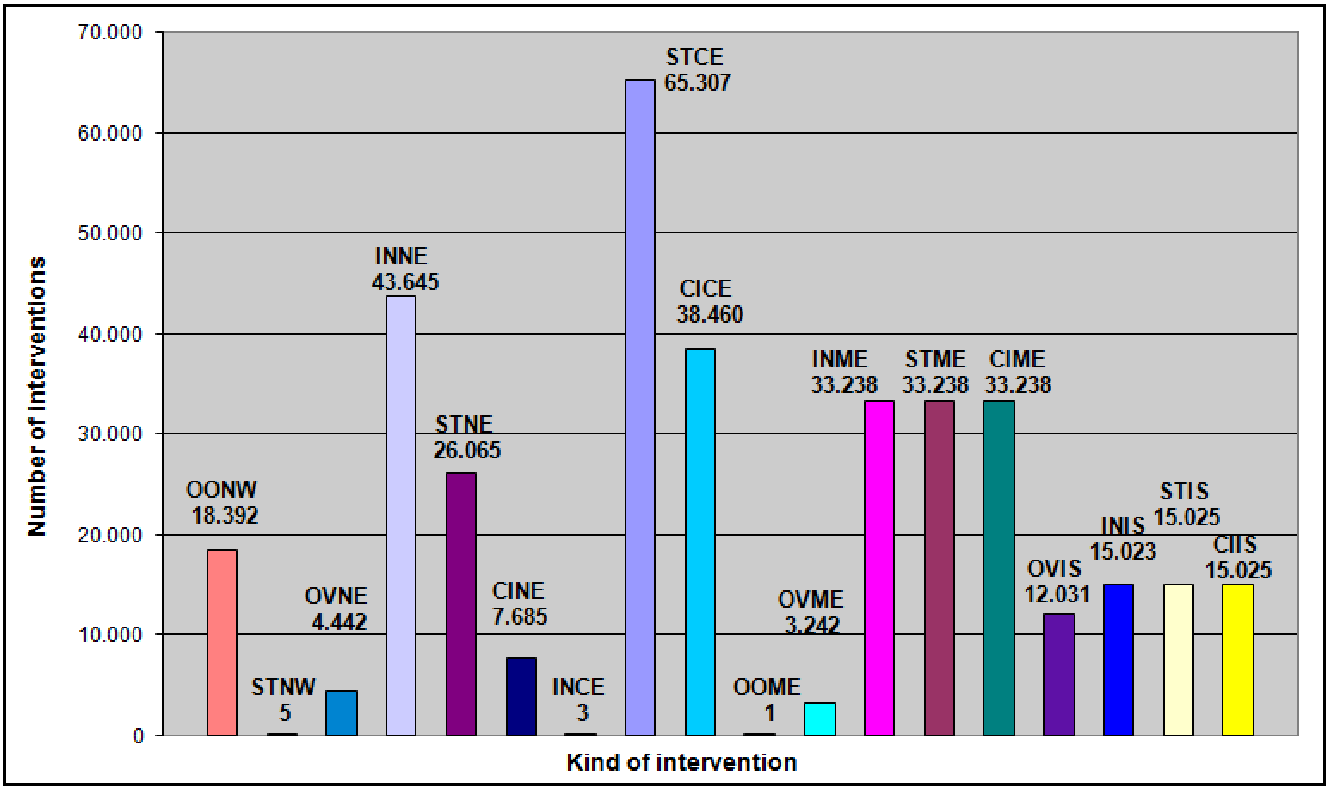


Fig. 5.4[10-ter] ***(Gini Ratio = 0,648)***

This latest scenario has finally led to a further distribution characterized by an overall energy saving level still higher than the one registered by Enea, even though with a lower necessary incentive budget.

An evident difference could instead be detected looking at the *Gini* ratio value (in this case sensibly lower because resting around ***0,648*** < ***0,829***).

5.8 Discussion and conclusion

According to the global "*data-processing-iter*" summed up by the overall procedural flow-chart before introduced (and analogously to what already done while dealing with the previous years), the next step of analysis should be now the definition and the evaluation of the consequent minimization scripts to be launched in function of the latest maximization results.

Notwithstanding, in the light of the above considerations and (once again) remarking the strategic key-role which should be played at this point and at a macro-decisional level by the politician vertices, the current research section has now been bounded by such latest results in order to go through the next research's task.

Indeed, by following the same analysis' criteria until now applied, the several optimization scripts could be indefinitely moulded, balanced and varied also exploiting the respective different testing results (for all the previous Enea reports as well as for the future ones).
But, actually, the main purpose for this step of research was to display and to prove the usefulness and helpfulness of such a linear programming assessment, also showing the simplex algorithm's powerful potentialities, if properly handled and exploited at an energy-strategy level.

Furthermore, also according to the latest guidelines issued by the European Commission in November 2013 with reference to the public subsidies for renewable energies which must be guaranteed (and that actually is another, particularly urgent task), it reveals quite well-fitting for the current assessment too what has been declared by the EU Energy Commissioner **Guenther Oettinger**:

"*The ultimate aim of the market is to deliver secure and affordable energy for our citizens and business. (…) Public intervention must support these objectives: it needs to be cost-efficient and be adapted to changing circumstances*".

And moreover, as highlighted at this reference by the energy consultant **Rod Janssen** in a recent post on his *Energy in Demand-Sustainable Energy* website**, "*State intervention is potentially harmful to the working of the market and the new guidelines are meant to prevent that and show member nations what "best practice" is*".**

Such a latest statement is also globally in line with the main aim of the analysis carried out by the present research: actually, the public and government policies must take into account, on the one hand the different building renovations' cost-effectiveness, but on the other hand they also should consider the consequent effect that the development and the empowering of one technology or retrofit measure instead of another one could have at a macroeconomic level.

Hence, the methodology here developed and applied could reveal particularly useful to fruitfully define **a financial policy and an overall strategy enough flexible and properly balanced**.
Furthermore, such a **decision-making process would be also able to easily adapt its main measures in function of any single technology to be fostered, along with its specific geographical field of interest**.

Overall final results summary

At this reference the following overall summary table, along with the several histograms hereinafter recalled, provides a global and exhaustive framework for all the different scenarios before analyzed.
Furthermore, they also depict a final comparison with the global results year by year registered by *ENEA*.

ASSESSED SCENARIOS	GINI RATIO		€/MWh SAVED COSTS	
YEAR 2007	SIMPLEX ASSESSMENTS	ENEA ASSESSMENT	SIMPLEX - FINAL 7th ASSESSED SCENARIO YEAR 2007	ENEA ASSESSMENT YEAR 2007
FIRST^{07} SCENARIO OUTPUT	1,000	0,621	50,79 €/MWh.	59,08 €/MWh
SECOND^{07} SCENARIO OUTPUT	1,000			
THIRD^{07} SCENARIO OUTPUT	0,890			
FOURTH^{07} SCENARIO OUTPUT	0,817			
FIFTH^{07} SCENARIO OUTPUT	0,804			
SIXTH^{07} SCENARIO OUTPUT	0,858			
SEVENTH^{07} SCENARIO OUTPUT	0,832			
YEAR 2008	SIMPLEX ASSESSMENTS	ENEA ASSESSMENT	SIMPLEX - FINAL 7th ASSESSED SCENARIO YEAR 2008	ENEA ASSESSMENT YEAR 2008
FIRST^{08} SCENARIO OUTPUT	1,000	0,646	41,64 €/MWh	53,48 €/MWh
SECOND^{08} SCENARIO OUTPUT	0,926			
THIRD^{08} SCENARIO OUTPUT	0,809			
FOURTH^{08} SCENARIO OUTPUT	0,829			
FIFTH^{08} SCENARIO OUTPUT	0,827			
SIXTH^{08} SCENARIO OUTPUT	0,829			
SEVENTH^{08} SCENARIO OUTPUT	0,824			
YEAR 2009	SIMPLEX ASSESSMENTS	ENEA ASSESSMENT	SIMPLEX - FINAL 7th ASSESSED SCENARIO YEAR 2009	ENEA ASSESSMENT YEAR 2009
FIRST^{09} SCENARIO OUTPUT	1,000	0,634	48,68 €/MWh	57,86 €/MWh
SECOND^{09} SCENARIO OUTPUT	0,937			
THIRD^{09} SCENARIO OUTPUT	0,841			
FOURTH^{09} SCENARIO OUTPUT	0,790			
FIFTH^{09} SCENARIO OUTPUT	0,784			
SIXTH^{09} SCENARIO OUTPUT	0,811			
SEVENTH^{09} SCENARIO OUTPUT	0,804			

Fig. 5.8 Synoptical Summary Table: Final results – Global comparison

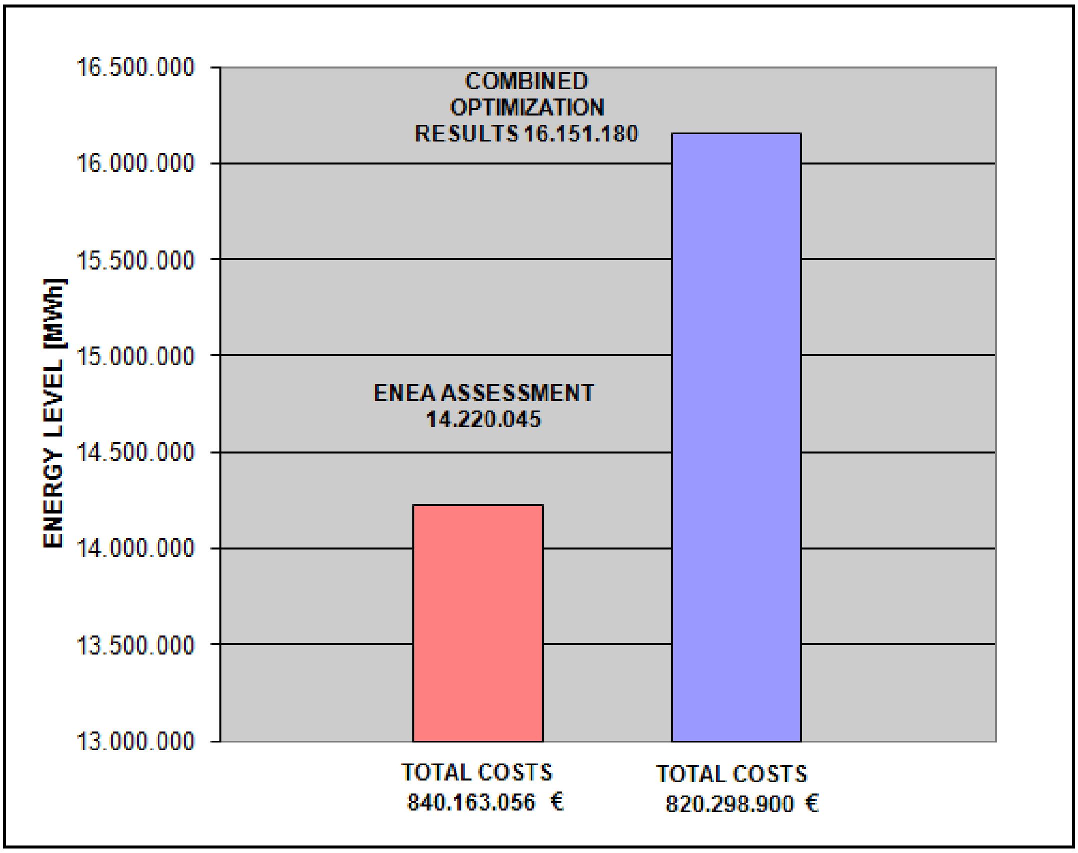


Fig. 5.9[07] GLOBAL COMPARISON TABLE - YEAR 2007

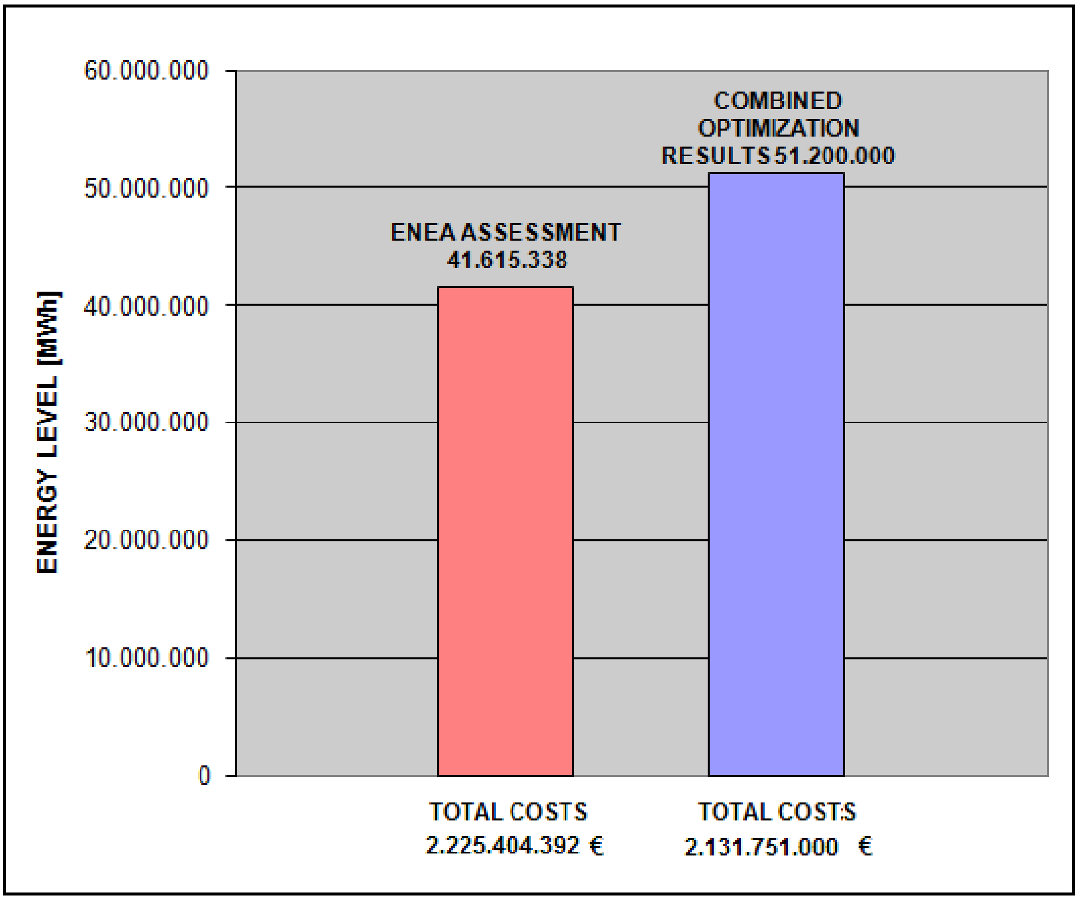


Fig. 5.9[08] GLOBAL COMPARISON TABLE - YEAR 2008

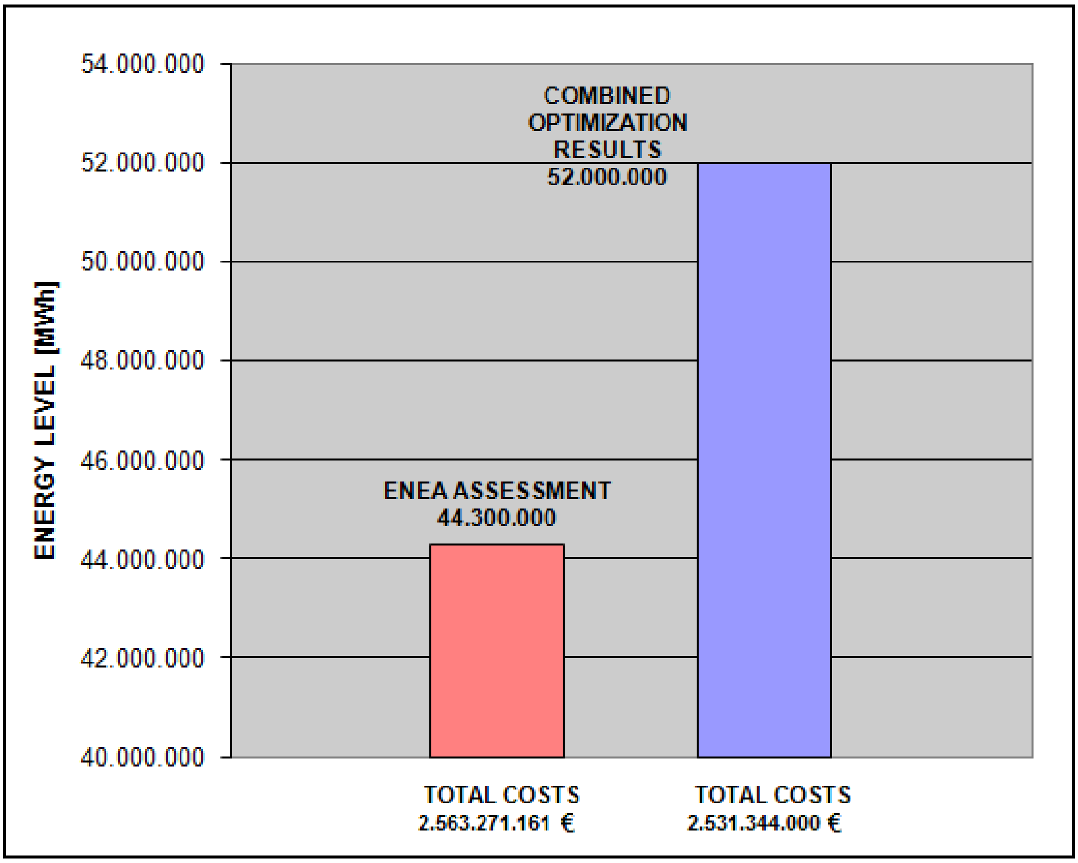


Fig. 5.9[09] GLOBAL COMPARISON TABLE - YEAR 2009

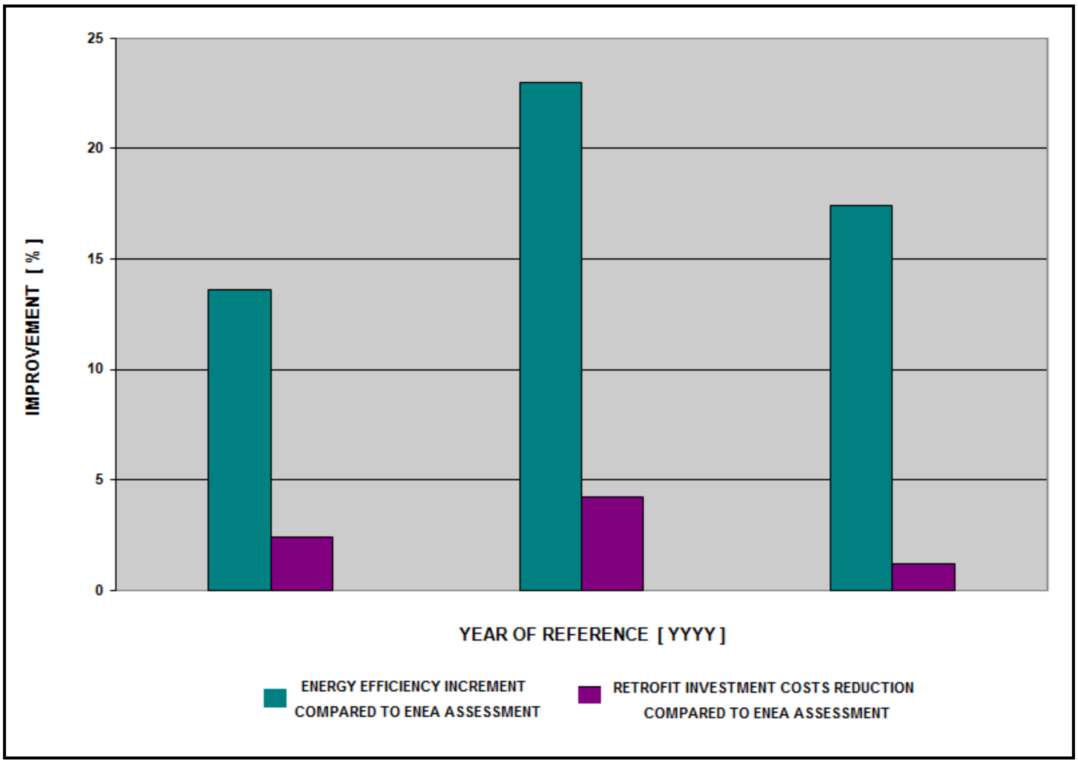


Fig. 5.10 CUMULATED RESULTS (YEAR 2007-2009)

PART IV

6 Shifting from a Top Down approach to a Bottom Up analysis.

After having analyzed into details the most important aspects and powerful potentialities provided by the linear programming tools, also dealing with the energy saving retrofits and policies for the existing building stock, the "macroscopic", Top→Down and statistical approach until now applied has been currently reversed. Actually, still with the purpose of analyzing the same main problem and its respective many facets, the present job's section has now applied a different approach (along with different evaluation's parameters) in order to define a fruitful assessment criterion to be applied for a wider class of case study.

Before going through such a Bottom→Up energy building retrofits' analysis, dealing with its fundamental working hypotheses and respective evaluation criteria clarification, it's important to recall the main topics involved in the current research.

This part of the study was focused on the most representative examples for a single detached house (respectively in Italy and Denmark), also performing the analysis with the main purpose of defining the specific retrofit measures which should be preferable to adopt to achieve acceptable energy consumptions levels.

As it's possible to gather by simply observing the two distinct specific buildings' locations, the dwelling's samples to be analyzed widely differ from each other, along with their respective boundary conditions.

However, as below highlighted, a relevant common aspect may be noticed (at the single nation level) looking at the overall building stock distribution, in Italy as well as in Denmark.

6.1 The Italian building stock: its characterization and typical building features.

As already highlighted by a research-work focused on such an urgent matter (and as observed in the respective article *"Economic efficiency of social housing thermal upgrade in Mediterranean climate",* G. Desogus, L. Di Pilla, S. Mura, G.L. Pisano, R. Ricciu), recent statistical studies have shown that nearly 76% of Italian dwellings are built before 1981, and around 49% are more than 50 years old.

Furthermore, the average annual increase registered for new dwellings during the time-span 1981–2011 was only the 1%.

The existing residential building stock distribution along the entire Europe is approximately the same (as hereinafter confirmed through the comparison with the specific Danish background) and almost its 70% is more than 30 years old, while instead a percentage of 35% is more than 50 years old.

Hence, these data highlight how much the Italian (and the entire European) building stock is aged.

EPOCA DI COSTRUZIONE	Edifici ad uso abitativo
Prima del 1919	2.150.259
Dal 1919 al 1945	1.383.815
Dal 1946 al 1961	1.659.829
Dal 1962 al 1971	1.967.957
Dal 1972 al 1981	1.983.206
Dal 1982 al 1991	1.290.502
Dopo il 1991	791.027
Totale	**11.226.595**

Fig.6.1 Residential buildings' distribution based on their respective year of construction (source ISTAT-XIV Census, Year 2001)

NUMERO DI ABITAZIONI	Edifici ad uso abitativo
0	12.626
1	6.902.088
2	2.280.428
Da 3 a 4	1.031.757
Da 5 a 8	517.100
Da 9 a 15	275.263
16 e più	207.333
Totale	**11.226.595**

Fig. 6.2 Average number of apartments registered for any residential building: single-family-houses' preponderance (source ISTAT-XIV Census, Year 2001)

Moreover, even though the first building legislation on energy performance had been adopted in 1976 and despite an update has been proposed in 1991, energy consumption levels in the residential sector haven't been successfully decreased.
After the regulation EPBD 2002/91 had been adopted (during 2005), a decrease in the growth trend of Energy consumption from 0,8% to 0,4% has been registered.

But it is evident that the low growth of new high performance dwellings is not enough to invert the growing consumption trend; it's instead necessary to adopt effective retrofit solutions for the so much wide existing building stock.

EPOCA DI COSTRUZIONE	Stato di conservazione				
	Ottimo	Buono	Mediocre	Pessimo	Totale
Prima del 1919	321.515	1.008.058	696.571	124.115	2.150.259
Dal 1919 al 1945	179.837	680.810	460.821	62.347	1.383.815
Dal 1946 al 1961	262.252	919.050	440.821	37.706	1.659.829
Dal 1962 al 1971	421.296	1.189.107	339.915	17.639	1.967.957
Dal 1972 al 1981	581.533	1.165.793	225.835	10.045	1.983.206
Dal 1982 al 1991	542.007	653.865	90.195	4.435	1.290.502
Dopo il 1991	566.397	199.656	23.320	1.654	791.027
Totale	**2.874.837**	**5.816.339**	**2.277.478**	**257.941**	**11.226.595**

Fig. 6.3 Synoptic table: residential buildings' distribution based on the respective years of construction and the different status of preservation (source ISTAT-XIV Census, Year 2001)

INVESTIMENTI IN COSTRUZIONI(*)

	2012(°) Milioni di euro	2008	2009	2010 (°)	2011 (°)	2012 (°)	2013(°)	2008-2012(°)	2008-2013(°)
		Variazioni % in quantità							
COSTRUZIONI	**130.679**	**-2,4%**	**-8,6%**	**-6,6%**	**-5,3%**	**-7,6%**	**-3,8%**	**-27,1%**	**-29,9%**
.abitazioni	69.577	-0,4%	-8,1%	-5,1%	-2,9%	-6,3%	-2,7%	-21,0%	-23,1%
- nuove (°)	*24.757*	*-3,7%*	*-18,7%*	*-12,4%*	*-7,5%*	*-17,0%*	*-13,0%*	*-47,3%*	*-54,2%*
- manutenzione straordinaria(°)	*44.820*	*3,5%*	*3,1%*	*1,1%*	*0,5%*	*0,8%*	*3,0%*	*9,3%*	*12,6%*
.non residenziali	61.102	-4,4%	-9,1%	-8,1%	-7,9%	-9,1%	-5,1%	-33,2%	-36,6%
- private (°)	*36.281*	*-2,2%*	*-10,7%*	*-5,4%*	*-6,0%*	*-8,0%*	*-4,2%*	*-28,6%*	*-31,6%*
- pubbliche (°)	*24.821*	*-7,2%*	*-7,0%*	*-11,5%*	*-10,5%*	*-10,6%*	*-6,5%*	*-38,9%*	*-42,9%*

(*) Investimenti in costruzioni al netto dei costi per trasferimento di proprietà

(°) Stime Ance

Elaborazione Ance su dati Istat

Fig. 6.4 Synoptic table: Italian buildings' investment overview for both the residential and for the non-residential field (source *ANCE - Associazione Nazionale Costruttori Edili: "Osservatorio congiunturale sull'industria delle costruzioni",* December 2012)

However, as other authors have already pointed out, there are many obstacles to the diffusion of good practices. And one of the main issues is related to the cost-effectiveness of home energy retrofits; in particular, the literature review highlighted some of the following most critical aspects:

- *National legislation can be too strict and prescribe energy efficiency requirements that make retrofits cost-ineffective for homeowners.*

- *Uncertainties concerning the future price of energy make the economic feasibility analysis of works quite difficult.*

- *Public subsidies are necessary to reduce payback time and increase economic benefits for investors.*

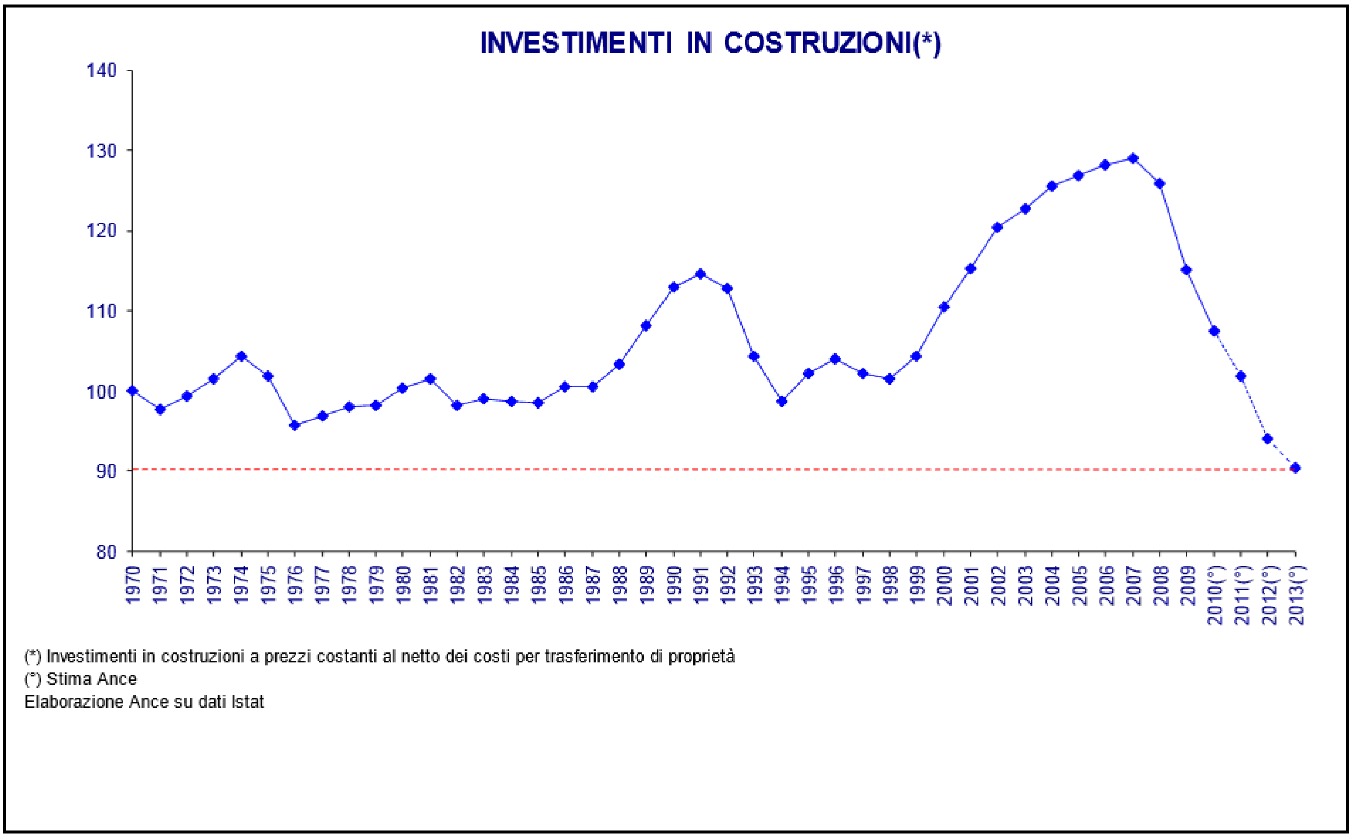


Fig. 6.5 Italian global investment trend registered for buildings and for the construction's field during the time span 1970-2012 (source *ANCE - Associazione Nazionale Costruttori Edili: "Osservatorio congiunturale sull'industria delle costruzioni",* December 2012)

6.2 The Danish building stock: its characterization and typical building features.

Quoting a recent report focused on the main Nordic Countries and their overall building characterization (Ibenholt, Liljefors - *Energy Efficiency in the Nordic Building sector – Potentials and Instruments*), it's possible to highlight that in Denmark, likewise in the majority of countries, the building stock is primarily composed of residential dwellings, accounting for approximately the 60% of the total stock (ref. *Statistics Denmark*), while instead the industrial and commercial buildings define the largest subgroup (i.e. the 28% of the total buildings).
Moreover, around the 43% of all the Danish dwellings consists in **detached houses**, with the 41% made up of multi-dwelling units.
In addition, still according to the source *Statistics Denmark*, it's possible to specify that the average number of occupants per each residential dwelling has markedly decreased from 3,01 people in 1960 to 2,15 occupants in 2007.

Furthermore, as recently highlighted by several studies and reports focused on such an issue, there is a large potential for energy savings in the Danish building stock: actually, approximately the 75% of the entire building asset has been erected before 1979 (ref. Dyrbøl, Tommerup & Svendsen). Year 1979 may be indeed considered as a fundamental watershed in the construction process, since the first essential tightening of demands for energy performance of buildings has been introduced starting from such a date.
Normally, Denmark is considered having a relatively high insulation standard (particularly if compared with the average Italian buildings' features), but it must be once again recalled that this is also true as regards new constructions.

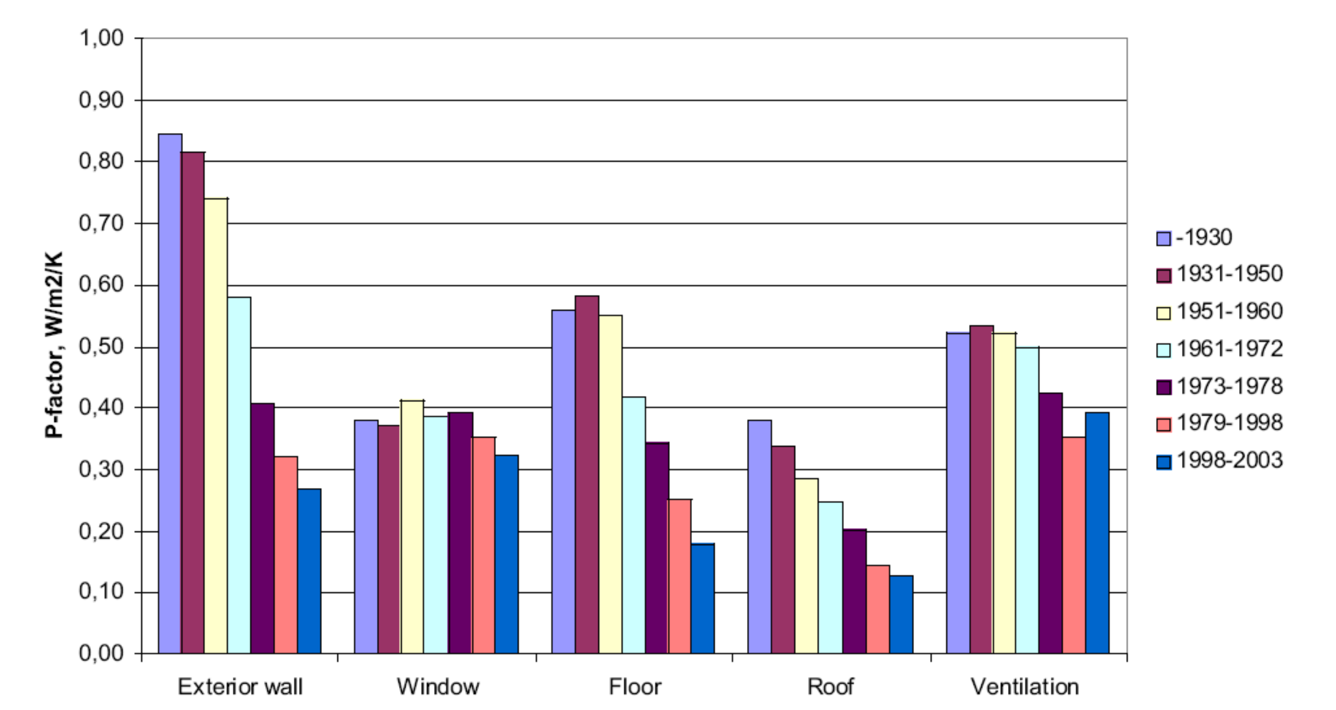


Fig. 6.6 Average heat loss in the Danish residential building stock dependent on year of construction, normalized by heated floor area. Data from the energy certification scheme 1998-2003 (quoting K.B. Wittchen, 2004: *assessment of potential for heat savings in the existing residential buildings - By og Byg Dokumentation 057 - Danish Building and Urban Research* and Dyrbøl, Tommerup & Svendsen: *savings potential in existing Danish building stock and new constructions*)

Furthermore it must be also highlighted that, looking at the remaining 25% building stock's percentage, its average energy performances may be globally considered about 25-50% below the fundamental energy requirements established by the most recent and stringent energy regulations: hence a huge energy savings' potential may be recognized for Denmark too.

In addition to the above remarks, it has to be noticed that, according to recent surveys and assessments, a lot of those single-family houses built in Denmark during the 1960s are currently facing a renovation: actually, either façades or roofs are going to be changed, even though this happens "*not because of a poor energy performance, (...) but mainly due to a wish for a more modern design or due to general demolition*" (Dyrbøl, Tommerup & Svendsen).

However, also for the above reason, "*it is very important to document and ensure that correct architectural renovation also includes energy renovation: an upgrading of the energy performance of a construction should be done simultaneously with the general renovation, as a subsequent upgrading will be expensive*".

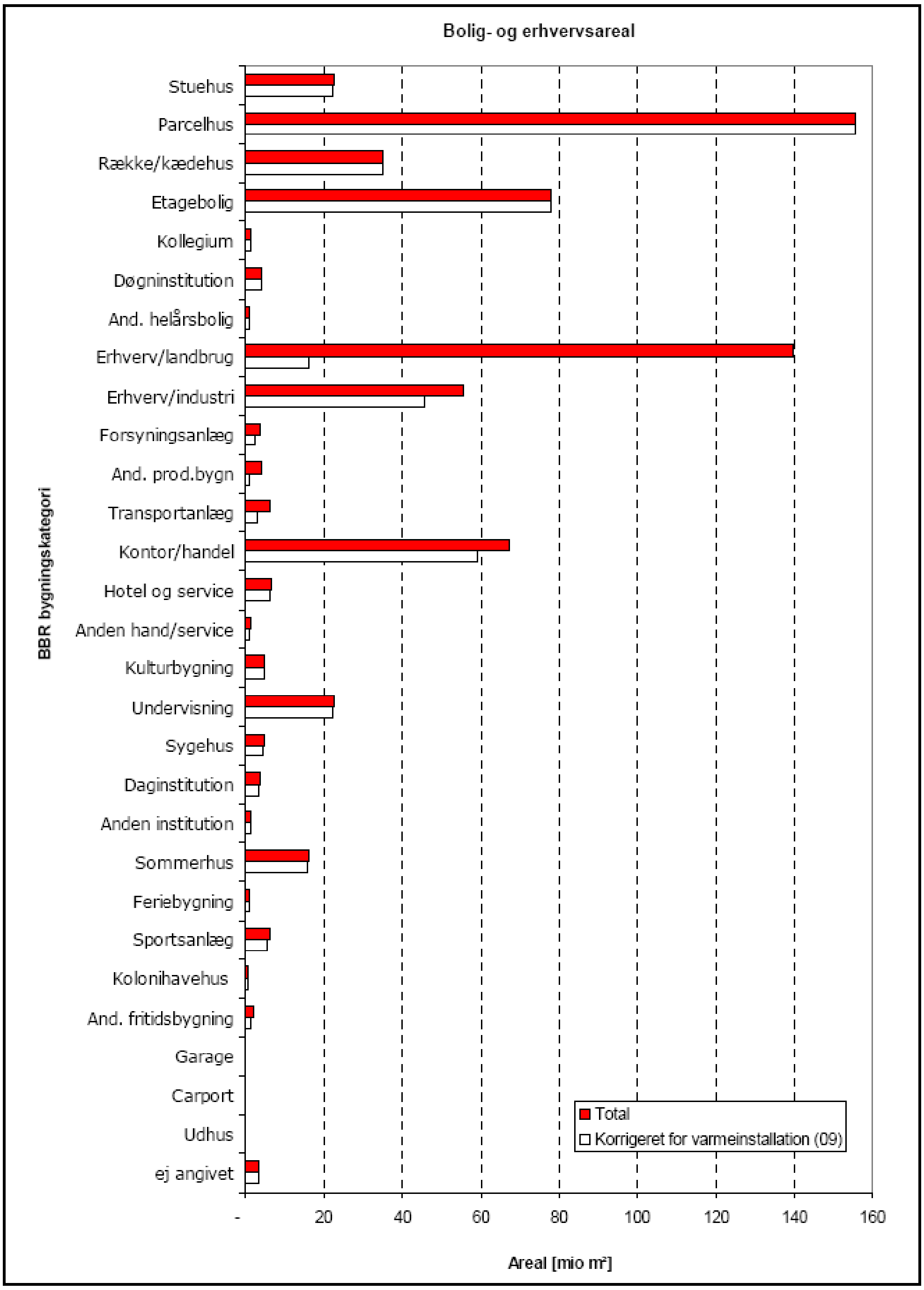


Fig. 6.7 Residential and commercial dwellings' distribution in Denmark and respective average building area (where "*parcelhuse*" indicates a single-family house). Ref. J. Kragh, K.B. Wittchen: *Danske bygningers energibehov I 2050, SBI 2010:56, Statens Byggeforskningsinstitut, Aalborg Universitet, 2010)*

Also a recent assessment performed by the Danish Building Research Institute (and reported by O.M. Jensen in the paper entitled "*Barriers for realizing energy savings within buildings*") has highlighted that such energy performances' upgrading processes are only principally carried out to a very small extent of existing buildings in connection with a major renovation.

Actually, some of the most relevant barriers for such a renovation and energy retrofitting process seem to be that people aren't aware and/or aren't interested into knowing how much energy they are using

(and, in any case, when they know their energy consumption, they cannot appraise if such a level is small or large).
Furthermore, a sensibly high inertia phenomenon is detectable for those investments which are not directly related to visible building improvements: and *"this means that changing the behaviour of building owners needs to be done by legislation and by effective control, as normal market forces do not exist within this area (...)".*
In the light of the above remarks, and despite the already highlighted so different climatic and geographical backgrounds, several common aspects may be therefore recognized into globally considering the Italian and the Danish overall building context to deal with.

6.3 Description of the method used: acting deep on the path towards *Cost-Optimality* levels – A *holistic approach*'s adoption

As recently highlighted by the several reports and documents recently issued about this task, and particularly by ***BPIE (The European Buildings Performance Institute*)**, by ***GBPN (Global Buildings Performance Network*)**, as well as by the ***European Council for an Energy Efficient Economy (ECEE)*,** the existing building stock offers significant opportunities for improving global energy performance levels. Actually, such an objective can be plentifully tapped through opportune and fruitful renovation processes.
Recalling that renovations are for the majority undertaken when a building needs to be maintained, improved or when a heating or ventilation system needs to be replaced, all these actions provide for enhanced energy saving opportunities and potentialities.
Deep savings potential may indeed be achieved by improving the building envelope and the systems which supply the building with heating, cooling, ventilation, hot water, lighting or other services. In the light of the previous experiences it's possible to assess that, usually, a standard renovation or a normal refurbishment is able to achieve savings of between 20% and 30%, and sometimes even less.
But much more is possible: actually, looking at the "state of the art" for most of those energy renovations that target a building by mean of a holistic manner, it's possible to assess that they can often reduce energy consumption by 75% or even as much as 90%.
Herein maybe recognized the classic principal "*agent/tenant barrier*": actually, the initial costs of these projects may be higher for the owner, but will yield savings over the building's life cycle, which can pay for the additional costs.
Therefore, such projects are able to save 3-5 times much energy than that of a standard renovation project; furthermore, these savings can also bring additional benefits to the user including higher occupant comfort levels and a better health. And, last but not least, they can also involve social and economic benefits.
As also highlighted by a recent study carried out by the ***Center for Climate Change and Energy Policy of CEU (The Central European University)*** entitled *"Best Practice Policies for Low Carbon & Energy Buildings"*, the current rate of renovations in developed countries is too low for the "*deep*" scenarios which should be preferably realized. In particular, it's possible to assess that a more aggressive energy-efficient renovation rate of 2,5% to 3% per year is needed.
At this regard, it must be highlighted that: "*Going 'deep' is both possible and feasible, but we need a radical shift in the way we think about buildings*".
Hence, being also aware that such a large energy saving potential in buildings is already possible to be performed through the main technologies and techniques nowadays available, it's necessary to recall that the current best practices need to be rapidly scaled up in all the climates and regions.

In the light of the above remarks and adopting such a new perspective, it must be highlighted that most of the existing building stock in Europe was built when the energy was cheap and abundant: hence, little or no attention was paid to energy efficiency and/or to the overall building energy performance.

And even today a lot of dwellings are designed and built based on principles where individual elements are assessed and optimized separately, without an integrated perspective on the overall performance. National or local requirements for buildings are often based on prescriptive codes where minimum performance standards are set for the individual components, such as windows, walls, roofs, floors or technical systems. This inevitably leads to the "sub optimization" of the building, as well as to a lost performance's enhancement potential.

Notwithstanding, when dealing with the existing building stock providing for its most suitable renovation, it's also possible to adopt a systematic approach into carrying out a holistic, integrated or a deep retrofit process.

Furthermore, also reducing energy consumption and offsetting investments by renewing technical systems can become a driver for more and better improvements of the building itself. They yield savings in technical systems and over the lifetime of the building and this can be therefore used to pay for additional investment costs in improving the building itself.

On the other hand, it has to be observed that applying integrated design principles to the renovation of existing buildings may be more challenging due to the fixed nature of some building characteristics (e.g., orientation) and can make it more difficult to increase the use of passive energy or other techniques. As with new building construction, a deep renovation requires more comprehensive planning and a closer collaboration among all the actors involved.

However, regardless of such limitations, the above fundamental systematic principles can still be applied and the integrated design in existing buildings is a fertile field with a lot of challenges. Furthermore, it also offers the opportunity for fruitfully exploiting the good practice examples already carried out, learning from their respective experiences and final progresses.

Beside the above remarks and in order to achieve these final goals, the adoption of an overall and globally integrated retrofit process could be therefore particularly useful: on the one hand by exploiting the main lessons learned by the European Commission's Guidelines into addressing such a renovation task until reaching cost-optimal levels for building retrofit; and on the other hand through the implementation of the additional aid and support provided by *ad hoc* software and programming tools (as hereinafter depicted).

The cost-optimal methodology's implementation:

As previously mentioned, the recast Energy Performance of Buildings Directive (EPBD, 2010/31/EU) requires Member States to implement a cost-optimal methodology to benchmark minimum requirements for the energy performance of buildings, as well as building elements.

Nevertheless, making the calculations for the cost-optimal analysis is a big challenge.

Recalling that, across the entire Europe, buildings are responsible for the largest share of energy consumption and associated greenhouse gas emissions, they actually play an undoubtable key role into reaching those long term climate and energy targets established by EU.

Such a sector has in fact a significant cost-effective energy and CO_2 emissions saving potential which should be properly addressed by far-sighted policies, in order to mobilize the market towards a low carbon society, also trigging multiple benefits.

To sum up, the building field (and in particular the existing building stock) reveals itself a crucial matter also in order to reach the independence by energy imports from politically unstable areas, also creating new job's opportunities, improving air quality and indoor comfort and globally revitalizing the entire investment sector.

In the light of the above remarks, while planning any building retrofit strategy, it should be necessary, on the one hand to consider such additional benefits, and on the other hand also involve in the global assessment the specific lifetime costs of buildings (rather than just focusing on the respective investment costs). At this regard, over the last decade, European building policies have widened their scope and

coverage and are also moving towards an integrated approach, taking into account not only the energy itself, but also the environmental, the financial and the main comfort-related aspects (source *BPIE*).
Furthermore, the EPBD recast stands as an important milestone for building policies, calling all the European Member States for:

- introducing minimum energy performance requirements for buildings, building elements and technical building systems;
- setting such above requirements based on a ***Cost-Optimal Methodology***, also taking into account the lifetime costs of the building;
- building only *nearly Zero-Energy Buildings* from 2020 onwards.

In particular, the *Cost-Optimal Methodology* introduces (for the first time) the prerequisite of considering the global lifetime costs of buildings for shaping their future energy performance requirements. Thus, the evaluation of buildings' requirements won't be anymore related only to the investment costs, but will additionally take into account also the operational, maintenance, disposal and energy saving costs of buildings.
At this reference, the Commission ***Cost-Optimality Delegated Regulation*** (*EU- N° 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*) establishes a comparative framework methodology to determine a cost-optimal level of minimum energy performance of buildings and building elements.

Moreover, a further guidance document about how to implement the methodology at a national level has been published by the EU Commission in April 2012, even though such regulations and guidelines provide to Member States a quite large degree of flexibility when selecting the input data and the main reference's parameters to be considered for the calculation.

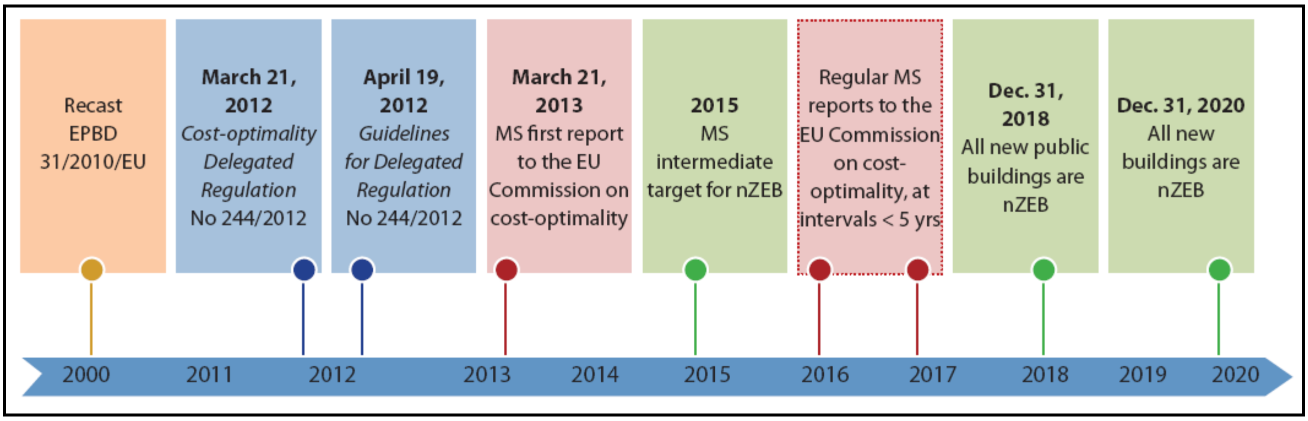


Fig.6.8 Implementation timeline for the *Cost-Optimality* and the *Nearly Zero Energy Buildings* requirements established by EPBD (source BPIE–*"Implementing the cost-optimal methodology in EU countries"*). A proposal for the framework was adopted by the European Commission on 16th January 2012; the Council voted on 1st March 2012 and thence the framework was announced, becoming legally binding from the 21st March 2012. According to such rules, Member States must report their level of energy requirements to the Commission at regular intervals of maximum five years, with the first report due by the 21st March 2013 (i.e. one year after the announcement).

Recalling what has been declared by the ***EPBD recast*** at **Art. 4.1**, "*Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels*".

Furthermore, they must also "*take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels*".

In particular, the ***Cost-Optimal Level*** is defined as "*the energy performance level which leads to the lowest cost during the estimated economic lifecycle*". Member States must determine this level by taking into account a wide range of costs, also including investments, maintenance, operating costs and energy savings.
Furthermore, the EPBD requires them to report on the **comparison** between their minimum energy performance requirements and the calculated cost-optimal levels using the **comparative methodology framework** provided by the Commission; specifically, such a methodology requires to follow the main steps hereinafter referred:

- to define those **reference buildings** which are characterized by and representative of their functionality and climate conditions. In particular, the reference buildings must cover residential and non-residential dwellings (both new and existing ones);
- to define those **main energy efficiency measures** which were assessed for the reference buildings. Such measures may be applied for buildings as a whole, for building elements or for a combination of several building elements;
- to assess the **final and primary energy need** for the reference buildings by calculating the specific impact of different packages of measures;
- to calculate the **costs** (i.e. the **NPV** - Net Present Value) for the different energy efficiency measures during the expected economic life cycle applied to the reference buildings, also taking into account investment costs, maintenance and operating costs, as well as the possible earnings from produced energy.

Moreover, Member States are required to report to the European Commission all the main input data implemented and the principal assumptions adopted into carrying out such calculations (along with the respective final results obtained) from two different perspectives:
the ***Macroeconomic Level*** (*Societal Level*) or the ***Financial Level*** *(Private Investor)*. Actually, they can choose which one applying at their national level.

At this regard it must be highlighted that, in case such a cost-optimal comparative analysis shows the specific requirements in force at a national level are much less ambitious than the cost-optimal level (i.e. if the energy requirements in force are more than 15% above the cost-optimal level), the single Member State has to justify this gap to the Commission.
Indeed, if such a gap cannot be justified, an opportune plan should be developed in order to outline appropriate and fruitful steps on how to significantly reduce the gap: and in that case the Commission will publish a report on the progresses achieved by the specific Member State.

***Cost-Optimality* vs. *Cost-Effectiveness* concept:**

It's possible to declare that such relevant concepts are strictly related, even though they are still different: actually, the latter consists in a special case of the first one.
However, both of them are based onto comparing the costs and (priced) savings for a potential action: in particular, in this case, they are directly connected to the introduction of a particular level of minimum energy performance requirements for buildings.

In general, it's possible to observe that a measure (or a package of specific measures) is **cost-effective** when the respective implementation costs are lower than the value of the consequent benefits over the expected lifetime of that measure.
In particular, both the future costs and savings have to be discounted, with the final result being a ***"Net Present Value"***: and if such a value is positive (i.e. NPV>0), the specific action may be considered as "cost-effective" (with reference to the particular set of assumptions implemented in the calculation). Hence, the single action or those combinations of actions which are able to maximize the Net Present Value consist in the "cost-optimal" actions.

However it must be noticed that, if on the one hand the cost-optimality level is relatively easy to be evaluated for single measures operating in well-defined conditions, on the other hand the entire assessment process is significantly more difficult in case of complete buildings, and even more complex for combinations of dwellings (such as a national building stock).

It may be therefore clearly appreciated the importance and the key role played, into such a tricky procedure, by specific calculation engines and *ad hoc* programming tools which are able to correctly and accurately operate with a complex and huge amount of data and information.
And actually, the specific one implemented in the present research-work (i.e. the ***BEopt*** software) consists in one of them.

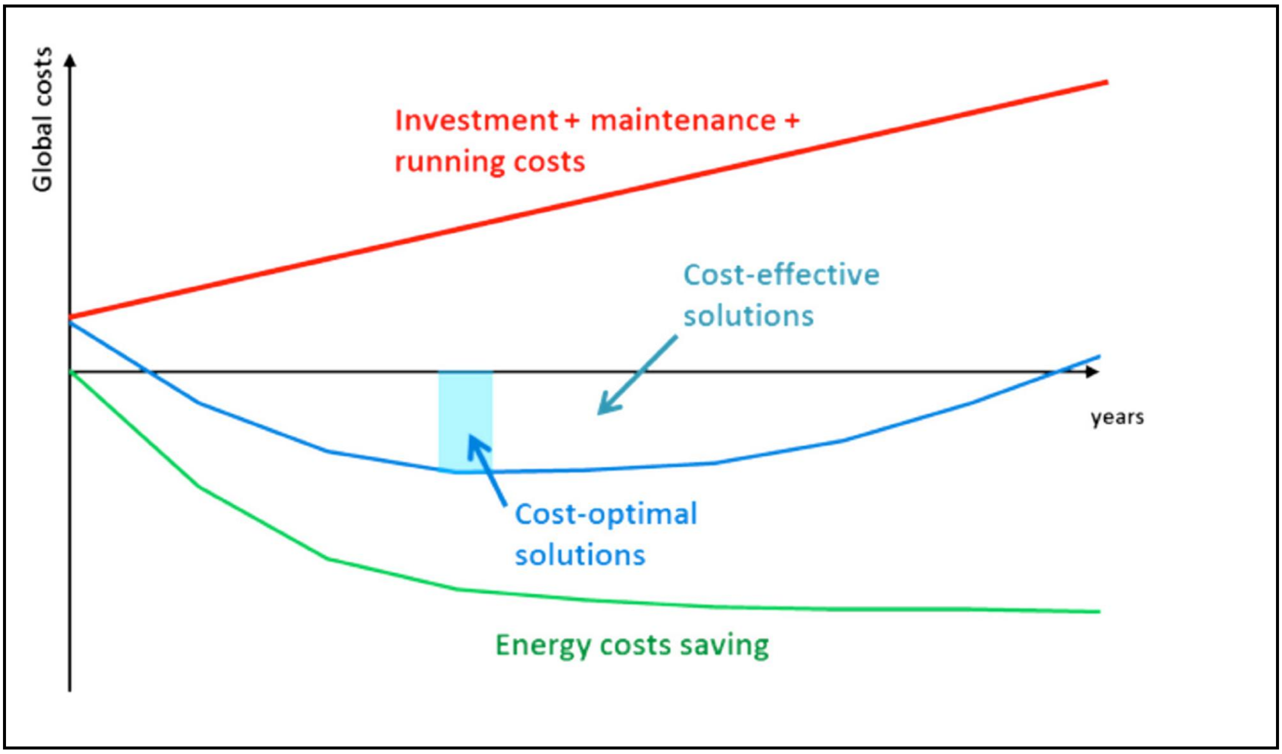


Fig. 6.9 Relationship between cost-optimality and cost-effectiveness (source BPIE, *"Implementing the cost-optimal methodology in EU countries"*)

Reference buildings	• Have to **be representative of the existing building stock** and **new buildings** in each country; • With **simple geometries;** • **Reproducible** in practice;
Selection of packages of measures	• Number of calculated packages have to be **at least 10** in addition to the reference case, which reflects actual regulations; • Should be **based on existing or planned national standards** or/and on widely accepted ones; • **Very ambitious packages** of measures should also be considered to provide an estimation of the financial and environmental implications of upcoming **nZEB** requirements;
Methodology and framework conditions	• Calculation based on **primary energy;** • Including energy use for: heating, cooling, ventilation, domestic hot water, auxiliary services of the building and non-residential building lighting; • Harmonized with the **European Standards;** • Comparison of packages of measures with all building requirements in place in the country; • **Accurate conversion factors** and periodically updated;
Costs of materials, work and equipment	• **Lack of accurate information** of the costs in Member States; • Scarce and not consistently collected data; • **Databases** should be developed and **open to periodical scrutiny** of main stakeholders;
Discount rates and energy prices development	• Discount rates have to reflect the actual costs of capital for long-term mortgages or the expected minimum return on investment in case of self-financing; • In the case of buildings, **the discount rate should be even lower than long-term mortgages** in order **to reflect the profitability of the investment** in energy savings measures at the time of the imminent construction or renovation of building; • The energy prices development as well the relation with discount rate influence the global costs calculation and may slightly shift the cost-optimal point;
Cost-optimality, nearly Zero-Energy Buildings and long-term climate goals	• Cost-optimality: a useful tool to estimate the **financial, energy and environmental gaps** between cost-optimal and nZEB levels • And for taking appropriate and implementing policies to bridge the gap.

Fig. 6.10 A short summary of the main recommendations and findings for the cost-optimality methodology's application (source BPIE,*"Implementing the cost-optimal methodology in EU countries"*)

6.4 Building design optimization tools and *BEopt* optimization software.

As depicted by a rich and accurate literature review about such a topic, the Building Performance Optimization (*BPO*) tools and optimization algorithms coupled to building simulation engines represent a wide field and an interesting area of active research and investigation.
In particular, the automated building performance optimization is a complex process which aims at the selection of the optimal solutions from a set of possible and available alternatives for a given design or control problem (also according to a set of performance requirements and settled criteria).

Moreover, the automated optimization has become increasingly popular for a wide-ranging variety of application domains, as also depicts a book entirely devoted to this topic (*Applications of Multi-Objective Evolutionary Algorithms*, A. Carlos, et al., World Scientific, Singapore, 2004).
In particular, starting from the late 1980s, a large group of engineers, mathematics and scientific groups have tackled the application of automated optimization in the field of Architectural, Engineering and Construction (*AEC*) industry, aiming to optimize building design and operation.
In this respect, currently there's a growing research trend for automated optimization approaches which could be fruitfully used and applied to map out and find pathways to building designs with desirable qualities, structure, comfort, energy conservation or economic features, rather than focusing onto just one particular outcome.

Furthermore, as before seen while dealing with the Simplex algorithm, the use of optimization as a means of providing input to energy policies and incentive measures could be one of its most important applications during these latest years.
For example, among all the several multi-core processors and optimization tools until now performed and currently available, the adoption and the properly exploitation of the main features offered by a particular building energy optimization model (i.e. ***BEopt***) could be particularly useful to evaluate the energy and the cost saving potential from constructing more efficient new homes (and/or retrofitting the existing ones).
Actually, this specific and powerful resource would also reveal particularly strategic to fulfill the call of the European Commission for implementing a valid methodology able to calculate cost-optimal levels in the EPBD framework.
Indeed, as already observed, European Member States are required to define cost-optimal levels of minimum energy performance according to their specificities and distinctive features.

The ***BEopt™*** software has been developed by ***NREL*** (the ***U.S. National Renewable Energy Laboratory***) and is mainly designed to find out optimal building configurations along the path to *ZNE - Zero Net Energy*. However, its powerful tools and capabilities may also be fruitfully exploited into assessing and evaluating different retrofit designs, along with their respective "depth's degrees" (as carried out through the present work).

Furthermore, such a computer program is able to accelerate the process of developing high-performance building designs, as well as cost-optimal existing buildings' retrofit solutions.

According to its main utilities, the user is called to select, from predefined options for various categories, the specific choices to be considered in the optimization; but is also allowed to create new customized options (as hereinafter carried out) in function of the specific needs and requirements.

Energy savings are calculated relatively to a reference: this can be either a user-defined base-case building (as performed within the current research), or a climate-specific *Building America Benchmark* dwelling (automatically generated by *BEopt* software).

The user can also review and modify detailed information about all the available options in a linked options library spreadsheet (as hereinafter detailed).

In principle the former simulation engines implemented by the ***BEopt*** software had been ***DOE2*** and ***TRNSYS***, while ***TMY2*** ("*Typical Meteorological Year 2*") weather data, derived from the 1961-1990 *National Solar Radiation Data Base* (***NSRDB***), had been used for all the simulations.
The following scheme sums up such an operating procedure:

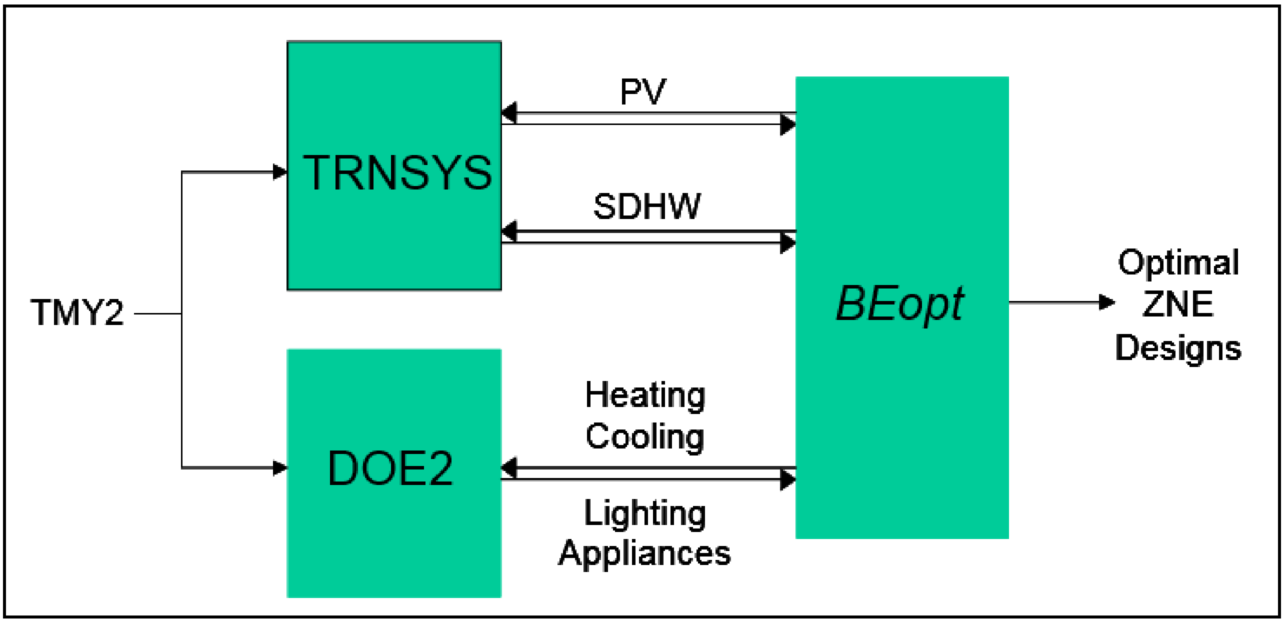


Fig. 6.11 Optimization process implementing multiple simulation programs (source *NREL, National Renewable Energy Laboratory*)

While instead the ***BEopt*** software version here adopted to develop the present job and to perform its respective assessments consists in one of its most recent releases: i.e. ***BeoptE+ 1.4***.
In particular, this specific building energy simulation software recalls and implements the dynamic ***EnergyPlus*** simulation engine and applies its respective ***EPW*** ("*Energy Plus Weather Data*") in order to run all the several simulations required.

More precisely, the *EnergyPlus* program (introduced in 2001) consists in a collection of many program modules that work together to calculate the energy required for heating and cooling a building, implementing a large variety of systems and energy sources.
This robust simulation tool is able to achieve such results by simulating the building and its associated energy systems when they are exposed to different environmental and operating conditions.

The core of the simulation is a model of the building that is based on fundamental heat balance principles.
Actually, after having defined the main characteristics for any building, *EnergyPlus* models and evaluates heating, cooling, lighting, ventilating and water usage - as well as carbon emissions - and is able to carry out an integrated evaluation of the building's energy flows.

Furthermore, the program also includes many innovative simulation capabilities, such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation and photovoltaic systems.

Its different modules and modeling units may be schematically depicted and summed up as follows.

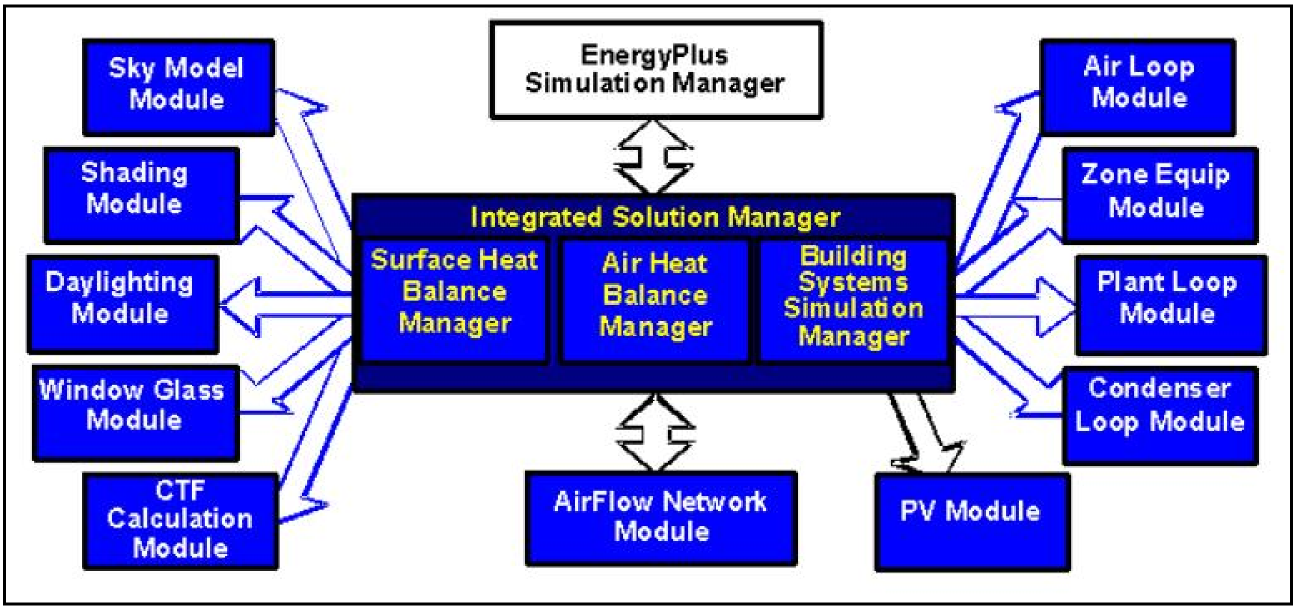


Fig. 6.12 ***EnergyPlus*** **program's working-scheme**
(ref. ***EnergyPlus, Engineering Reference, the reference to EnergyPlus calculations, 2013*****)**

It must be however noticed that *EnergyPlus* is a stand-alone simulation program without a "user friendly" graphical interface; the program reads input and writes output as text files (with and *".idf"* extension). Hence, in this regard, the *BEopt* software here implemented is able to provide a useful and handy interface, also easy to be applied and directly used for customizing and exploiting all the several capabilities offered by such a program.

Nevertheless, as depicted by a wealth of literature on the main *EnergyPlus* applications and as shown by a huge and a wide corpus of references, several other studies and analyses have already implemented and exploited its powerful capabilities (see, for instance, what performed by *P.C. Tabares-Velasco, C.Christensen, M.Bianchi* in *Verification and validation of EnergyPlus phase change material model for opaque wall assemblies*, or the study carried out by *Ellis, P.G., P.A. Torcellini* in *Simulating Tall Buildings Using EnergyPlus* etc..)

Coming back to the specific process applied by BEopt into implementing the main *EnergyPlus* modeling and analysis capabilities, it's possible to report as follows its global running process and the different, specific calculations here developed.

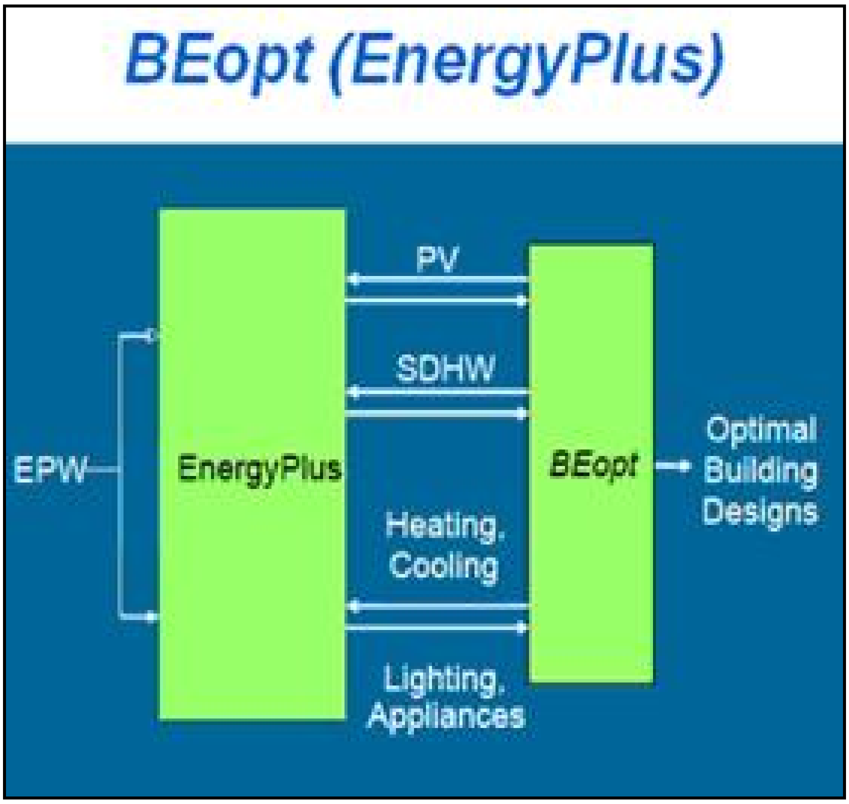


Fig. 6.13 *BEopt* latest optimization scheme and respective simulation engine (source *NREL– National Renewable Energy Laboratory*)

Beside the **optimization searching** capabilities above highlighted, *BEopt* also includes a main **input screen** which allows the user to select, from many predefined (or new customized) options, those ones to be applied in the optimization.

Furthermore, there's also an **output screen** that allows the user to display detailed results for many optimal and near-optimal building designs, as well as an **options library spreadsheet** which allows reviewing and modifying detailed information on all the available options.
Such interface components (input, library, and output) are going to be shown hereinafter.

As previously observed the software is able to find out optimal and near-optimal designs, based on discrete building options which reflect realistic construction properties, and also handles special situations with positive or negative interactions among options in different categories.
It includes a results browser that allows the user to navigate through different design points and retrieve detailed results regarding energy end-use and option costs in different categories.

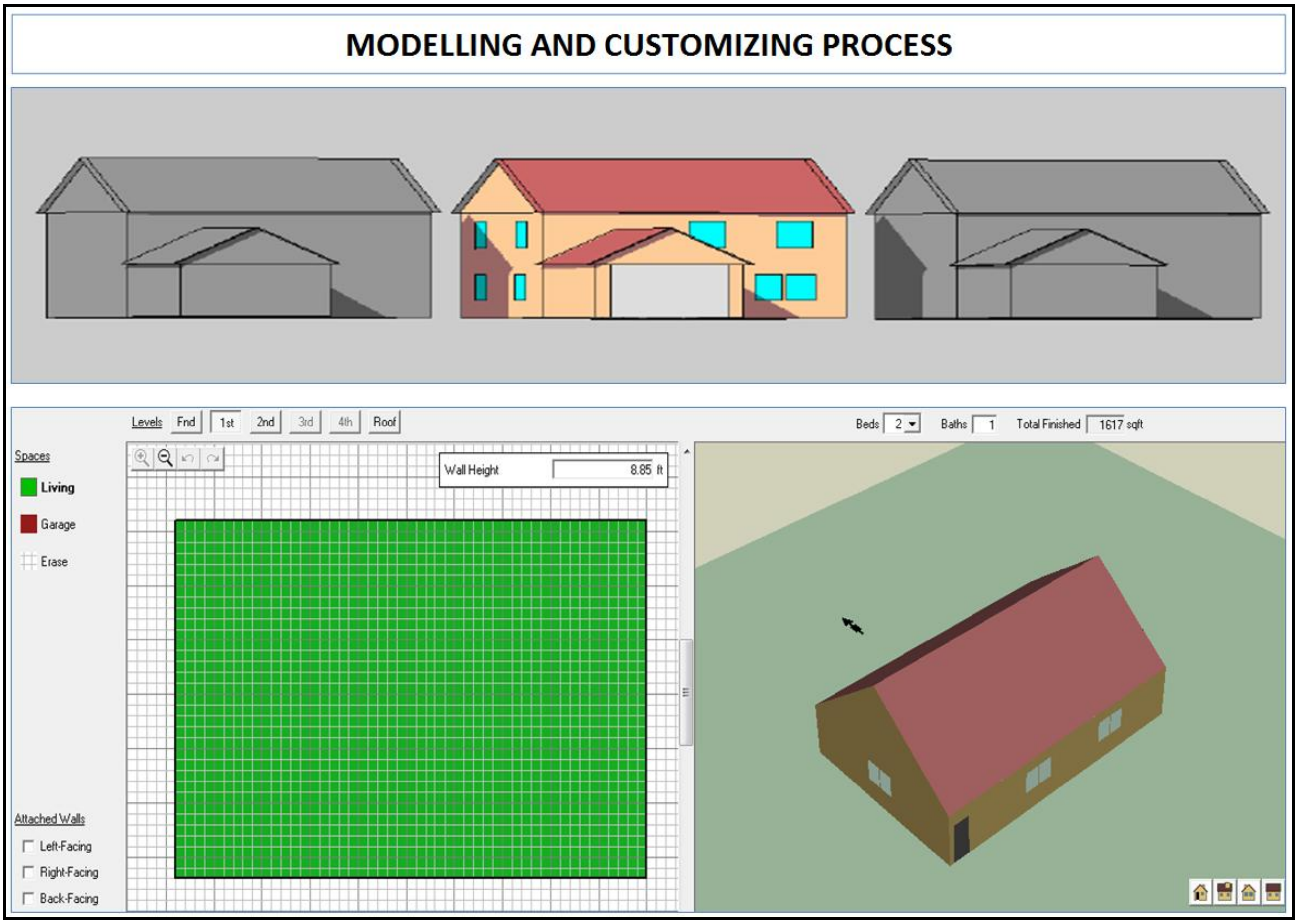


Fig. 6.14 Input Screen: Specific study cases's definition
Building Geometry – Single detached House

In addition, multiple cases - based on a selected parameter such as **climate conditions** - can be included in a *BEopt* project file for comparative purposes: in particular, as carried out in the present research, specific *EnergyPlus* Weather Data files (representative for the different scenarios to be assessed, i.e. Italy and Denmark) have been uploaded and selected in the BEopt default database.

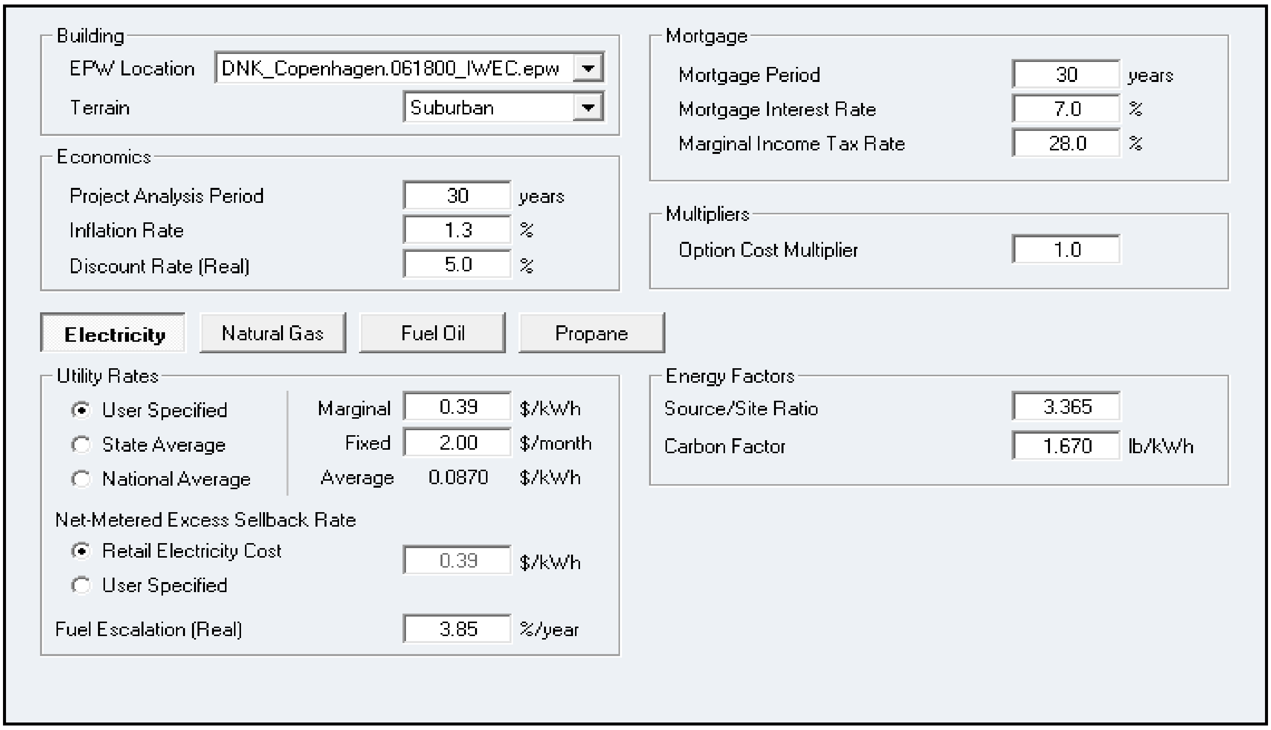


Fig. 6.15 Input Screen – Site Screen: Building Location
(study case of example: Danish weather patterns and specific main settings)

Moreover, energy and cost results can be plotted in terms of annual energy-related costs (the sum of utility bills and mortgage payments for energy options) versus the percentage of energy savings.
But, in this regard, it's important to recall that a further, *ad hoc* customization has been necessary in order to adapt the existing-standard *BEopt* costs and energy database (actually based on American Dollars values and respective US energy sources average prices) to the specific European (i.e. Italian vs. Danish) average values.

Several parameters' conversions were therefore required, along with those ones connected to the main reference units to be adopted: actually, BEopt only works with US metrics and doesn't recognize the International System's standard units.
A further step was thence worked out, first of all in order to properly insert the specific data and information to be processed, and finally in order to correctly appreciate the final output.

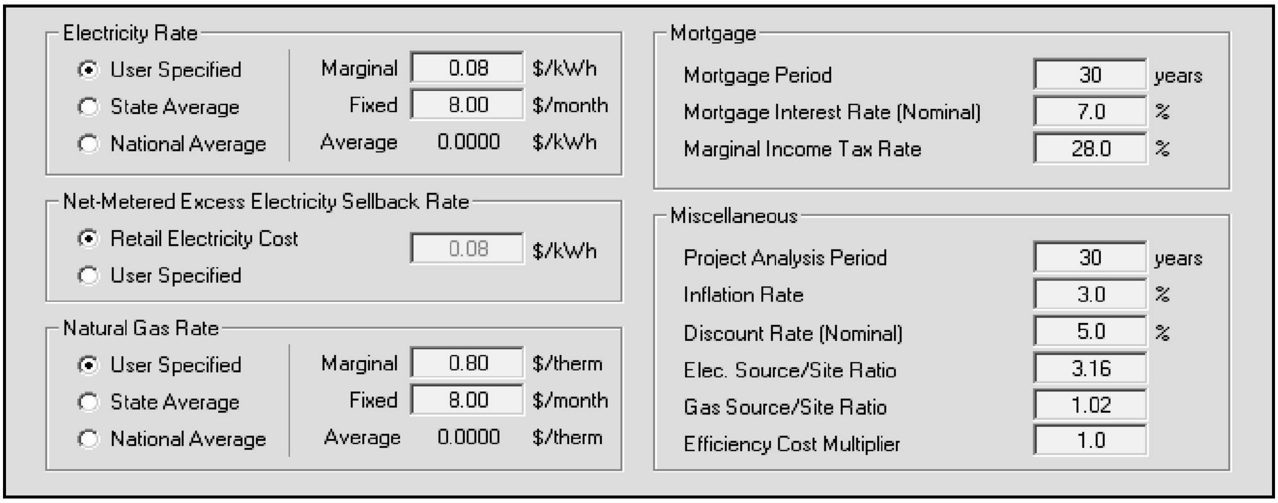


Fig. 6.16 Input Screen: Specific economic and financial parameters

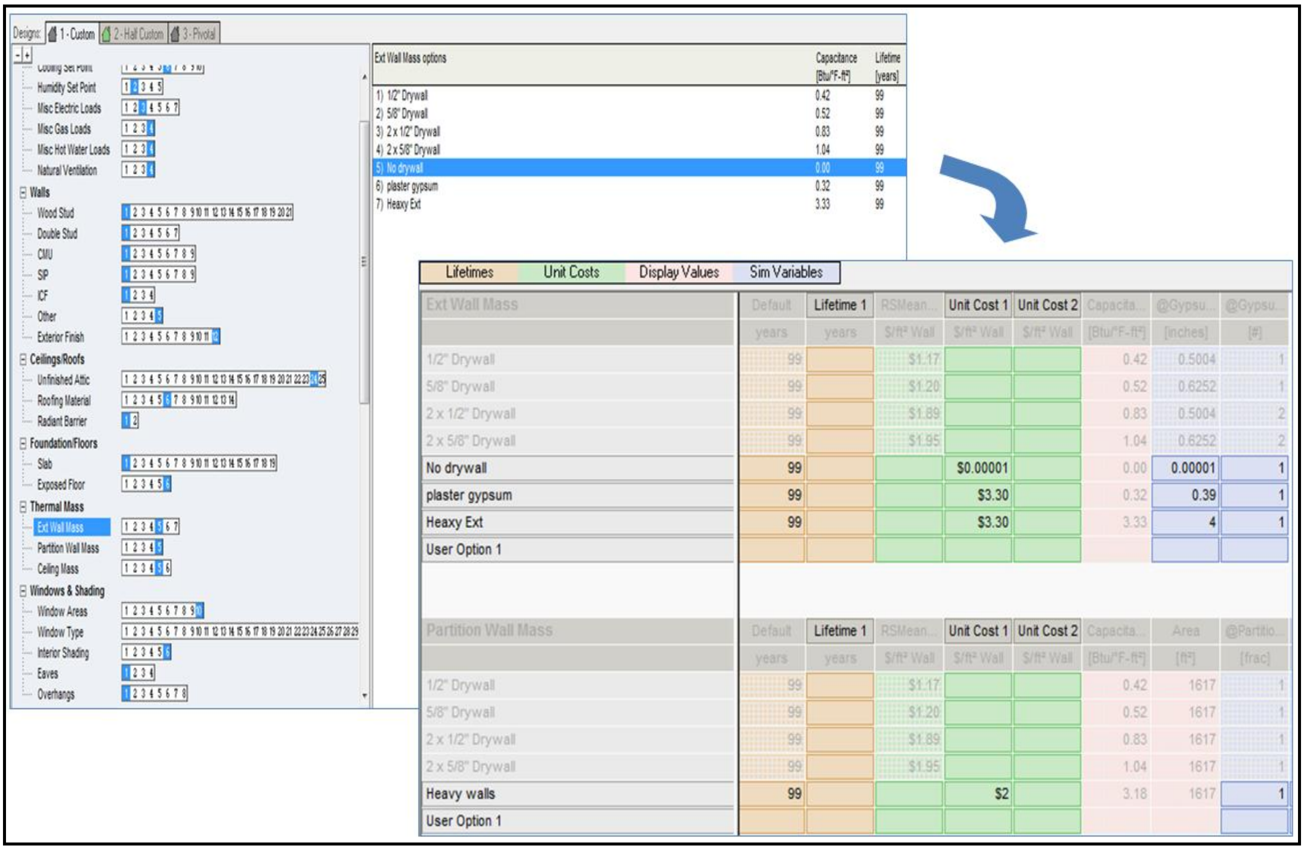


Fig. 6.17 Customization process: *BEopt Options Screen (Energy-Saving Options)* and *Library Manager Section*

Furthermore, the *Options Library Spreadsheet* of below contains detailed information for all the *BEopt* categories and specific options and can be properly customized and modified by means of an Excel interface:
actually, while in some cases it could be only necessary using the *BEopt* standard input screen in order to specify optimization details, a further access to the options library would allow the user to handle, review and modify specific characteristics for each option (such as energy properties and cost assumptions).

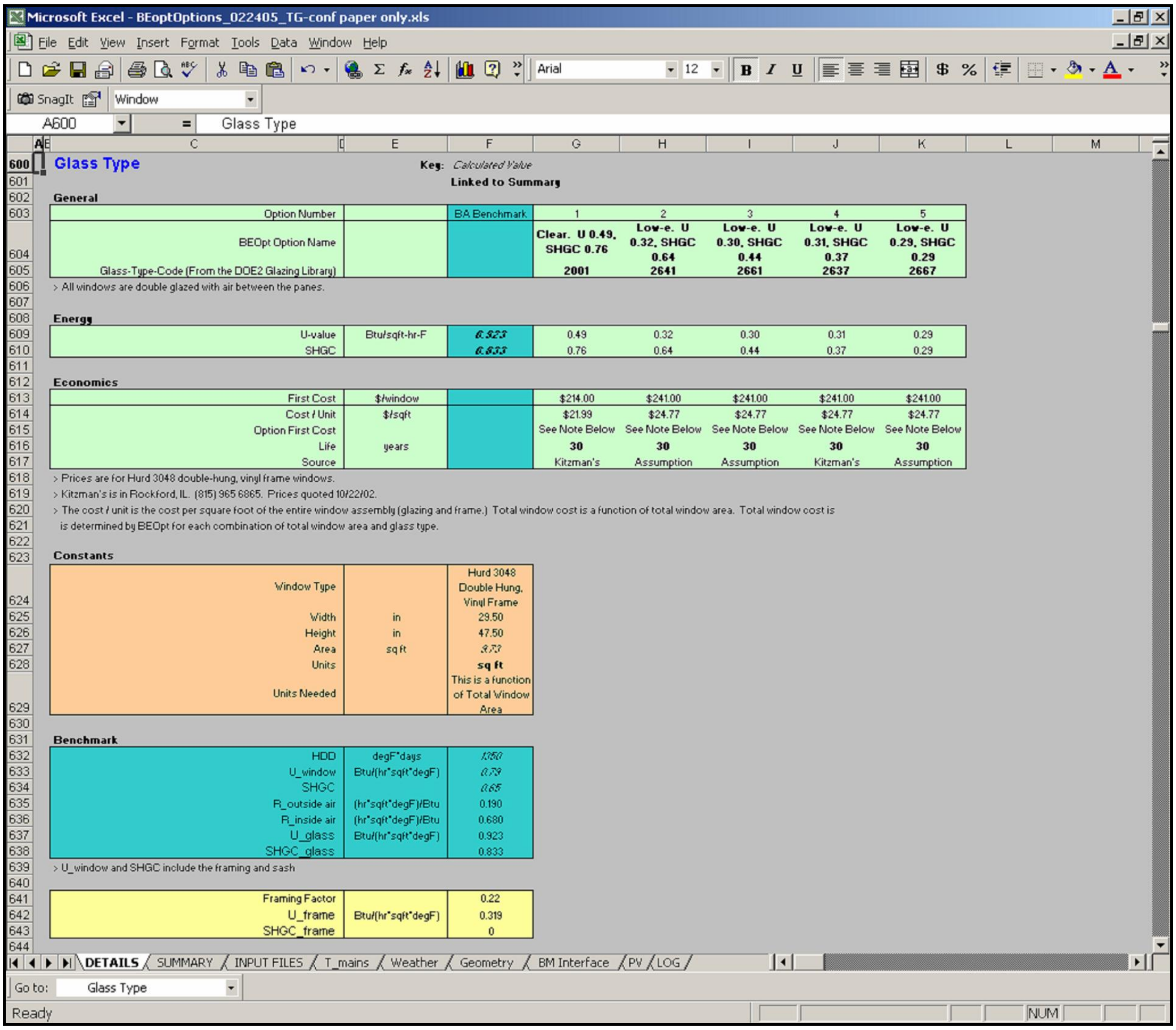


Fig. 6.18 Options library spreadsheet

The *path to zero net energy* called and implemented by the software into seeking out the optimal solution extends from a base case (e.g., a current-practice building, a code-compliant building, or another reference building, as in the current case) to a *ZNE* building with 100% of energy savings.
Such an **optimal path** is defined as the lower bound of results from all the possible building designs (i.e., connecting minimal cost points for various levels of energy savings).
Alternatively, net present value or other economic figures of merit could be shown on the y-axis.

In addition, points of particular significance on the path sketched out by the figure of below can be described as follows:

- from the base case until **Point 1**, energy use is reduced by employing building efficiency options (e.g., improvements in wall R-value, furnace efficiency, air conditioner properties, etc.);
- thence, a minimum annual cost optimum occurs at **Point 2** (obviously assuming the minimum doesn't occur at the base case);
- then, additional possible building efficiency options may be employed until the marginal cost of saved energy for these options becomes equal to the cost of producing photovoltaic energy at **Point 3**;

- finally, from the above latest point on, the main possible energy savings may be solely a result of adding PV capacity until ZNE is achieved at **Point 4.**

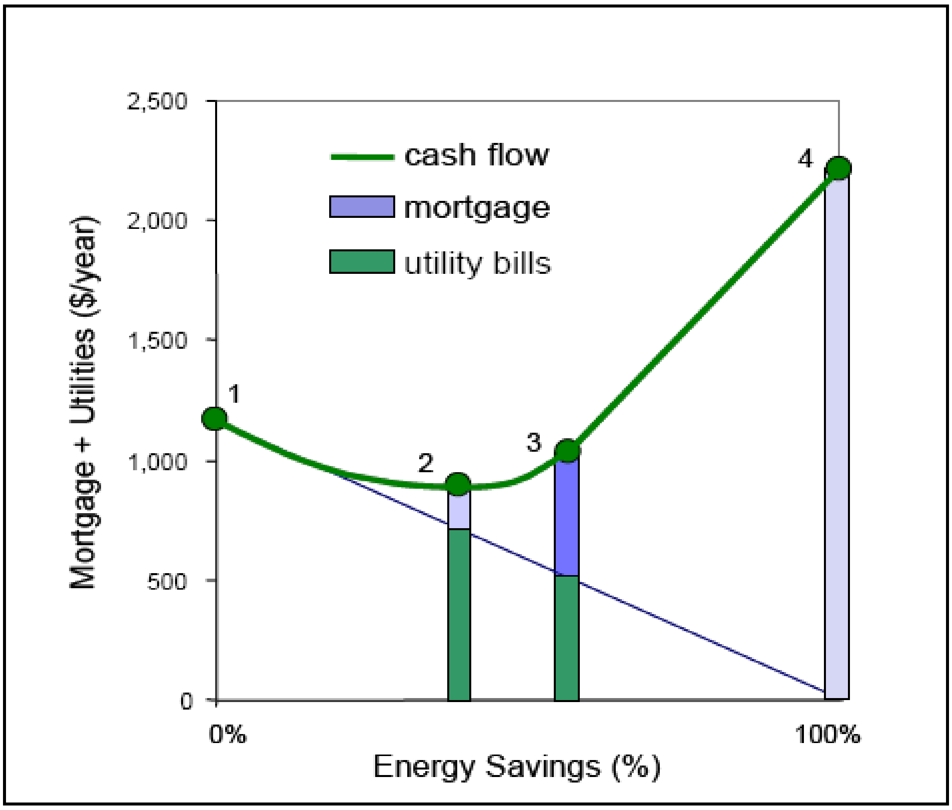


Fig. 6.19 Conceptual Plot of the path to *ZNE – Zero Net Energy* (source *NREL – National Renewable Energy Laboratory - BEopt™ Software for Building Energy Optimization: Features and Capabilities*)

Once an optimization has been completed, each single case contains its respective input screen, along with its specific output screen (as following shown in **Fig. 6.20**).
The main output screen includes a **Results Browser**: it allows the user to navigate among the different results associated to any particular building design previously simulated and analyzed during the optimization process.
Actually, for each single building design, the browser is able to display detailed output information about energy consumption, costs and other different options.
Furthermore, if multiple cases exist in a project file, a **Combined Graphs** output screen may be available.

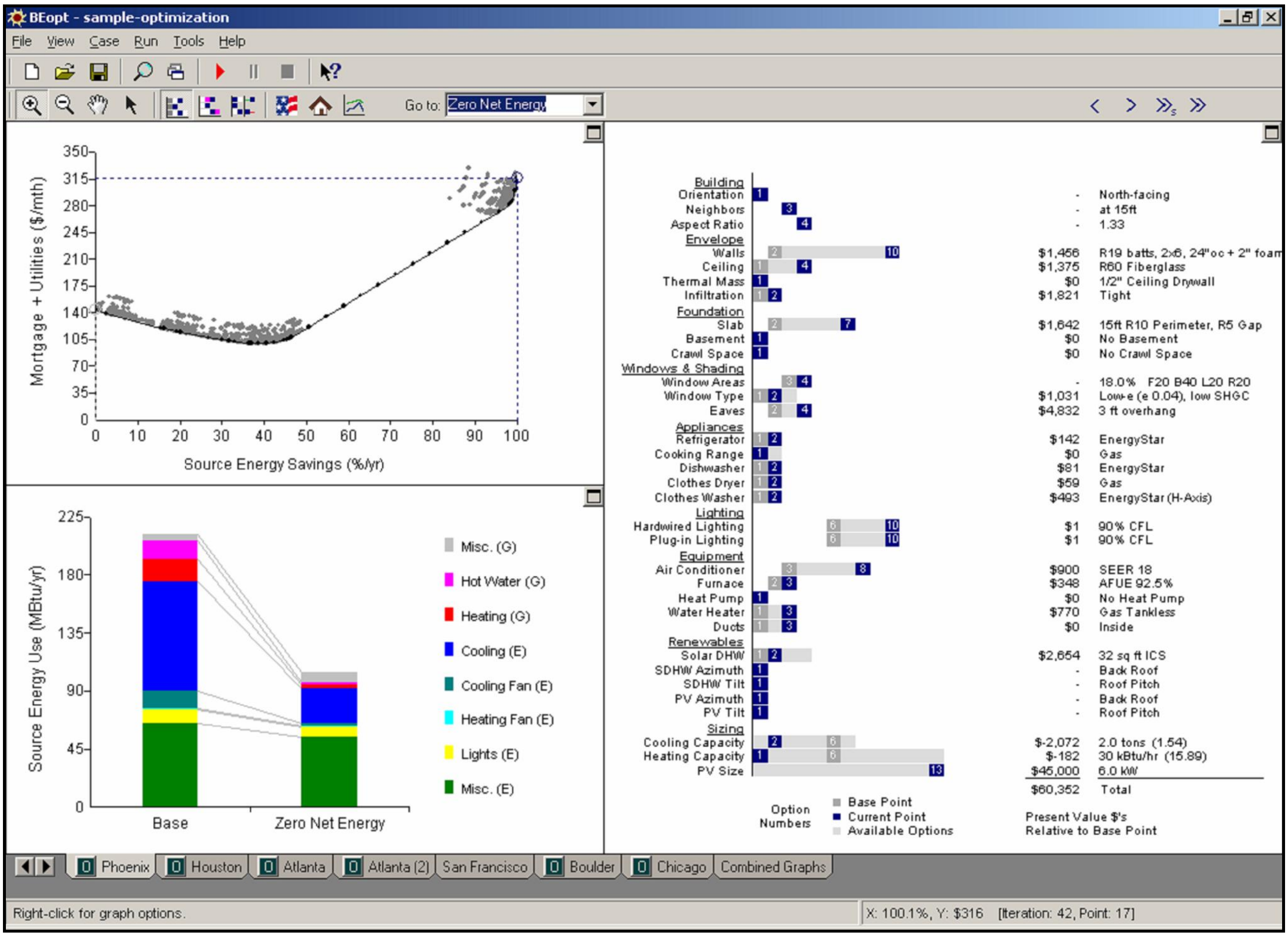


Fig. 6.20 *BEopt* Output Screen (Results Browser)

The curve depicted on the top-left part of the above output sample graph connects the points with the **<u>lowest annualized energy cost for any given energy savings</u>**.

Furthermore, as it's going to be hereinafter detailed, the user is also allowed to explicitly include or exclude one or more options from the several evaluations to be carried out.
For instance, if the user is interested in the interaction between south-facing glazing areas and additional thermal mass, simply selecting available options within these two categories may not suffice: and this is caused by the specific nature of the particular sequential search optimization technique applied by the software.
Actually, an option from either the thermal mass category or the glazing area category must be first <u>independently cost-effective</u> in order for the combination of an additional thermal mass and glazing area is evaluated by BEopt; however, if the user has got a specific technical experience and is thence able to recognize this situation, an ***Include Combinations*** category can be created in order to explicitly select such *ad hoc* combinations for the optimization.
Likewise, the user can also create ***Exclude Combinations*** categories in order to explicitly exclude from the optimization certain particular combinations that the user knows are not cost-effective (indeed, such a choice is a way of directly reducing runtime for combinations).

Moreover, the colored stacked bars reported by the bottom-left part of the above graph (i.e. the ***End Use Graph***) express the several respective end use output values (e.g. gas misc., gas hot water, gas heating, electric cooling, etc.).
In particular, the left-hand bar shows the main results associated to the base case, while instead the right-hand bar depicts the specific results associated to the single point selected.

In addition, the user can also select whether the y-axis shows building energy consumption in terms of source energy (*MBtu/year*), site energy (*MBtu/year*), or cost of energy *($/year*).

Finally, it's also possible to carry out a **Sensitivity Analysis** (as below summed up) by varying one or more of the main parameters implemented in the simulation: actually, such a process allows the user to assess and estimate their single influence and the role played within the overall building asset.

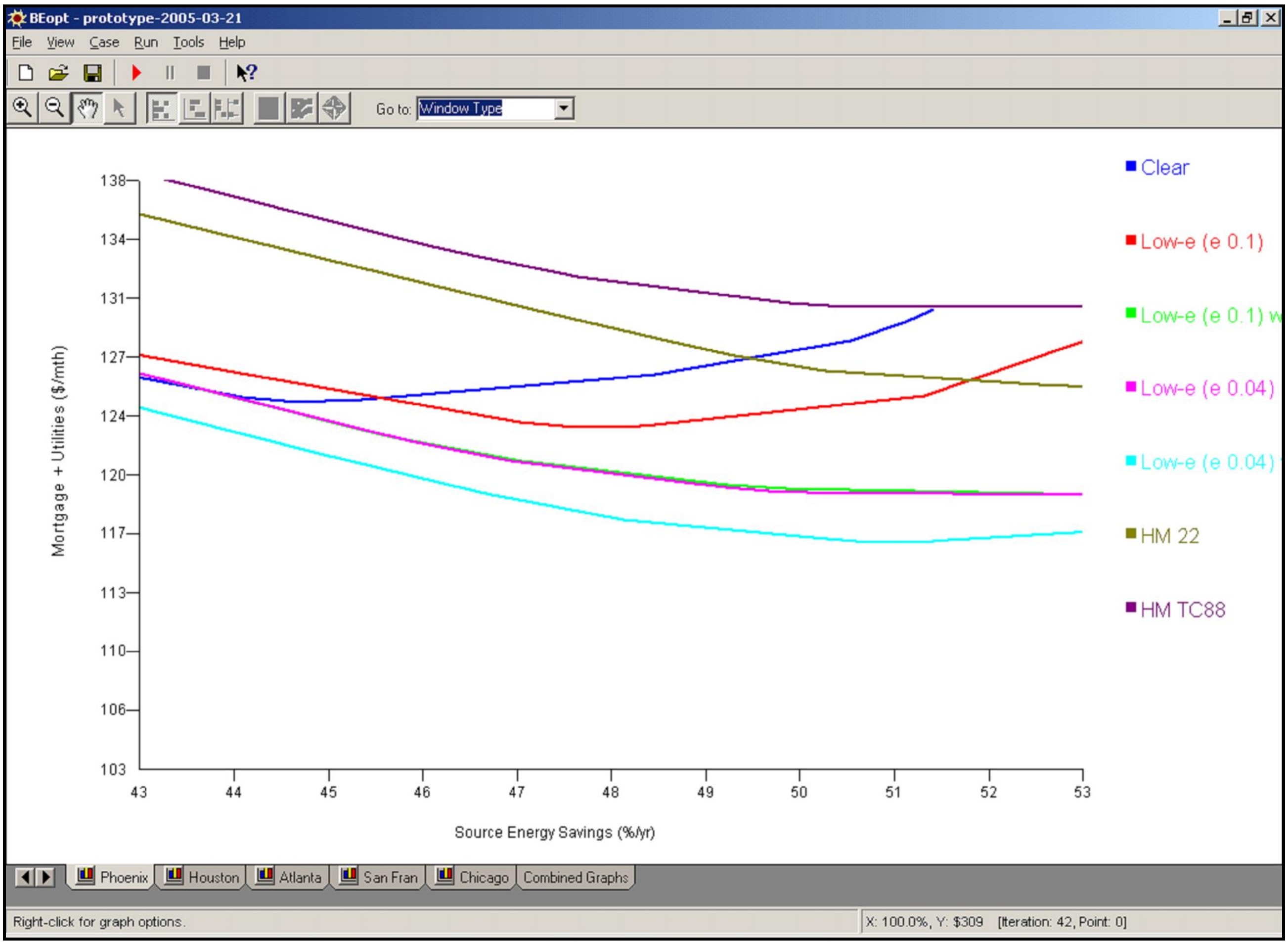


Fig. 6.21 Options sensitivity graph

6.5 Definition of the different analysis scenarios and their respective boundary conditions: Italy vs. Denmark

6.5.1 Italian background investigation and specific main settings

It must be noticed that, first of all, the specific **Weather Files** of interest for the main Italian scenarios to be assessed were downloaded from the *Energy Plus* Database and were therefore uploaded in the BEopt interface.

Since it has been chosen to focus the present research on the **Italian Island of *Sardinia***, its most representative weather patterns were adopted; and recalling that such a region mainly involves two different climatic zones (i.e. the ***C Zone*** and the ***D Zone***, as it's possible to notice looking at the map of below), the following locations were selected and picked up:

- for the ***C Zone*** (Degree Days between 900 & 1.400): ***Olbia*** (1.142 Degree Days, i.e. an intermediate value between the two extremes) and its respective Energy Plus Weather Data;

- for the ***D Zone*** (Degree Days between 1.400 & 2.100): ***Pozzomaggiore*** (1.748 Degree Days, i.e. another middle-ranking value) and its respective Energy Plus Weather Data;

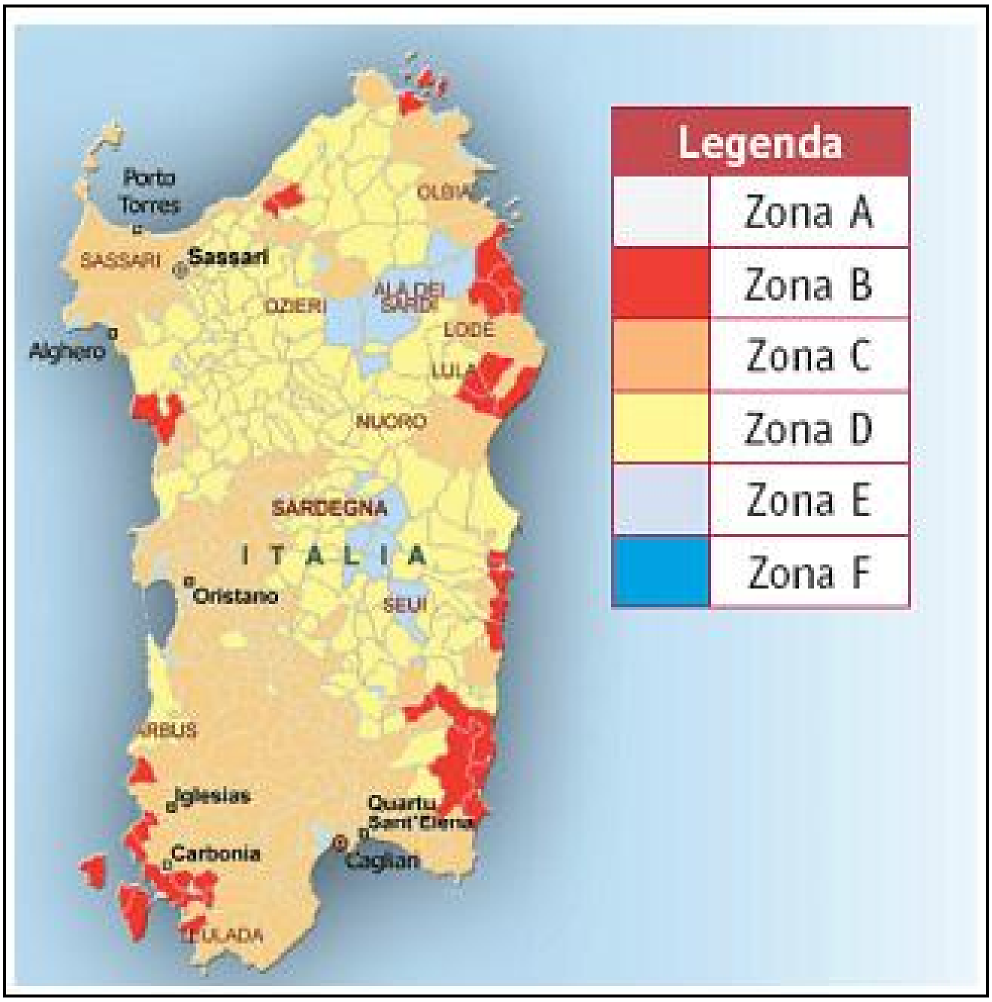


Fig. 6.22 Sardinian Climatic zones' distinction (source *Edilportale.com*)

Thence, in order to properly settle and customize *ad hoc* the BEopt database with the main aim of achieving a complete retrofit optimization, the following further steps were carried out.
Actually, the present research has gone through several investigations for the purpose of evaluating the most suitable average energy costs to be used for energy sources (as well as for the main appliances and materials to be adopted), for both the Italian and the Danish background.
Indeed, as previously mentioned, besides shifting from U.S. Dollars to the European currencies, it's necessary to be aware that average costs of energy sources widely differ from State to State.

The ***BEopt Site Screen*** was thence adjusted according to the average Italian energy prices and, even though by means of this schedule it's possible to provide and adjust also the Fuel Oil and the Propane costs, only **Electricity** and **Natural Gas** Utility Rates were considered and consequently customized.
Actually, only the two latest energy sources of above were effectively implemented and used within the specific building model here analyzed.

6.5.2 Electric energy utility prices and rates: Italy vs. Denmark

After a review and an accurate analysis about the average energy prices currently applied in Italy (available on the National website *http://www.autorita.energia.it*), it has been chosen to implement and adopt the latest, more complete information provided with reference to year 2012.
As a matter of fact, the Italian BEopt Site Screen's customization was based onto all the main data and average values collected and reported by the ***AEEG*** (***The Regulatory Authority for Electricity and Gas***) in a Summary delivered to the Italian Senate on 9th July 2013.

As below depicted, this document had quoted all the latest ***Surveys and Reports*** collected by ***Eurostat*** with reference to the **Electricity** rates applied for private consumers - both in Italy and Denmark - as well as those ones referred to the **Natural Gas** prices registered during year **2012.**

c€/kWh; anno 2012

	Consumatori per fascia di consumo annuo (kWh)									
	< 1.000		1.000-2.500		2.500-5.000		5.000-15.000		> 15.000	
Paesi	**netti**	**lordi**	**netti**	**lordi**	**netti**	**lordi**	**netti**	**lordi**	**netti**	**lordi**
Danimarca	15,52	32,94	15,52	32,94	13,05	29,85	11,24	26,13	11,24	26,13
Francia	19,86	24,6	11,83	16,09	10,06	14,21	8,96	13,03	8,67	12,76
Germania	25,31	39,73	16,43	28,86	14,37	26,36	13,2	25,04	12,8	24,08
Italia	19,02	26,16	14,03	19,35	14,85	22,15	17,91	27,36	20,44	30,61
Regno Unito	18,29	19,2	18,06	18,94	16,52	17,34	14,78	15,52	13,62	14,3
Spagna	28,43	35,72	19,67	24,71	17,78	22,33	15,99	20,1	14,38	18,07
Unione Europea	21,56	28,37	15,18	20,63	13,63	19,295	12,68	18,485	12,12	17,75
Area Euro	23,09	31,22	15,06	21,395	13,51	20,25	12,78	19,825	12,37	19,21

Fonte: Dati Eurostat, media dei valori semestrali[3].

Fig. 6.23 Electricity Utility Prices for Italy and Denmark
(sources: *Eurostat* and *AEEG* - latest update 4th October 2012)

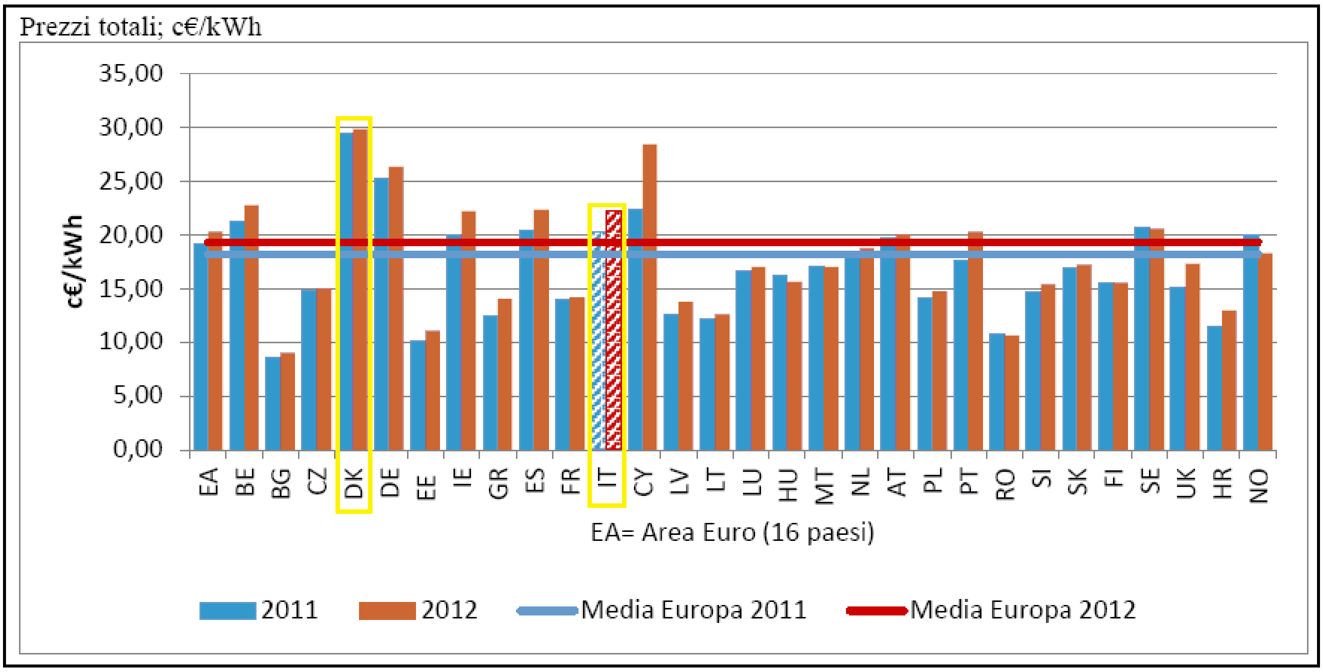


Fig. 6.24 Electric Energy Prices for private consumers for an average consumption range of 2.500-5.000 kWh/year (sources: *Eurostat* and *AEEG*)

According to the above data and assuming an average energy consumption belonging to the **2.500 – 5.000 kWh/year** range (i.e. assuming to model and analyze a **single-detached-family-house**), the Italian BEopt Site Screen was settled and defined as follows:

BEOPT *USER SPECIFIED* ELECTRICITY PRICE [ITALY]:

MARGINAL (including VAT)	0,2215 €/kWh
FIXED (including VAT)	13,00 €/month

(ref. 2012 customer's representative sample bill)

BEOPT *USER SPECIFIED* ELECTRICITY – FUEL ESCALATION RATE EVALUATION

Furthermore, according to the main information gathered with reference to the average energy rates adopted during the time span 2009-2013 (and available, once again, in the National website *http://www.autorita.energia.it*), **an average value based on the time-span here investigated has been calculated for the fuel escalation annual percentage: such an evaluation was carried out in order to guess the most reliable future electricity rate.**

The main information and data collected are depicted as follows (see **Fig. 6.25**)

YEAR	TRIMESTER	ENERGY & SUPPLY [c€/kWh]	NETWORK COSTS [c€/kWh]	GENERAL COSTS [c€/kWh]	TAX BURDEN [c€/kWh]	TOTAL RATE [c€/kWh]
2009						
	I	11,03	2,49	1,23	2,39	17,15
	II	10,72	2,49	1,23	2,36	16,80
	III	10,42	2,51	1,36	2,34	16,63
	IV	10,42	2,51	1,36	2,34	16,63
2010						
	I	10,15	2,50	1,30	2,31	16,26
	II	9,61	2,50	1,40	2,26	15,76
	III	9,42	2,50	1,51	2,25	15,68
	IV	9,27	2,52	1,56	2,25	15,59
2011						
	I	9,36	2,49	1,47	2,24	15,57
	II	9,49	2,49	1,90	2,30	16,18
	III	9,51	2,49	2,17	2,33	16,49
	IV	9,43	2,49	2,25	2,33	16,49
2012						
	I	9,97	2,56	2,38	2,38	17,28
	II	10,89	2,56	3,10	2,54	19,09
	III	10,87	2,56	3,16	2,55	19,13
	IV	11,01	2,56	3,27	2,57	19,40
2013						
	I	10,38	2,77	3,44	2,55	19,13
	II	9,99	2,78	3,64	2,53	18,94

Fig. 6.25 Italian Electricity Energy rates (source http://www.autorita.energia.it)

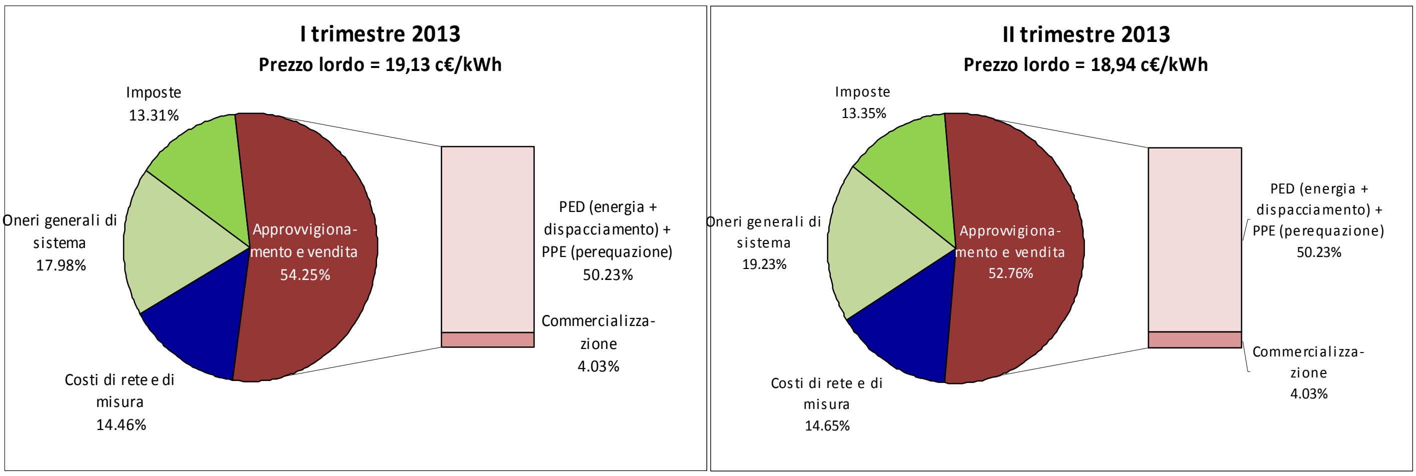


Fig. 6.26 a-b Italian Electricity Energy costs (source http://www.autorita.energia.it)

BEOPT *USER SPECIFIED* ELECTRICITY – FUEL ESCALATION RATE [ITALY]:

(as evaluated on the average) **~ 3% / year**

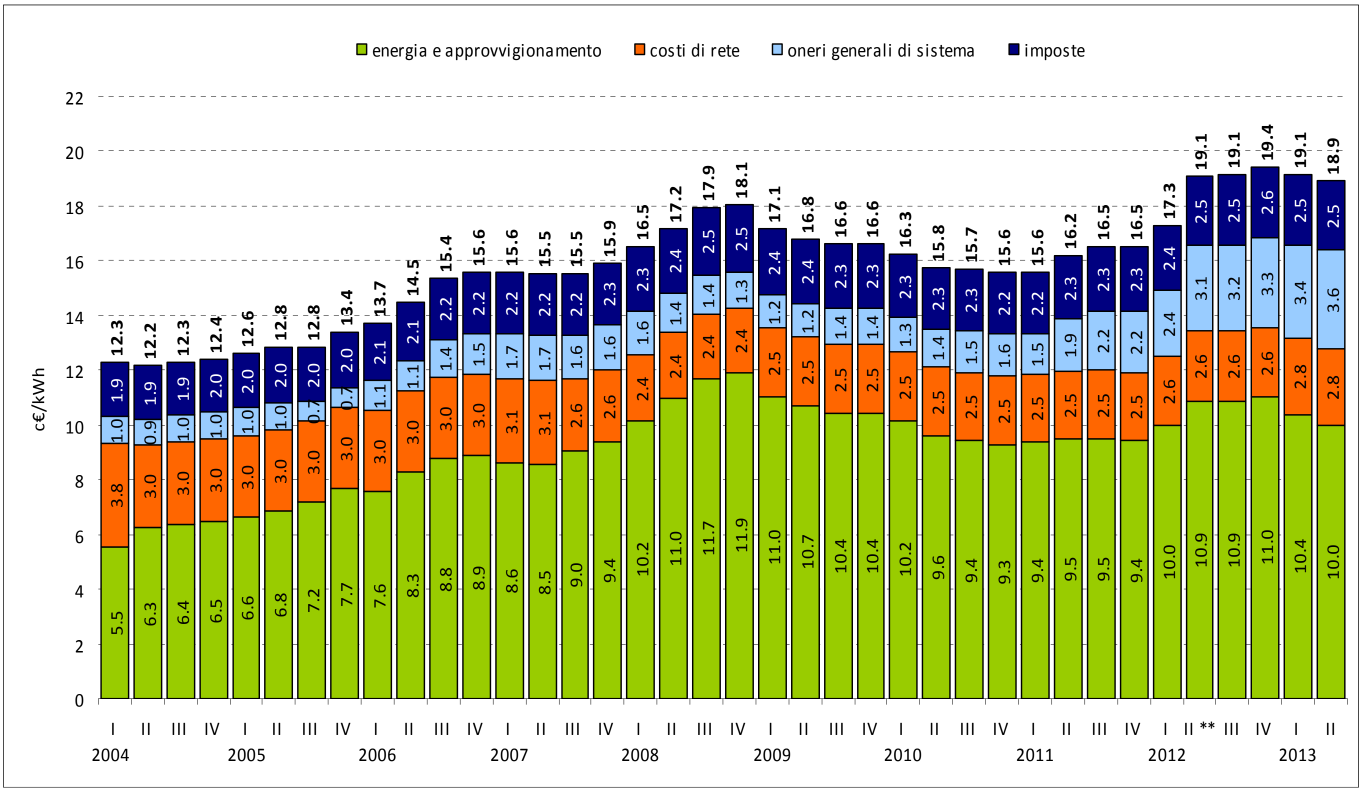


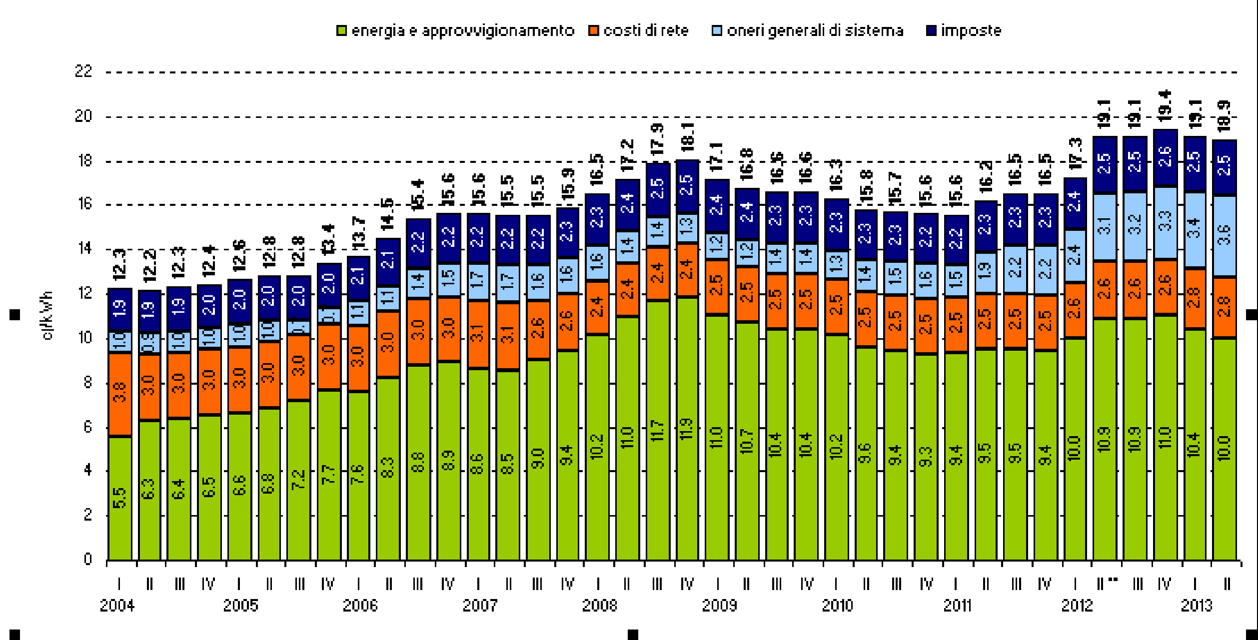
Fig. 6.27 Italian Electricity Energy rates' trend (source *http://www.autorita.energia.it*)

ANDAMENTO DEL PREZZO DELL'ENERGIA ELETTRICA PER UN CONSUMATORE DOMESTICO TIPO

Condizioni economiche di fornitura per una famiglia con 3 kW di potenza impegnata e 2.700 kWh di consumo annuo

Anni 2004-corrente; c€/kWh

	c€/kWh				
	energia e approvvigionamento	costi di rete	oneri generali di sistema	imposte	tariffa totale
I 2009	11.03	2.49	1.23	2.39	17.15
II	10.72	2.49	1.23	2.36	16.80
III	10.42	2.51	1.36	2.34	16.63
IV	10.42	2.51	1.36	2.34	16.63
I 2010	10.15	2.50	1.30	2.31	16.26
II	9.61	2.50	1.40	2.26	15.76
III	9.42	2.50	1.51	2.25	15.68
IV	9.27	2.52	1.56	2.25	15.59
I 2011	9.36	2.49	1.47	2.24	15.57
II	9.49	2.49	1.90	2.30	16.18
III	9.51	2.49	2.17	2.33	16.49
IV	9.43	2.49	2.25	2.33	16.49
I 2012	9.97	2.56	2.38	2.38	17.28
II **	10.89	2.56	3.10	2.54	19.09
III	10.87	2.56	3.16	2.55	19.13
IV	11.01	2.56	3.27	2.57	19.40
I 2013	10.38	2.77	3.44	2.55	19.13
II	9.99	2.78	3.64	2.53	18.94



AVVERTENZA: esiste una discontinuità tra il periodo antecedente e quello successivo al 1° luglio 2007. Prima di tale data i costi di rete includevano i costi di commercializzazione dell'attività di vendita enucleati nella componente COV che, a partire dalla stessa data, è stata attribuita ai costi di energia e approvvigionamento.

Fig. 6.28 Italian Electricity Energy prices & trend (source *http://www.autorita.energia.it*)

6.5.3 Natural gas utility prices and rates: Italy vs. Denmark

In order to evaluate in €/kWh (and then calculate the correspondent value in $/Therm as required by BEopt interface) all the information provided by the main sources of reference, it's important to recall the essential properties and the specific characteristics of the Natural Gas quality used for heating and cooking in almost every Italian Region:

• *Potere calorifico superiore* (***PCS-Gross Calorific Potential***): 38.100 Kj/Nm^3 → **10,6 kWh/Nm^3**

• *Rapporto di miscelazione* ***(Components mix Ratio)***: 99,5 % Methane;
0,1 % Ethane;
0,4 % Nitrogen;

Gas naturale	Nazionale % vol	Russo % vol	Nord Europa % vol	Algerino % vol
Metano	99,33	97,92	90,31	83,62
Etano	0,05	0,77	4,83	8,42
Altri idrocarburi	0,01	0,35	1,63	2,68
Anidride carbonica	0,03	0,09	1,14	0,51
Azoto	0,57	0,86	2,05	4,62
Elio	0,01	0,01	0,04	0,15
Potere calorofico superiore (MJ/Sm³)	37,58	37,886	39,054	39,985
Potere calorofico inferiore (MJ/Sm³)	33,836	34,125	35,244	36,137

Fig. 6.29 Italian Natural Gas Components mix Ratio (source *Snamretegas*)

Thence assuming to use, for the current BEopt Italian building model, the same quality of Natural Gas above detailed and implementing once again all those data and information provided by ***Eurostat*** with reference to year 2012, it's possible to report the following, detailed values (for both Italy and Denmark):

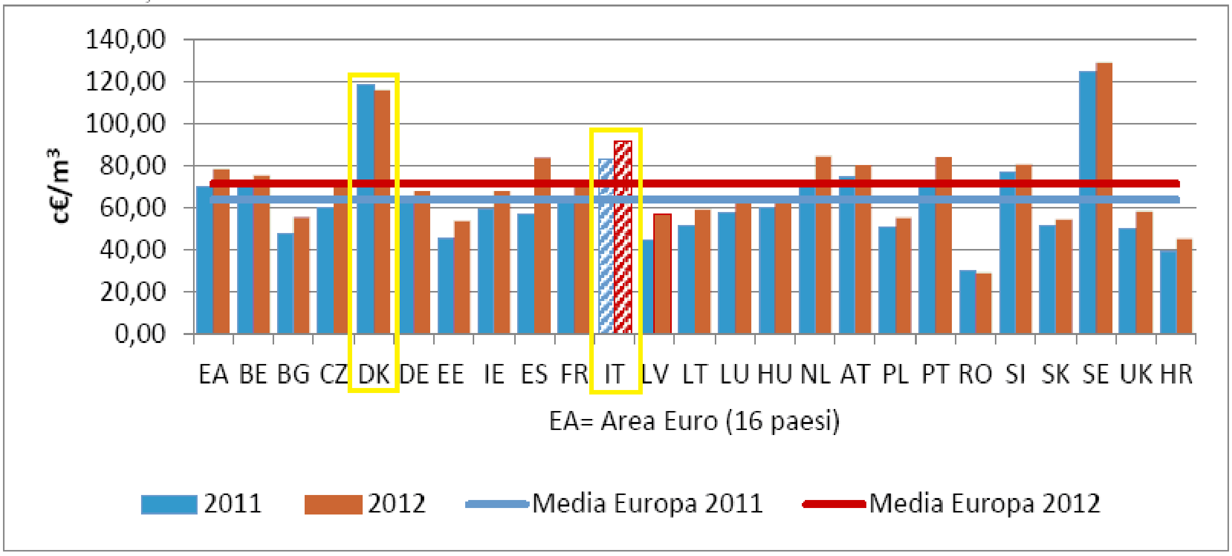
c€/m^3; anno 2012

	Consumatori per fascia di consumo annuo (m^3)					
	< 525,36		525,36-5.253,60		>5.253,60	
Paesi	**netti**	**lordi**	**netti**	**lordi**	**netti**	**lordi**
Danimarca	56,15	115,87	56,15	115,87	56,15	115,87
Francia	108,36	130,1	58,04	69,63	51,09	61,02
Germania	84,06	110,59	50,84	67,97	48,16	64,77
Italia	83,28	111,62	61,12	91,84	51,47	84,25
Regno Unito	64,05	67,22	55,39	58,14	48,86	51,3
Spagna	91,98	109,33	70,64	83,94	56,7	67,36
Unione Europea	78,61	98,48	55,12	71,28	48,98	64,87
Area Euro	88,47	114,78	57,20	78,29	50,38	71,28

Fonte: Dati Eurostat, media dei valori semestrali.

Fig. 6.30 Natural Gas Utility Prices for Italy and Denmark
(sources: Eurostat and *AEEG* - latest update 4th October 2012)

Prezzi totali; c€/m³



Fonte: Dati Eurostat, media dei valori semestrali.

Fig. 6.31 Natural Gas prices for private consumers for an average consumption range of 20-200 GJ/year ~ 525-5.254 m³/year (sources *Eurostat* and *AEEG*)

<u>BEOPT *USER SPECIFIED* NATURAL GAS PRICE [ITALY]:</u>

MARGINAL (including VAT)	0,097 €/kWh
FIXED (including VAT)	6,24 €/month

(ref. 2012 customer's representative sample bill)

An analogous review about the average **Natural gas prices applied during the time span 2009 - 2013 has led to the application of the following escalation rate:**

<u>BEOPT *USER SPECIFIED* NATURAL GAS – FUEL ESCALATION RATE [ITALY]:</u>

(as evaluated on the average) **<u>~ 2% / year</u>**

ANDAMENTO DEL PREZZO DEL GAS NATURALE PER UN CONSUMATORE DOMESTICO TIPO

Condizioni economiche di fornitura per una famiglia con riscaldamento autonomo e consumo annuale di 1.400 m3.

ridefinito in base ai nuovi ambiti tariffari

c€/m^3 a valori correnti

	Costi infrastrutturali	Costi di vendita	Materia prima	Imposte	Totale
III 2009	13.75	6.93	20.61	27.03	68.32
IV 2009	14.37	6.94	19.26	26.91	67.48
I 2010	14.13	6.92	21.12	27.17	69.34
II 2010	14.15	6.76	23.37	27.53	71.81
III 2010	14.21	6.73	25.32	27.85	74.13
IV 2010	14.43	6.73	25.06	27.85	74.07
I 2011	14.33	6.70	25.99	27.98	75.00
II 2011	14.34	6.74	27.25	28.20	76.52
III 2011	14.23	6.74	30.09	28.65	79.70
IV 2011	14.39	6.81	33.21	29.67	84.07
I 2012	14.47	7.02	34.88	30.01	86.38
II 2012	14.91	7.06	35.71	30.24	87.92
III 2012	15.10	7.06	37.48	30.58	90.22
IV 2012	15.47	7.16	37.89	30.73	91.24
I 2013	16.98	7.09	37.76	30.95	92.78
II 2013	16.42	7.09	35.03	30.39	88.93

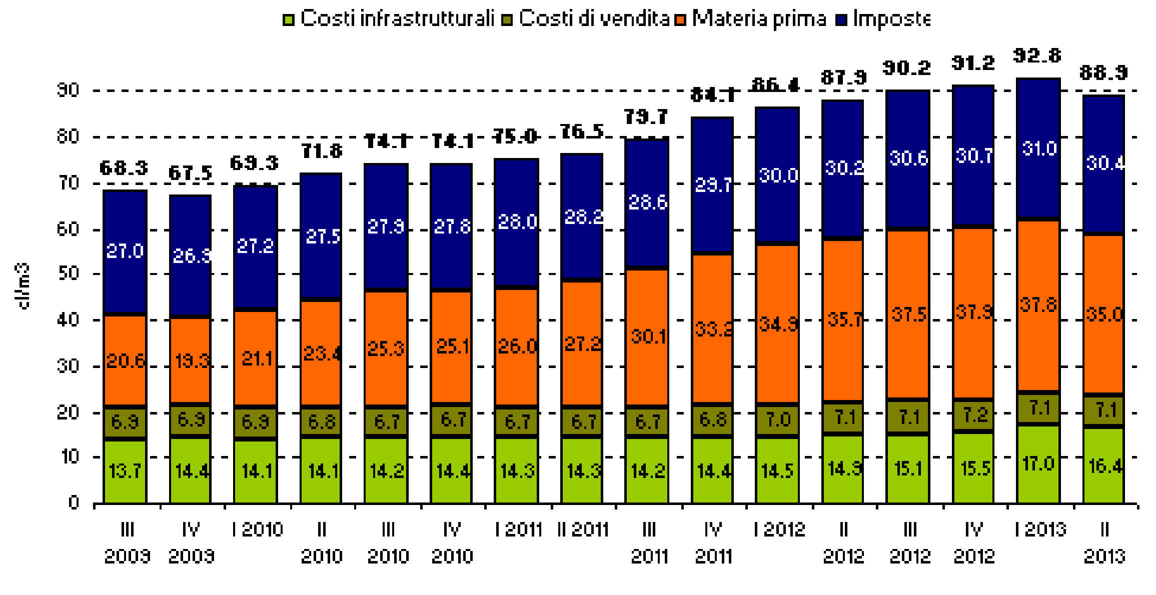


Fig. 6.32 Italian Natural Gas prices & trend (source http://www.autorita.energia.it)

Tanks to the above information, it's therefore possible assessing the different utility costs also adjusting the respective fuel escalation rates (first for Italy and then for Denmark and with reference to electricity and natural gas too).

Actually, in order to define the Danish boundary conditions and their economic background, a detailed review of the global energy prices adopted in Denmark during the year 2012 was necessary (analogously to what already done for the Italian context).
As previously mentioned, the current assessment has in fact established to adopt the above year as the main point of reference.

Hence, by means of an investigation carried out through the following Institutional websites and data sources, the key-references hereinafter summed up have been gathered.

http://energitilsynet.dk;
http://www.ens.dk;
http://www.elpristavlen.dk;
http://www.hef.dk;
http://www.energinord.dk;
http://www.aalborgcityforsyning.dk;
http://www.nordpoolspot.com

Gennemsnitlige månedlige el-forsyningspligtpriser for forbrugere og virksomheder i Danmark angivet i øre/kWh. Priser gældende for hele landet.

Kilde: Dansk Energis totaltælling pr. 1. januar samt prisoplysninger fra 33 else
Note: For yderligere information om elprisstatistikken henvises til metodebeskr

Husholdninger (4.000 kWh)	Jan-09	Jan-10	Jan-11	Jan-12	Jan-13	Feb-13	Mar-13
Elpris (forsyningspligt)	53.2	35.0	45.2	45.0	38.4	38.4	38.4
Abonnement	2.5	2.6	2.6	2.7	2.7	2.7	2.7
Nettarif lokal	13.9	14.5	14.9	16.3	17.5	17.5	17.5
Abonnement (net)	15.0	15.5	15.8	15.9	15.5	15.5	15.5
Reg. Transmission	0.8	0.6	0.9	0.95	0.5	0.5	0.5
Net- og systemtarif	7.4	6.2	7.4	7.6	6.9	6.9	6.9
PSO-tarif	5.3	11.5	6.0	11.3	17.4	17.4	17.4
Samlet elpris ex moms	98.2	85.9	92.8	99.7	98.9	98.9	98.9
Elafgift	55.0	61.3	68.4	69.6	70.9	70.9	70.9
Eldistributionsafgift	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Elsparebidrag	0.6	0.6	0.6	0.6	0.6	0.6	0.6
CO2-afgift	8.9	6.2	6.3	6.4	6.5	6.5	6.5
Moms	41.7	39.5	43.0	45.1	45.2	45.2	45.2
Samlet elpris incl. moms	208.4	197.6	215.1	225.4	226.1	226.1	226.1

Fig. 6.33 Average monthly electric service prices for private consumers in Denmark (expressed in *DKK cents/ kWh*)

Gennemsnitlige elpriser for hele landet, marts 2013

Pris i øre/kWh kWh	Husholdninger 4.000	Små virksomheder 100.000	Store virksomheder 50 mio.
Net-abonnement	15,5	3,5	0,1
Nettarif	42,3	40,2	28,6
Heraf til distribution	17,5	15,5	4,2
Heraf regional transmission	0,5	0,5	0,2
Heraf PSO-tarif	17,4	17,4	17,4
Heraf net- og systemtarif	6,9	6,9	6,9
Samlet netbetaling	**57,7**	**43,7**	**28,7**
Ren elpris-abonnement	2,7	0,1	0,0
Ren elpris	38,4	38,4	31,2
Samlet elpris uden afgifter og moms	**98,9**	**82,3**	**60,0**
Afgifter og moms	127,2	10,9	8,7
Heraf CO2-afgift	6,5	6,4	5,2
Heraf elafgift	70,9	3,5	3,5
Heraf elsdistributionsbidrag	4,0	1,0	0,0
Heraf elsparebidrag	0,6	0,0	0,0
Heraf moms	45,2	0,0	0,0
Samlet elpris med afgifter og moms	**226,1**	**93,2**	**68,7**

Kilde: Dansk Energis totaltælling pr. 1. januar samt prisoplysninger fra 33 elselskaber på Elpristavlen.
Data kan hentes i Excel-format fra Energitilsynets hjemmeside:
http://energitilsynet.dk/el/priser/prisstatistik/

Fig. 6.34 Average electric service prices' composition for private consumers in Denmark (expressed in *DKK cents/ kWh* and assuming an average energy consumption of 4.000 kWh/year)

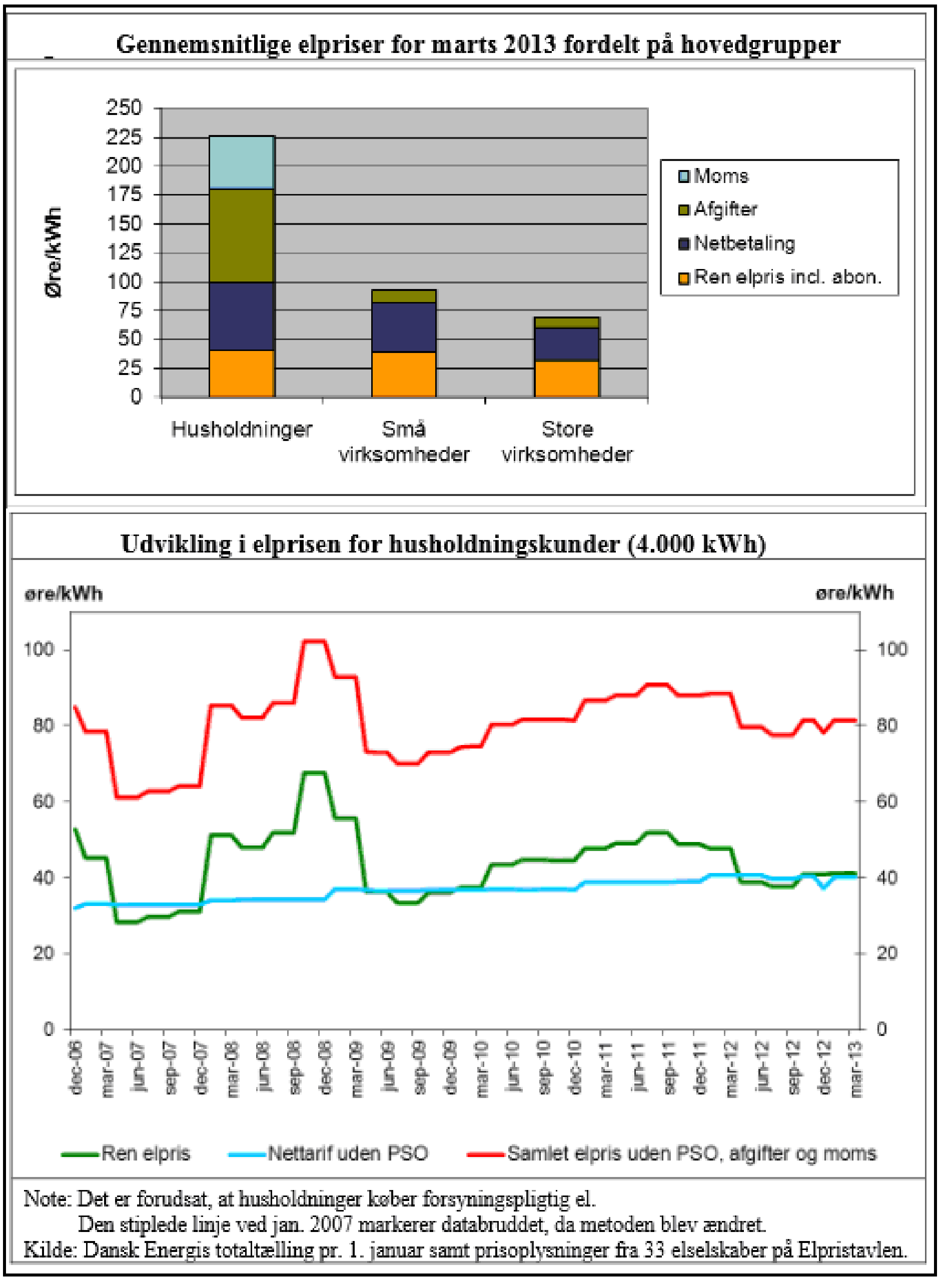


Fig. 6.35 Average electric service prices parameters in Denmark (expressed in *DKK cents/ kWh*)

<u>BEOPT *USER SPECIFIED* ELECTRICITY PRICE [DENMARK]:</u>

MARGINAL (including VAT)	0,2985 €/kWh
FIXED (including VAT)	18,30 €/month

With reference to the **fuel escalation annual percentage**, and once again **in order to guess the most reliable future electricity rate, an average value based on the same time-span investigated for the Italian background has been instead assessed.**

<u>BEOPT *USER SPECIFIED* ELECTRICITY – FUEL ESCALATION RATE [DENMARK]:</u>

(as evaluated on the average) **<u>~ 3,85% / year</u>**

Moreover (and once again analogously to what already done for the Italian context too) some further investigations were performed for the Danish background with reference to the natural gas rates to be adopted.

Actually, in order to evaluate in €/kWh (and then calculate the correspondent value in $/Therm) its respective utility prices, the main information and key-data provided by **the *Institutional Danish Energy Regulatory Authority*** (*http://energitilsynet.dk/gas/*), along with the websites *http://www.ens.dk* and *http://www.hef.dk* - *http://www.aalborgcityforsyning.dk* were used.

Furthermore, the same natural gas characteristics and main technical data provided by the ***Dansk Gas Forening (Danish Gas Association)*** were adopted.

Actually, they are based on the main characteristics summed up in the following table (**Fig.6.36**):

Gas quality		Natural gas	Town gas
Methane	CH_4	87.2 %	27.8 %
Ethane	C_2H_6	6.8 -	1.2 -
Propane	C_3H_8	3.1 -	0.5 -
iso-Butane	C_4H_{10}	0.4 -	-
n-Butane	C_4H_{10}	0.6 -	0.2 -
iso-Pentane	C_5H_{12}	0.1 -	-
n-Pentane	C_5H_{12}	0.07 -	
Hexane+h	C_6+	0.05 -	
Nitrogen	N_2	0.3 -	20.9 -
Carbon dioxide	CO_2	1.4 -	8.0 -
Carbon monoxide	CO	-	2.8 -
Oxygen	O_2	-	3.2 -
Hydrogen	H_2	-	35.4 -
Lower calorific value	MJ/m^3_n	40.1	15.6
Lower calorific value	kWh/m^3_n	11.1	4.34
Lower calorific value	MJ/kg	47.4	20.5
Upper calorific value	MJ/m^3_n	44.3	17.5
Upper calorific value	kWh/m^3_n	12.3	4.87
Upper calorific value	MJ/kg	52.4	23.0
Wobbe index (upper)	MJ/m^3_n	54.8	22.8
Density	kg/m^3_n	0.85	0.76
Relative density	-	0.65	0.59
Methane number[1)]	-	70	-[2)]
Stoichiometric combustion [3)]			
Air requirement	m^3_n/m^3_n gas	10.8	3.8
Water vapour content of flue gas	vol-%	18.0	20.8
Flue gas CO_2 (wet)	vol-%	9.9	9.1
Flue gas CO_2 (dry)	vol-%	12.2	11.5
Temperature of flame	°C	2040	2020
Vaporisation point of flue gas	°C	58.2	61.1

Fig. 6.36 Main properties and composition for the specific Natural Gas quality used in Denmark (sources http://www.gasteknik.dk/pdf/ngas_uk.pdf and http://www.dongenergy.dk)

Since the natural gas currently in use is characterized, as above depicted, by a ***PCS - Upper Calorific Value*** of 12,3 kWh/Nm^3, after necessary unit's conversions and retail costs' adjustments, the following values have been settled:

1,1587 € $/m^3$ → 0,11 €/kWh (ref. *Eurostat* and the Danish Institutional websites of above)

The ***BEopt Site Screen*** was therefore adjusted according to the following data:

<u>BEOPT *USER SPECIFIED* NATURAL GAS PRICE [DENMARK]:</u>

MARGINAL (including VAT) 0,11 €/kWh

FIXED (including VAT) 16,76 €/month

<u>BEOPT *USER SPECIFIED* NATURAL GAS – FUEL ESCALATION RATE [DENMARK]:</u>

(as evaluated on the average) **<u>~ 5,75% / year</u>**

Tanks to all the main information and data previously reported, it's therefore possible to sum them up by filling out the complete tables of below (for the Italian context and for the Danish background too). Actually, such global charts reveal themselves quite useful in order to better understand and sort out the several customizations required by *BEopt* interface.

ITALIAN SINGLE DETACHED HOUSE: SITE SCREEN MAIN SETTINGS			
ENERGY SOURCE (User Specified)		**TO BE OBSERVED**	**EUROPEAN CURRENCY**
ELECTRICITY	**MARGINAL**	In principle, from 1st Jan 2012, *The Italian Regulatory Authority for Electricity and Gas (Aeeg)* imposed the application of two-rate time-of-day tariff for domestic customers. But, since BEopt doesn't allow the application of such a distinction, only one low voltage electricity rate has been settled, based on a total maximum domestic energy power consumption of 3kW. (ref. *http://www.enel.it/it-IT/clienti/enel_servizio_elettrico/tariffe_per_la_casa/tariffe_monorarie_per_la_casa/tariffa_D2.aspx* and *http://www.enel.it/it-IT/doc/clienti/enel_servizio_elettrico/aprile_giugno_2013_comp_a_uc_mct_euro_anno_.pdf*) and *http://www.autorita.energia.it/it/dati/eep35.htm*	**0,22 € / kWh** (incl.VAT)
	FIXED		**13,00 € / month** (incl.VAT)
	FUEL ESCALATION (REAL)		**+ 3,00 % / year**
NATURAL GAS	**MARGINAL**	Ref. *http://epp.eurostat.ec.europa.eu* *(assuming in this case a PCS-Gross Calorific Potential of 10,6 kWh/Nm³)*	**0,918 € / Nm³** (incl.VAT) = **<u>0,097 € / kWh</u>**
	FIXED		**6,24 € / month** (incl.VAT)
	FUEL ESCALATION (REAL)		**+ 2,00 % / year**
FUEL OIL		Ref. *IEA (International Energy Agency) (however, this kind of energy source is not implemented into the current BEopt model)*	**1,915 € / liter** (Retail Price)
PROPANE		Ref. *EUROPE'S ENERGY PORTAL (however, this kind of energy source is not implemented into the current BEopt model)*	**0,730 € / liter** (Retail Price)
PROJECT ANALYSIS PERIOD			**30 YEARS**
INFLATION RATE (registered during year 2012)		Ref. *http://epp.eurostat.ec.europa.eu*: ***HICP-HARMONIZED INDICES OF CONSUMER PRICES*** - Annual Average Rate of Change	**+ 3,30 %**
DISCOUNT RATE (REAL)		***(Ref. EUROPEAN UNION CENTRAL BANK – BCE and EUROPEAN COMMISSION).*** The European Central Bank, on the webpage ***http://ec.europa.eu/competition/state_aid/legislation/reference_rates.html,*** had provided historical Discount Rates - distinguished according to the different European Member States - only until the year 2008. Thence, in order to settle the respective 2012's rate, a unique discount value - for both Italy and Denmark - has been adopted, based on the available data provided by European Commission.	**1,50 %** (updated on 31/12/2012)

Tab. 6.1 Main parameters to be introduced in *BEopt* for defining the Italian Boundary conditions

DANISH SINGLE DETACHED HOUSE: SITE SCREEN MAIN SETTINGS			
ENERGY SOURCE (User Specified)		**TO BE OBSERVED**	**EUROPEAN CURRENCY**
ELECTRICITY	**MARGINAL**	*Ref* *http//www.ens.dk/forbruger/boligen/energimaerkning/enfamilieshuse* http://www.elpristavlen.dk http://www.nordpoolspot.com http://www.energitilsynet.dk/ (hp.HUSHOLDNINGER 4000 kWh)	**0,2985 € / kWh** (incl.VAT)
	FIXED		**18,30 € / month** (incl.VAT)
	FUEL ESCALATION (REAL)		**+ 3,85 % / year**
NATURAL GAS	**MARGINAL**	*Ref.* *http:/www.ens.dk/forbruger/boligen/energimaerkning/enfamilieshuse* ***http://energitilsynet.dk/gas/prisstatistik/naturgasprisstatistik-1-kvartal-2013/*** *http://epp.eurostat.ec.europa.eu* **http://gasprisguiden.dk - *http://www.aalborgcityforsyning.dk* *(Abonnement Price Privatkunder ved Aalborg City Forsyning)*** *(assuming in this case a PCS-Gross Calorific Potential of 12,3 kWh/Nm^3)*	**1,1587 € / Nm^3** (incl.VAT) = **0,11€ / kWh**
	FIXED		**16,76 € /month** (incl.VAT)
	FUEL ESCALATION (REAL)		**+ 5,75 % / year**
FUEL OIL		*Ref.* *http://www.ens.dk/forbruger/boligen//energimaerkning/enfamilieshu* *(however, this kind of energy source is not implemented into the current* BEopt model)	**1,962 € / liter** (Retail Price)
PROPANE		*Ref.* *http://www.ens.dk/forbruger/boligen//energimaerkning/enfamilieshu* *(however, this kind of energy source is not implemented into the current* BEopt model)	**1,208 € / liter** (Retail Price)
PROJECT ANALYSIS PERIOD			**30 YEARS**
INFLATION RATE (registered during the year 2012)	Ref. *http://epp.eurostat.ec.europa.eu*: ***HICP-HARMONIZED INDICES OF CONSUMER PRICES*** - Annual Average Rate of Change		**+ 2,40 %**
DISCOUNT RATE (REAL)	***(Ref. EUROPEAN UNION CENTRAL BANK – BCE and EUROPEAN COMMISSION).*** The European Central Bank, at the webpage ***http://ec.europa.eu/competition/state_aid/legislation/reference_rates.html***, had provided historical Discount Rates - distinguished according to the different European Member States - only until the year 2008. Thence, in order to settle the respective 2012's rate, a unique discount value - for both Italy and Denmark - has been adopted, based on the available data provided by European Commission.		**1,50 %** (updated on 31/12/2012)

ab. 6.2 Main parameters to be introduced in *BEopt* for defining the Danish Boundary conditions

As shown by the above table, ***BEopt* Site Screen** also requires to be settled according to the main hypotheses and assumptions adopted while running the optimization process: thence, beside the **Analysis Period** to be investigated, also the average and most reliable **Inflation Rate** and **Discount Rate** were settled.

Inflation Rate [Italy and Denmark]

These information were gathered through a global review of all the main economic and financial reference Authorities established in Italy (***ISTAT*** *– National Institute of Statistic*, ***ANSA*** *– National Associated Press Agency* and ***DT*** *– Ministerial Treasury Department*), as well as in Europe (***BCE*** *– European Union Central Bank,* the ***European Commission*** and, above all, the ***EUROSTAT***).

Hence, according to the global analysis of the European money market and in function of the economic trend registered during these latest years - particularly with reference to the Eurozone ***HICP*** (*Harmonized Index of Consumer Prices*), ***CPI*** (*Consumer Price Index*) and ***EONIA*** (*Euro Overnight Index Average*) – the values of **3,3%** and **2,4%** were respectively adopted for Italy and Denmark: these values are in fact reported as being the average inflation rates registered by *EUROSTAT* during year 2012.

Discount Rate (Real) [Italy and Denmark]

With reference to this task, a further investigation was necessary in order to better understand how the software implements and deals with the Real Discount Rate: first of all, it's necessary to distinguish between the ***Nominal Dollars*** (also known as ***Current Dollars***) and the ***Real Dollars*** (also known as ***Constant Dollars***).

As detailed in the book entitled ***Secrets of Economic Indicators, The Hidden Clues to Future Economic Trends and Investment Opportunities*** (written by **Bernard Baumhol)**: "[…] *anything measured in dollars can be looked at in two ways. Nominal dollars (also referred to as current dollars) represents the actual amount of money spent or earned over a period of time* [….]. *However, nominal (or current) dollars gives you only part of the story. What's missing is how inflation can distort such numbers* […..]. *Nominal dollars simply reflects the present value of goods and services exchanged in the marketplace. However, real dollars tells you the true value of goods and services produced or sold because it strips out the effects of inflation.*
When economists and investors want to compare the performance of the economy over different time frames, they generally look at both measures — nominal and real. They note the change in the size of the economy in nominal dollars because that points to what individuals, businesses, and the government actually spent. However, to find out if the economy genuinely expanded by producing more in quantity or volume, economists and investors look at the numbers in real-dollar terms".

After the above enlightenments, as well as after a further review about the Reference-Discount Rates' and Recovery Rates' trend evaluated by European Commission from 1997 until 2008 (for all the EU Members), a unique discount value of **1,5 %** was adopted for both Italy and Denmark.
Actually, it was gathered from the available data provided by European Commission, also recalling that the European Central Bank had provided historical Discount Rates - distinguished according to the different European Member States - only until year 2008.

The further information needed for achieving a complete and all-embracing assessment are also connected to the definition of the ***OPTION COST MULTIPLIER***: actually, it lists the effective multipliers by which unit costs are multiplied in order to calculate total option costs.
Indeed, some building categories may have multiple cost multipliers. But, for the current building model, a unique cost multiplier was settled and then the value by which filling up the respective box was fixed in **1,0**.

Loan

Since BEopt allows dealing with the several retrofit and investment costs either in cash or through a financial loan, it's possible to settle and adjust both the ***Loan Period*** and the respective ***Loan Interest Rate***.

With reference to such an issue it's important to highlight that, while on the one hand the *DISCOUNT RATE* is usually applied in order to guess the actual, current value of a cash flow which will occur in the future, the *INTEREST RATE* is instead applied when, starting from an initial, real economic amount, the main investor's aim is that to guess the corresponding, future amount (i.e. the deficiency payment) to be paid.

To sum up, for any *INTEREST RATE* (***i***), exists a corresponding *DISCOUNT RATE* (***d***) and *vice versa*: namely, it's possible to state that

$$d = i / (1 + i)$$

N.B The only further information which is not possible to settle and customize through the Software Site Screen is connected to the selection of those optional, potential fiscal incentives in case of energy retrofit and building improvements (as currently allowed by the Italian Legislation - i.e. the **55%** and/or **65%** tax cut - also known as ***Incentivi e Detrazioni Fiscali per l'Efficienza Energetica***) before analyzed into details.
Thence, in order to include also the above latest information while running the different simulations, it would be necessary resorting to some artifices and expedients to "force" BEopt for achieving such an assessment (and/or plan to "spread" along the entire analysis period the incentives and tax cut even though, in principle, they should last only ten years).

N.B Moreover, another expedient to be settled in order to avoid taking into account the several expenses connected to natural replacements for the main building appliances and devices (e.g. refrigerator, washing machine, water heater etc.) after their lifetime's expiry, is to artificially fix at "***99 years***" their respective lifetime.

An alternative could also be selecting the option "***none***" in the respective *BEopt* checkboxes since, otherwise, the software usually automatically provides for them.

ITALIAN & DANISH OVERALL FRAME AND GLOBAL OBSERVATIONS:

	2008s1	2008s2	2009s1	2009s2	2010s1	2010s2	2011s1	2011s2	2012s1	2012s2	2012s2 / 2011s2
	in national currency per kWh										%
EU-27	0.159	0.167	0.164	0.164	0.168	0.173	0.180	0.185	0.189	0.197	6.56%
EA	0.165	0.172	0.173	0.173	0.177	0.182	0.189	0.194	0.199	0.206	6.13%
BE	0.197	0.215	0.192	0.186	0.196	0.197	0.214	0.212	0.233	0.222	4.91%
BG	0.139	0.161	0.161	0.160	0.159	0.162	0.162	0.171	0.166	0.187	9.24%
CZ	3.210	3.210	3.590	3.590	3.460	3.460	3.640	3.640	3.770	3.770	3.57%
DK	1.965	2.076	2.010	1.901	1.987	2.018	2.169	2.215	2.228	2.215	0.00%
DE	0.215	0.220	0.228	0.229	0.238	0.244	0.253	0.253	0.260	0.268	5.73%
EE	1.274	1.330	1.443	1.440	1.518	1.571	0.097	0.104	0.110	0.112	7.77%
IE	0.177	0.203	0.203	0.186	0.180	0.188	0.190	0.209	0.216	0.229	9.73%
EL	0.105	0.110	0.115	0.103	0.118	0.121	0.125	0.124	0.139	0.142	14.54%
ES	0.137	0.156	0.158	0.168	0.173	0.185	0.198	0.209	0.219	0.228	8.96%
FR	0.121	0.120	0.121	0.121	0.128	0.135	0.138	0.142	0.139	0.145	1.97%
IT	0.203	0.223	0.210	0.200	0.197	0.192	0.199	0.207	0.213	0.230	11.23%
CY	0.178	0.204	0.156	0.164	0.186	0.202	0.205	0.241	0.278	0.291	20.56%
LV	0.059	0.071	0.074	0.074	0.074	0.074	0.083	0.095	0.097	0.095	0.63%
LT	0.297	0.299	0.329	0.320	0.399	0.420	0.419	0.422	0.435	0.438	3.87%
LU	0.165	0.161	0.188	0.188	0.173	0.175	0.168	0.166	0.170	0.171	2.65%
HU	39.280	38.780	43.000	45.060	46.220	43.920	45.310	44.931	46.368	44.094	-1.86%
MT	0.099	0.154	0.171	0.151	0.170	0.170	0.170	0.170	0.170	0.170	0.00%
NL	0.177	0.180	0.198	0.189	0.171	0.176	0.174	0.184	0.186	0.190	3.10%
AT	0.178	0.177	0.191	0.191	0.197	0.193	0.199	0.197	0.198	0.202	3.00%
PL	0.439	0.458	0.506	0.540	0.537	0.551	0.581	0.579	0.602	0.631	8.87%
PT	0.148	0.153	0.151	0.159	0.158	0.167	0.165	0.188	0.199	0.206	9.68%
RO	0.390	0.408	0.413	0.416	0.428	0.450	0.452	0.466	0.461	0.487	4.42%
SI	0.115	0.116	0.135	0.134	0.140	0.143	0.144	0.149	0.154	0.154	3.35%
SK	4.580	4.630	0.154	0.156	0.152	0.164	0.168	0.171	0.172	0.172	0.70%
FI	0.122	0.127	0.130	0.129	0.133	0.137	0.154	0.157	0.155	0.156	-0.89%
SE	1.592	1.720	1.740	1.710	1.800	1.820	1.870	1.864	1.800	1.777	-4.69%
UK	0.113	0.131	0.131	0.125	0.121	0.123	0.124	0.137	0.138	0.143	3.86%
IS	:	:	:	:	:	:	:	:	18.098	18.451	:
NO	1.303	1.445	1.392	1.339	1.623	1.526	1.669	1.452	1.425	1.310	-9.79%
ME	:	:	:	:	:	:	0.087	0.085	0.091	0.101	18.52%
HR	0.720	0.850	0.850	0.850	0.836	0.843	0.841	0.857	0.911	1.038	21.11%
MK	:	:	:	:	:	:	:	:	:	4.869	:
TR	0.188	0.235	0.246	0.256	0.271	0.271	0.269	0.282	0.306	0.337	19.35%
AL	:	:	:	:	:	:	16.200	16.200	16.200	16.200	0.00%
BA	:	:	:	:	0.145	0.144	0.146	0.154	0.157	0.158	2.34%

Tab. 6.3 Electricity prices in Europe (complete statistical database sources available at: *http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables*)

	2008s1	2008s2	2009s1	2009s2	2010s1	2010s2	2011s1	2011s2	2012s1	2012s2	2012s2 / 2011s2
	in national currency per kWh										%
EU-27	0.054	0.063	0.059	0.053	0.052	0.057	0.056	0.065	0.063	0.072	10.34%
EA	0.061	0.071	0.066	0.058	0.057	0.063	0.062	0.072	0.069	0.079	10.35%
BE	0.059	0.073	0.061	0.052	0.053	0.060	0.063	0.073	0.069	0.073	0.41%
BG	0.069	0.077	0.093	0.068	0.072	0.084	0.084	0.092	0.097	0.109	17.77%
CZ	1.107	1.307	1.343	1.216	1.208	1.284	1.326	1.478	1.660	1.660	12.36%
DK	:	0.713	0.685	0.717	0.796	0.808	0.866	0.808	0.824	0.807	-0.05%
DE	0.064	0.076	0.065	0.059	0.057	0.057	0.059	0.064	0.064	0.065	1.25%
EE	0.524	0.580	0.617	0.567	0.567	0.627	0.042	0.044	0.050	0.052	18.54%
IE	0.054	0.065	0.064	0.055	0.050	0.053	0.051	0.062	0.061	0.067	8.74%
EL	:	:	:	:	:	:	:	:	:	0.102	:
ES	0.058	0.065	0.061	0.054	0.053	0.054	0.054	0.054	0.068	0.091	68.70%
FR	0.052	0.058	0.055	0.058	0.052	0.058	0.058	0.065	0.064	0.068	5.57%
IT	0.063	0.072	0.076	0.053	0.062	0.079	0.069	0.088	0.077	0.097	10.63%
LV	0.022	0.035	0.037	0.027	0.022	0.029	0.027	0.032	0.036	0.039	21.12%
LT	0.114	0.132	0.147	0.140	0.130	0.156	0.150	0.186	0.176	0.211	13.20%
LU	0.056	0.051	0.049	0.046	0.043	0.047	0.051	0.058	0.058	0.059	2.59%
HU	10.261	11.620	13.962	12.913	14.544	15.449	15.102	16.476	16.491	17.897	8.62%
NL	0.070	0.076	0.081	0.068	0.063	0.067	0.064	0.074	0.076	0.084	13.90%
AT	0.059	0.062	0.065	0.062	0.062	0.060	0.069	0.072	0.076	0.076	5.83%
PL	0.145	0.182	0.174	0.193	0.170	0.202	0.183	0.215	0.199	0.238	10.72%
PT	0.063	0.063	0.060	0.060	0.059	0.063	0.061	0.074	0.074	0.085	15.58%
RO	0.122	0.124	0.124	0.114	0.114	0.119	0.119	0.119	0.119	0.124	4.38%
SI	0.056	0.071	0.066	0.054	0.058	0.067	0.067	0.079	0.080	0.073	-7.83%
SK	1.380	1.410	0.046	0.048	0.044	0.045	0.047	0.051	0.052	0.051	0.39%
FI	:	:	:	:	:	:	:	:	:	:	:
SE	0.871	1.001	0.949	0.977	0.983	0.987	1.060	1.063	1.043	1.082	1.78%
UK	0.031	0.039	0.038	0.038	0.035	0.036	0.037	0.045	0.043	0.046	1.76%
HR	0.199	0.199	0.235	0.239	0.278	0.278	0.278	0.278	0.289	0.354	27.38%
MK	:	:	:	:	:	:	:	:	:	:	:
TR	0.061	0.090	0.084	0.067	0.065	0.066	0.064	0.072	0.074	0.094	29.46%
BA	:	:	:	:	0.074	0.088	0.089	0.105	0.109	0.109	3.43%

	2008s1	2008s2	2009s1	2009s2	2010s1	2010s2	2011s1	2011s2	2012s1	2012s2	2012s2 / 2011s2
	in national currency per GJ										%
EU-27	15.100	17.460	16.330	14.760	14.420	15.760	15.600	18.010	17.580	19.870	10.33%
EA	17.050	19.650	18.390	16.020	15.880	17.590	17.230	19.870	19.220	21.910	10.27%
BE	16.260	20.240	16.820	14.330	14.700	16.780	17.600	20.310	19.130	20.390	0.39%
BG	19.260	21.240	25.700	18.910	19.970	23.427	23.360	25.630	26.840	30.200	17.83%
CZ	307.450	363.030	373.120	337.810	335.500	356.770	368.280	410.460	461.010	461.170	12.35%
DK	0.000	198.070	190.350	199.270	221.000	224.380	240.500	224.380	228.860	224.260	-0.05%
DE	17.810	21.170	18.000	16.350	15.700	15.860	16.340	17.770	17.700	18.010	1.35%
EE	145.508	161.224	171.488	157.600	157.530	174.281	11.640	12.140	13.880	14.380	18.45%
IE	15.090	18.050	17.890	15.290	13.790	14.630	14.140	17.180	17.060	18.680	8.73%
EL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	28.250	:
ES	15.981	18.137	16.980	14.876	14.832	14.999	14.890	15.000	18.780	25.320	68.80%
FR	14.460	16.055	15.290	16.200	14.460	15.980	16.110	17.950	17.630	18.950	5.57%
IT	17.468	19.990	21.041	14.841	17.148	21.860	19.270	24.320	21.360	26.890	10.57%
LV	6.080	9.810	10.270	7.420	6.180	8.000	7.600	8.950	9.940	10.840	21.12%
LT	31.583	36.689	40.739	38.965	36.016	43.458	41.690	51.750	48.910	58.600	13.24%
LU	15.480	14.280	13.680	12.820	12.070	13.130	14.190	16.090	16.060	16.490	2.49%
HU	2 850.470	3 228.140	3 878.726	3 587.330	4 040.200	4 291.670	4 195.440	4 577.090	4 581.150	4 971.750	8.62%
NL	19.370	21.040	22.420	18.760	17.520	18.480	17.900	20.580	21.010	23.460	13.99%
AT	16.270	17.110	18.030	17.230	17.290	16.710	19.290	20.030	21.050	21.200	5.84%
PL	40.370	50.570	48.340	53.500	47.250	55.990	50.880	59.580	55.280	65.980	10.74%
PT	17.366	17.477	16.780	16.517	16.491	17.494	16.950	20.510	20.520	23.690	15.50%
RO	33.813	34.481	34.340	31.658	31.694	33.018	33.010	33.000	33.010	34.440	4.36%
SI	15.510	19.770	18.280	14.960	16.177	18.685	18.560	22.010	22.160	20.280	-7.86%
SK	383.220	391.820	12.829	13.212	12.111	12.390	12.930	14.210	14.320	14.290	0.56%
FI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	:
SE	241.870	278.040	263.570	271.330	272.960	274.080	294.450	295.180	289.620	300.430	1.78%
UK	8.514	10.855	10.580	10.519	9.798	9.920	10.250	12.600	11.920	12.830	1.83%
HR	55.200	55.300	65.400	66.440	77.260	77.090	77.090	77.210	80.280	98.340	27.37%
MK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	:
TR	17.068	24.948	23.338	18.578	18.150	18.374	17.710	20.090	20.650	26.010	29.47%
BA	0.000	0.000	0.000	0.000	20.540	24.360	24.600	29.200	30.200	30.200	3.42%

Tab. 6.4 a-b Natural Gas prices in Europe (complete statistical database sources available at: h*ttp://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables*)

According to the analysis of all the main information and average values provided by the International, Official Authorities of reference, as well as observing the summary tables above shown and analyzing the recent report related to the Italian Senate on 9th July 2013, it's possible to notice:

- the **taxation's influence** registered in **Italy** confirms a quite high and progressive escalation rate (in a different way than most of the other European Members);
- actually, e.g. in **Denmark**, U.K., and Spain (and according to the *Eurostat* assessment), the taxes' burdens still **remain almost unchanged** together with an increase of average consumption levels;
- moreover, with the single exception of **Denmark** (where the tax burden is particularly high), only for the lowest consumers' band the **Italian** taxation level is still comparable to the one applied in the other European Member States. It results indeed markedly higher for the other two Italian consumption classes.

6.6 Case study's main settings: Italian and Danish detached house

Single Detached House: Building's site and main Building's characteristics

Focusing now the specific analysis on the main characteristics which may be detected, on the average, for a **typical Italian Detached House** and in order to evaluate its main building components and material properties (also assessing their respective heath losses), it's possible to describe as follows the *BEopt* model which has been carried out.
As a matter of fact, such steps will allow a better understanding of "where and how" it should be preferable addressing and planning those main and most profitable building's improvements to be provided for the present case study.

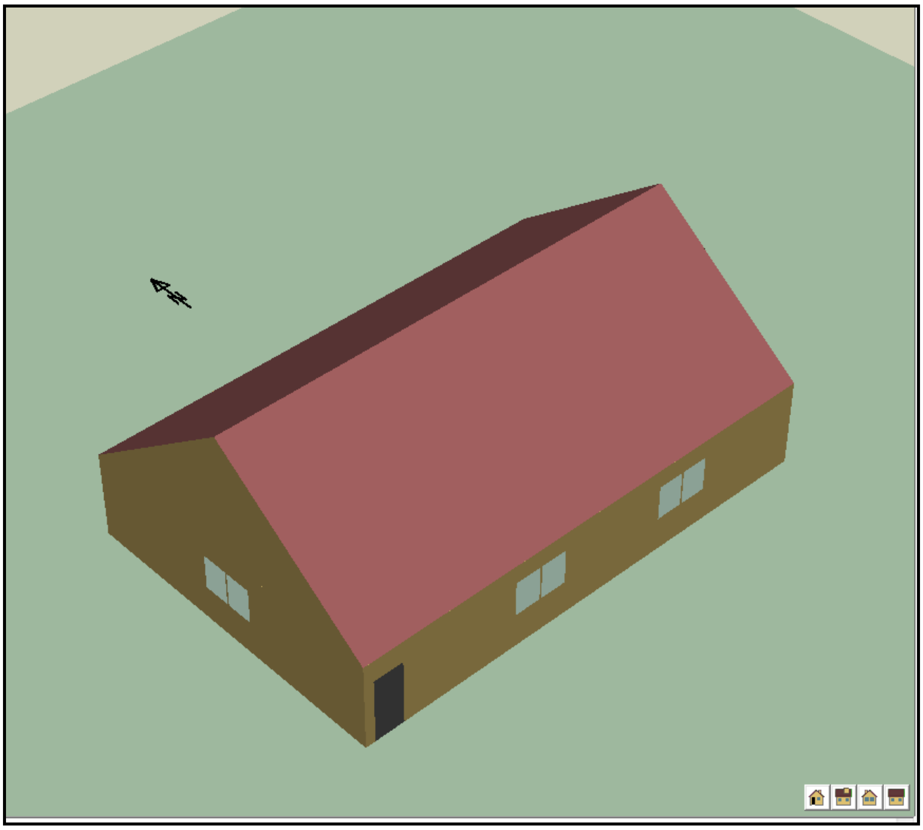


Fig. 6.37 Building Model Scheme (Italy & Denmark)
Default case – Single Detached House

6.7 Modeling vs. Improvement: evaluation and results - State of the Art – Italian case

Building's site and main Building's characteristics

ITALIAN SINGLE DETACHED HOUSE	
BOUNDARY CONDITIONS and MAIN BUILDING'S INFORMATION	
LOCATION	SARDINIA – ITALY (Energy Plus Weather Files to be settled according to those main working hypotheses hereinafter specified)
TERRAIN	SUBURBAN AREA
FLOOR NUMBER	1 FLOOR
FINISHED AREA	150,219 m^2
ROOMS & BATHS	2 BEDROOMS 1 BATHROOM
ORIENTATION	SOUTH
NEIGHBORS	NONE
ROOF TYPE	PITCHED *GABLE* Roof Type with a *RAFTER* Structure and a ROOF PITCH RATIO of (9:12)
WALLS' HEIGHT	2,7 m
OPERATION and BEOPT MAIN SETTINGS	
HEATING SET POINT (ref. Reg. UNI 11300-1 and EN 15251:2007 – Table A.2 Res. Cat. II)	20 °C
COOLING SET POINT (ref. EN 15251:2007 – Table A.2 Res.Cat. II)	26 °C
HUMIDITY SET POINT (ref. EN 15251:2007 – Tab.B.6 Res.Cat. II)	50 % RH
MISC. ELECT. LOADS (ref. Reg. UNI 11300-1, sec.13.1)	1,50 (4.169 kWh/yr gas/electric 4.453 kWh/yr All electric)
MISC. GAS LOADS	0,00
MISC. HOT WATER LOADS	LOW-FLOW SHOWERS & SINKS
NATURAL VENTILATION	COOLING MONTHS ONLY

Tab. 6.5 Main Italian building model's boundary conditions and *BEopt* Operation settings

BUILDING ELEMENTS	ELEMENTS' PROPERTIES TO BE ADAPTED AND CUSTOMIZED THROUGH BEOPT	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIALLY EVALUATED VALUES
WALLS	"MURATURA A CASSETTA"	External walls:" STEP 4 LAYERS " custom		
	4 LAYERS ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER	4 LAYERS		
	LAYER 1: BRICKS	LAYER 1: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m^3 SPECIF.HEAT: 840 J/kg*°K THERMAL CONDUCT: 0.3 W/m*°K	
	LAYER 2: RENDERING / ROCK DASH	LAYER 2: RENDER CEMENT MORTAR	LAYER WIDTH: 1 cm DENSITY: 2000 kg/m^3 SPECIF.HEAT: 670 J/kg*°K THERMAL CONDUCT: 1.4 W/m*°K	
	LAYER 3: INSULATION	LAYER 3: GLASS WOOL (FIBERGLASS) BOARD INSULATION	LAYER WIDTH: 5 cm DENSITY: 30 kg/m^3 SPECIF.HEAT: 800 J/kg*°K THERMAL CONDUCT: 0.039 W/m*°K	GLOBAL R ASSEMBLY VALUE (FOR THE ONLY 4 LAYERS SETTLED): (2.36 m^2*°K/W) ---------------------------- CONSEQUENT U VALUE: (0.424 W/m^2*°K) GLOBAL R ASSEMBLY VALUE (resultant from the sum of the 2 different BEOPT customizing sections): (2.36+0.035) m^2*°K/W= 2.395 m^2*°K/W -------------------------------------
	LAYER 4: BRICKS	LAYER 4: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m^3 SPECIF.HEAT: 840 J/kg*°K THERMAL CONDUCT: 0.3 W/m*°K	
WALLS - EXTERIOR FINISH	WHITE LIME-GYPSUM PLASTER	WHITE LIME-GYPSUM PLASTER	LAYER WIDTH: 2 cm DENSITY: 1400 kg/m^3 SPECIF.HEAT: 1010 J/kg*°K THERMAL CONDUCT: 0.7 W/m*°K	RESULTANT R VALUE (FOR THE ONLY EXTERIOR FINISH LAYER): (0.035 m^2*°K/W) ---- CONSEQ. U VALUE: (28.6 W/m^2*°K) CONSEQUENT U VALUE to be considered for the exterior walls: .42 W/m^2*°K
			ABSORPTIVITY (solar radiation absorptance of exterior finish - fraction: 0.2) INFRA RED EMISSIVITY - fraction: 0.91	
CEILINGS / ROOF	UNFINISHED ATTIC	UNINSULATED, VENTED	DEFAULT BEOPT OPTION CASE	CEILING NOMINAL R-ASSEMBLY: (0.335 m^2*°K/W) ------------------------------------ CONSEQUENT U VALUE: (2.99 W/m^2*°K)
	ROOFING MATERIAL RADIANT BARRIER	TILES, MEDIUM CUSTOM NONE	ROOFING MATERIAL ABSORPTIVITY (FRACTION):0.65 ROOFING MATERIAL EMISSIVITY (FRACTION):0.85	ROOF R-ASSEMBLY: (0.352 m^2*°K/W) ------------- CONSEQ U VALUE: (2.839 W/m^2*°K)
FOUNDATION / FLOORS	SLAB ON GRADE	UNINSULATED SLAB ON GRADE		SLAB PERIMETER CONDUCTANCE: (1.33 W/m*°K)

Tab. 6.6 Main Italian model's elements and properties and respective *BEopt* Operation settings

			100 % EXPOSED FLOOR (all the above-grade floor surfaces in conditioned spaces are assumed to be UNCARPETED)		
THERMAL MASS (FURTHER CUSTOMIZ. ALLOWED)	EXTERNAL WALL MASS	*"INTERNAL CEMENT MORTAR"* custom	CEMENT MORTAR-PLASTER THICKNESS: (0.79 inches GYPSUM THICKNESS for the EXT. WALL) 1 SHEET of default DRYWALL layer	RESULTANT CAPACITANCE: 0.66 Btu/°F*ft²	THE MAIN PROBLEM RELATED TO THIS TASK IS CONNECTED TO THE FACT THAT BEOPT DEFAULT SETTINGS ONLY ALLOW TO CUSTOMIZE THESE CATEGORIES AS IF THEY CONSIST INTO *DRYWALLS*
	PARTITION WALL MASS	*"HEAVY WALLS"* custom	LAYER THICKNESS: 8 cm THERMAL CONDUCT: 0.25 W/m*K DENSITY: 600 kg/m³ SPECIF. HEAT: 920 J/kg*K	RESULTANT CAPACITANCE: 1.97 Btu/°F*ft²	
	CEILING MASS	*"NO DRYWALL"* custom	THICKNESS: 0.025 cm *Since there isn't any sheet of drywall attached to ceiling of the house (but BEOPT doesn't allow us to neglect them), the smallest valid value has been settled* 1 SHEET of default DRYWALL layer	RESULTANT CAPACITANCE: 0.01 Btu/°F*ft²	
WINDOWS & SHADING	WINDOW AREAS	The WINDOW AREAS OPTION takes into account the total windows area evaluated as a percentage of exterior wall area, with a respective distribution into [Front, Back, Left, Right] and including both glazing and framing.	TOTAL WINDOWS AREA PERCENTAGE: 7.0 % CORRESPONDENT TOTAL WINDOWS AREA: (9.1 m²)		
	WINDOW TYPE	2 PANE, CLEAR glass, NON METAL frame	U-Value = (2.799 W/m²*K) SHGC – Solar Heat Gain Coefficient: 0.564		
	INTERIOR SHADING	*SUMMER 0,5– WINTER 0,95*	Heating Season (frac): 0,95 Cooling Season (frac): 0,5		
	EAVES	NONE	NONE		
	OVERHANGS	NONE	NONE		
AIRFLOW	INFILTRATION RATE	LEAKY	0.53 ACH — LEAKY	According to the Italian Requirements *UNI 11300-1 par 12.1.1*, a *Tight* inf. rate (0,3 ACH) should be respected	
	MECHANICAL VENTILATION	NONE	NONE		
MAJOR APPLIANCES	REFRIGERATOR	CHOOSEN AMONG THE AVAILABLE DEFAULT OPTIONS	ENERGY STAR, TOP MOUNT FREEZER (374 kWh/yr Elect.Use Volume 510 liters)		
	COOKING RANGE	CUSTOM OPTION	GAS, CONVENTIONAL CUSTOM (67 kWh/yr Elect.Use – Gas Use: =703.84 kWh/yr)		
	DISHWASHER	CUSTOM OPTION	Annual Energy Use: 276 kWh/yr		
	CLOTHES WASHER	CUSTOM OPTION	Mod.En.Fact.2.47 ft³/kWh*cycle–Ann.cons. 247 kWh–Drum's Vol = 42.5 lit ~ 5kg		
	CLOTHES DRYER	NONE	CLOTHES LINE		

Tab. 6.6 – cont: Main Italian model's elements and properties and respective *BEopt* Operation settings

LIGHTING	LIGHTING OPTION	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	100% FLUORESCENT, HARDWIRED Total Energy Use = 1056 kWh/yr	
SPACE CONDITIONING	SIMPLE HEATING SYSTEM SETTLED	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	GAS FURNACE – 92.5% AFUE (Annual Fuel Utilization Efficiency)	
	AIR CONDITIONER	NONE		
	HYDRONIC HEATING	NONE		
	HEAT PUMP	NONE		
	GROUND SOURCE HEAT PUMP	NONE		
	DUCTS	NONE		
	CEILING FANS	NONE		
	DEHUMIDIFIER	NONE		
WATER HEATING	WATER HEATER	CUSTOM OPTION	GAS STANDARD CUSTOM (0.59 ENERGY FACTOR – TANK VOLUME ~ 11 liters)	
	DISTRIBUTION	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	UNINSULATED, TrunkBranch, Copper	
	SOLAR DHW (Solar Domestic Hot Water heating)	NONE		
	SDHW AZIMUTH			
	SDHW TILT			
POWER GENERATION	PHOTOVOLTAIC SYSTEM	NONE		
	PV AZIMUTH			

Tab. 6.6 – cont: Main Italian model's elements and properties and respective *BEopt* Operation settings

N.B.$_1$ Regarding the main appliances here settled, the selection among all the available *BEopt* default options or the creation of new, custom tasks, was based on the real possibility that the U.S. standards of reference are possible to be adapted or not to the main European settings.

N.B.$_2$ Regarding the different appliances' lifetimes here selected (all evaluated in years), the same *BEopt* references, parameters and statements were applied.

<u>Heat Transfer Contributions' evaluation through the different Building Elements: ITALIAN MODEL</u>

HEAT TRANSFER'S CONTRIBUTIONS THROUGH THE DIFFERENT BUILDING ELEMENTS (*)					
ITALY	To be observed with reference to surface's evaluation	U [W/m^2*K]	A [m^2]	U*A [W/K]	
CEILING	It takes into account the total finished area of the floor	2,989	150,219	449,005	(***)
ROOF	It Includes the two pitches of the *BEopt Gable* Roof Type with a *Rafter* Structure and a Roof Pitch ratio of (9:12)	2,839	187,826	533,238	
EXTERNAL WALLS	It was calculated basing on the data and information provided by *BEopt* (some small different approximations still exist while basing the evaluations on *BEopt* walls' height vs. *BEopt* windows' areas deductions)	0,420	130,060	54,625	
WINDOWS	It takes into account the total windows area evaluated as a percentage of exterior wall area, with a respective distribution into [Front, Back, Left, Right] and including both glazing and framing.	2,799	9,104	25,482	
FOUNDATION SLAB	It takes into account the total finished area of the floor	0,633	150,219	66,096	(**)

Tab. 6.7 Main Italian dwelling model's properties and respective building elements' heat loss

(*) Some rounding off approximations must be noticed due to the conversions made from/to *U.S. Metrics* ⇆ *S.I. Metrics* and/or vice versa.

(**)With reference to the method applied in order to evaluate the Foundation Slab Transmittance, there was considered an **uninsulated** slab which consists of **uncarpeted**, 4 inches (10 cm) heavy weight concrete (CC03 in the DOE-2.1E library), with a resistance = 0,44 hr*ft^2*F/Btu (0,078 m^2*K/W). Applying the same criteria reported by the *Winkelmann Article* (see *http://gundog.lbl.gov/dirun/23n_d_1.pdf* for EnergyPlus simulations), the following results were obtained

Slab Surface Area: A =33*49= 1.617 ft^2 (150,219 m^2)

Slab Exposed Perimeter: P_{exp}= (2*33)+(2*49) =164 ft

Effective Slab Resistance: R_{eff}= A/(*F2**P_{exp}) = 1617/(**0,77***164) = 12,805 hr*ft^2*F/Btu

(where *F2* is the Perimeter Conduction Factor for Concrete Slab-on-Grade as reported by *Table 1* of the *Winkelmann Article* – recalling "Y.J. Huang, L.S. Shen, J.C. Bull, L.F. Goldberg, *Whole-house Simulation of Foundation Heat Flows Using the DOE-2.1C Program, ASHRAE Transactions 94 (2) (1988)*")

Effective Slab U-value:

U_{eff}=1/R_{eff}=1/**12,805** = 0,078 Btu/hr*ft^2*F= **0,44 W/m^2*K**

Actual Slab Resistance: R_{us}=0,44+R_{film}=0,44+0,77= 1,21 hr*ft^2*F/Btu=**0,213 m^2*K /W**

Despite the current study case analyzes an uninsulated, **uncarpeted** slab, the above value of **0,77** is gathered from the right column (hp. slab **carpeted**) of the previous *Table 1* since the percentage of carpeted/uncarpeted slab surface is automatically evaluated by the software in proportion with the floor exposure percentage selected through the *Exposed Floor Category* of *BEopt*.

The calculations above implemented required some assessment's approximations: that's because, being aware that heating transmission through the soil is, for a slab on grade, due to different contributions (lateral horizontal dispersion and vertical dispersion through the soil), it has been necessary recalling how Italian – and European - regulations evaluate these contributions (ref. *UNI 11300-1 par.11*, and *UNI EN ISO 13370*) and it has been revealed quite difficult transferring such criteria to the *BEopt* model.

Furthermore, still quoting the ***Winkelmann Article*** *http://gundog.lbl.gov/dirun/23nd1.pdf*

« Heat Transfer:

Care needs to be taken in describing the construction of an underground surface in order to get a correct calculation of the heat transfer through the surface and a correct accounting for the thermal mass of the surface, which is important in the weighting factor calculation for the space. In the LOADS program, DOE-2 calculates the heat transfer through the underground surface as:

$$Q = U*A(T_g - T_i)$$

*where **U** is the conductance of the surface, **A** is the surface area, T_g is the ground temperature and T_i is the inside air temperature. If the raw U-value of the surface is used in this expression the heat transfer will be grossly overcalculated. This is because the heat transfer occurs mainly through the surface's exposed perimeter region (since this region has relatively short heat flow paths to the outside air) rather than uniformly over the whole area of the surface. For this reason, users are asked to specify an effective U-value with the U-EFFECTIVE keyword. This gives:*

$$Q = [U\text{-}EFFECTIVE]*A(T_g - T_i)$$

*In general **U-EFFECTIVE** is much less than the **raw U-value**.*

The following procedure shows how to determine U-EFFECTIVE for different foundation configurations. It also shows how to define an effective construction for an underground surface that properly accounts for its thermal mass when custom weighting factors are specified.

The procedure assumes that the monthly ground temperature is the average outside air temperature delayed by three months, which is similar to how the ground temperatures on the weather file are calculated. […….] ».

Thence we should assume that the program doesn't take into account the vertical, only one-way thermal exchanges along the perpendicular to the basement's slab surface.
Besides, recalling once again the *Winkelmann Article*:

« Procedure for defining the underground surface construction:

***1)** Choose a value of the perimeter conduction factor, $\boldsymbol{F_2}$ […….] for the configuration that best matches the type of surface (slab floor, basement wall, crawl-space wall), foundation depth and amount and/or location of insulation.*
***2)** Using $\boldsymbol{F_2}$, calculate $\boldsymbol{R_{eff}}$, the effective resistance of the underground surface, which is defined by the following equation:*
$\boldsymbol{R_{eff} = A / (F_2 * P_{exp})}$
*where **A** is the area of the surface (ft^2 or m^2) and $\boldsymbol{P_{exp}}$ is the length (ft or m) of the surface's perimeter that is exposed to the outside air. […….]. If $\boldsymbol{P_{exp}}$ is zero (§), set $\boldsymbol{R_{eff}}$ to a large value, e.g. $\boldsymbol{R_{eff}}$ = 1.000*
3)** Set **U-EFFECTIVE = 1/$\boldsymbol{R_{eff}}$
The program will calculate the heat transfer through the underground surface to be
Q = [U-EFFECTIVE]* A ($\boldsymbol{T_g - T_i}$)
***4)** Define a construction, shown in the figure below, consisting of the following:*

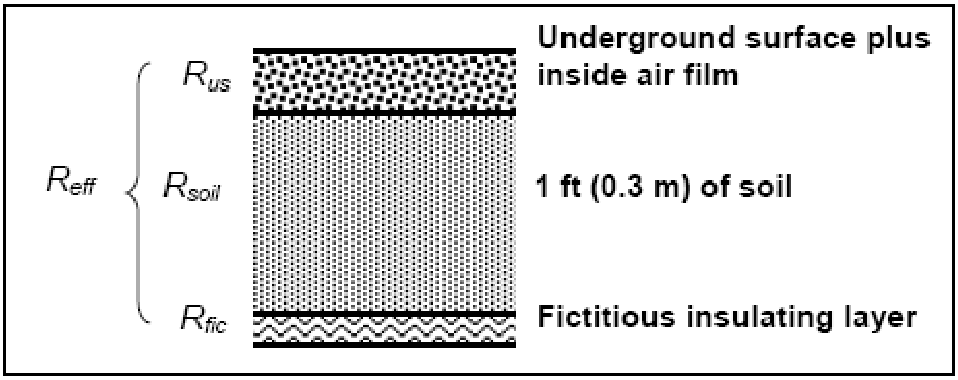


FIG. 6.38 Quoting *the "Procedure for defining the underground surface construction"*
(sources*:* http://gundog.lbl.gov/dirun/23n_d_1.pdf and http://SimulationResearch.lbl.gov)

(§) <u>The procedure makes the approximation that the heat transfer through an underground surface with no exposed perimeter, such as a basement floor, is zero.</u>

- *The underground wall or floor, including carpeting (if present) and inside film resistance (overall resistance = $\boldsymbol{R_{us}}$)*
- *A 1 ft (0,3 m) layer of soil (resistance = R_{soil} = 1,0 hr*ft^2*F/Btu [0,18 m^{2*}K/W])*
- *A fictitious insulating layer (resistance = R_{fic})*

The layer of a soil represents the thermal mass of the ground in contact with the underground surface (a 1 ft [0,3 m] layer is sufficient to account for most of the thermal mass effect). The fictitious insulating layer is required to give the correct effective resistance for the construction, i.e.

$\boldsymbol{R_{eff} = R_{us} + R_{soil} + R_{fic}}$

From this we get
$R_{fic} = R_{eff} – R_{us} – R_{soil}$

[…….] »

(**) While, taking into account also the **Resistance of fictitious insulation layers under the soil layer** and considering that here the value of 0,77 hr*ft^2*F/Btu is the average of the air film for *Heat Flow Up* (i.e. 0,61 hr*ft^2*F/Btu=0,11 m^2*K/W) and *Heat Flow Down* (i.e. 0,92 hr*ft^2*F/Btu=0,16 m^2*K/W), we may say that:

the **Resistance of fictitious layer** is

$$\mathbf{R_{fic} = R_{eff} - R_{us} - R_{soil}} = 8{,}963 – 1{,}21 – 1 = 6{,}753 \text{ hr*ft}^2\text{*F/Btu} = \mathbf{1{,}189\ m^2{*}K\ /W}$$

Hence, by summing up the **Actual Slab Resistance** and the **Resistance of fictitious insulation layers under the soil layer**, we get the following expression:

$$\mathbf{R_{us} + R_{fic}} = (1{,}21 + 6{,}753) \text{ hr*ft}^2\text{*F/Btu} = 7{,}963 \text{ hr*ft}^2\text{*F/Btu}$$
$$= 1{,}402 \text{ m}^2\text{*K /W}$$

Some uncertainties are still connected to the necessary approximations and hypotheses here assumed while dealing with such calculations. However, since the default model slab is completely uninsulated, it should be also clear that a necessary improvement is still required.

(***) Furthermore, it must be observed that, while on the one hand the **roof** separates two unconditioned zones (i.e. the unfinished attic from the exterior), on the other hand instead the **ceiling** surface lies between the unconditioned unfinished attic area and a heated zone (i.e. the finished and conditioned living area).
Thence, recalling that the current main goal is to minimize as much as possible the conditioned zones' heating losses and since the ceiling is immediately in contact with the heated area (actually it distinguishes two different thermal zones), such a remark should be taken into particular account while evaluating and planning the several improvement options and retrofitting alternatives to be adopted.
And this, even though its global contribution is lower than the roof's one (as a matter of fact, 448,854 W/K < 533,238 W/K).

Nonetheless, as an alternative, it would be also possible considering as a unique global thermal zone the <u>whole attic area</u> and thence evaluate the following combined U value:

$$\mathbf{U_T = 1/R_{TOT} = 1/\ (R_{CEIL} + R_{ROOF})} = 1/(0{,}3346+0{,}3522) \text{ m}^2\text{*K/W} =$$
$$= 1/\ (0{,}6868) \text{ m}^2\text{*K/W} \rightarrow \underline{\mathbf{U_T = 1{,}456\ W/m^2{*}K}}$$

It reveals however still more fruitful and convenient to focus the main insulating solutions which should be applied for the top of the building onto its ceiling.

In the light of all the above remarks, it's therefore possible detecting and highlighting those most critical building elements to be privileged within a global retrofit and improvement project.

6.8 Modeling vs. Improvement: evaluation and results - state of the art – Danish case

Building's site and main Building's characteristics

DANISH SINGLE DETACHED HOUSE	
BOUNDARY CONDITIONS and MAIN BUILDING'S INFORMATION	
LOCATION	DENMARK – COPENHAGEN (Energy Plus Weather Files "DNK_ COPENHAGEN")
TERRAIN	SUBURBAN AREA
FLOOR NUMBER	1 FLOOR
FINISHED AREA	150,219 m^2
ROOMS & BATHS	2 BEDROOMS 1 BATHROOM
ORIENTATION	SOUTH
NEIGHBORS	NONE
ROOF TYPE	PITCHED *GABLE* Roof Type with a *RAFTER* Structure and a ROOF PITCH RATIO of (9:12)
WALLS' HEIGHT	2,7 m
OPERATION & BEOPT GLOBAL SETTINGS	
HEATING SET POINT (ref.Danish Standards-Building Reg. and EN 15251:2007 – Tab. A.2 Res.Cat. II)	20 °C
COOLING SET POINT (ref. EN 15251:2007– Tab.A.2 Res.Cat. II)	26 °C
HUMIDITY SET POINT (ref. EN 15251:2007– Tab.B.6 Res.Cat. II)	50 % RH
MISC. ELECT. LOADS (ref. EN 832:2001, sec.6)	2,00 (5.559 kWh/yr gas/electric 5.938 kWh/yr All electric)
MISC. GAS LOADS	0,00
MISC. HOT WATER LOADS	LOW-FLOW SHOWERS & SINKS
NATURAL VENTILATION	COOLING MONTHS ONLY

Tab. 6.8 Main Danish building model's boundary conditions and *BEopt* Operation settings

BUILDING ELEMENTS	ELEMENT S' PROPERTIES TO BE ADAPTED AND CUSTOMIZED THROUGH BEOPT	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIAL EVALUATED VALUES	
WALLS	"LECA 3 LAYERS WALL" 3 LAYERS	External walls: " LECA 3 LAYERS WALL " custom 3 LAYERS		GLOBAL *R ASSEMBLY VALUE* (FOR THE ONLY 3 LAYERS SETTLED): (2.13 m²*°K/W) ---------------------------------- CONSEQUENT *U VALUE*: (0.469 W/m²*°K)	
	ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER				
	LAYER 1: BRICKS	LAYER 1: KLINKER BRICKS	LAYER WIDTH: 11 cm DENSITY: 1800 kg/m³ SPECIF.HEAT: 1000 J/kg*°K THERMAL CONDUCT: 1 W/m*°K		
	LAYER 2: INSULATION	LAYER 2: GLASSWOOL INSULATION	LAYER WIDTH: 5 cm DENSITY: 30 kg/m³ SPECIF.HEAT: 800 J/kg*°K THERMAL CONDUCT: 0.039W/m*°K		GLOBAL *R ASSEMBLY VALUE* (resultant from the sum of the 2 differents BEOPT customizing sections): (2.13 + 0.106) m²*°K/W = 2.236 m²*°K/W -- CONSEQUENT U VALUE to be considered for the exterior walls: 0.447 W/m²*°K
	LAYER 3: LECA BRICKS	LAYER 3: LECA	LAYER WIDTH: 10 cm DENSITY: 700 kg/m³ SPECIF.HEAT: 1000 J/kg*°K THERMAL CONDUCT: 0.21 W/m*°K		
WALLS – EXTERIOR FINISH	WHITE BRICKS	WHITE BRICKS custom	LAYER WIDTH: 11 cm DENSITY: 1800 kg/m³ SPECIF.HEAT: 920 THERMAL CONDUCT: 1 W/m*°K	RESULTANT *R VALUE* (FOR THE ONLY *EXTERIOR FINISH LAYER*): (0.106 m²*°K/W) ------------------------- CONSEQUENT U VALUE: (9.46 W/m²*°K)	
			ABSORPTIVITY (solar radiation absorptance of the exterior finish - fraction: 0.60 INFRARED EMISSIVITY - fraction: 0.92		
CEILINGS/ROOF	UNFINISHED ATTIC	CUSTOM – DK GLASS-WOOL INSULATED	THICKNESS OF CEILING INSULATION (GLASS-WOOL): 10 cm R-VALUE OF CEILING INSULATION (GLASS-WOOL): 2.7 m²*°K/W THICKNESS OF CEILING JOISTS: 10 cm	CEILING NOMINAL R-ASSEMBLY: (2.7 m²*°K/W) -- CONSEQUENT *U VALUE*: (0.37 W/m²*°K)	
	ROOFING MATERIAL	TILES, MEDIUM, CUSTOM	ROOFING MATERIAL ABSORPTIVITY (FRACTION):0.65 ROOFING MATERIAL EMISSIVITY (FRACTION):0.85	ROOF R-ASSEMBLY: (0.352 m²*°K/W) ---------- CONSEQ U *VALUE*: (2.839 W/m²*°K)	
	RADIANT BARRIER	NONE			

Tab. 6.9 Main Danish model's elements and properties and respective *BEopt* Operation settings

FOUNDATION / FLOORS	SLAB ON GRADE	UNINSULATED SLAB ON GRADE		SLAB PERIMETER CONDUCTANCE: (1.33 W/m*°K)
			100 % EXPOSED FLOOR (all the above-grade floor surfaces in conditioned spaces are assumed to be UNCARPETED)	
THERMAL MASS (FURTHER CUSTOMIZATIONS ALLOWED)	EXTERNAL WALL MASS	*"NO DRYWALL"* custom	THICKNESS: 0.025 cm (0.01 inches). Since there isn't any sheet of drywall attached to ceiling of the house (but BEOPT doesn't allow us to neglect them), the smallest valid value has been settled	RESULTANT CAPACITANCE: 0.01 Btu/°F*ft² — ALSO IN THE CURRENT CASE, THE MAIN PROBLEM RELATED TO THIS TASK IS CONNECTED TO THE FACT THAT BEOPT DEFAULT SETTINGS ONLY ALLOW TO CUSTOMIZE THESE CATEGORIES AS IF THEY CONSIST INTO *DRYWALLS*
			1 SHEET of default DRYWALL layer	
	PARTITION WALL MASS	*"HEAVY WALLS DK"* custom	LAYER THICKNESS (hollow bricks): 8 cm	RESULTANT CAPACITANCE: 3.61 Btu/°F*ft²
			THERMAL CONDUCT (hollow bricks): 0.36 W/m*°K	
			DENSITY: 1100 kg/m³	
			SPECIF.HEAT: 920 J/kg*°K	
	CEILING MASS	*"GYPSUM CEILING-DK"* custom	GYPSUM CEIL. THICKN.:1.5 cm	RESULT CAPACITANCE: 0.5 Btu/°F*ft²
			1 SHEET of default DRYWALL layer	
WINDOWS & SHADING	WINDOW AREAS	The WINDOW AREAS OPTION takes into account the total windows area evaluated as a percentage of the exterior wall area, with a respective distribution into [Front, Back, Left, Right] and including both glazing and framing.	TOTAL WINDOWS AREA PERCENTAGE: 7.0 %	
			CORRESPONDENT TOTAL WINDOWS AREA: (9.1 m²)	
	WINDOW TYPE	2 PANE, CLEAR glass, NON METAL frame	U-Value: (2.799 W/m²*K)	
			SHGC – Solar Heat Gain Coefficient 0.564	
	INTERIOR SHADING	*Winter = 0,95*	Heating Season (frac): 0.95	
			Cooling Season (frac): 0.70	
	EAVES	NONE	NONE	
	OVERHANGS	NONE	NONE	
AIRFLOW	INFILTRATION RATE	LEAKY	0.53 ACH — LEAKY	According to the Danish Regulations (ref.Danish Building Reg. 6.3.1.2) a *Tight* Inf. rate (0,3 ACH) should be respected

Tab. 6.9 – cont: Main Danish model's elements and properties and respective *BEopt* Operation settings

	MECHANICAL VENTILATION	NONE	NONE
MAJOR APPLIANCES	REFRIGERATOR	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	ENERGY STAR, TOP MOUNT FREEZER (374 kWh/yr Elect.Use - Volume = 510 lit.)
	COOKING RANGE	CUSTOM OPTION	GAS, CONVENTIONAL CUSTOM (67 kWh/yr Elect.Use – Gas Use 24 therms/yr=2401607 Btus/yr=703.84 kWh/ yr)
	DISHWASHER	CUSTOM OPTION	Annual Energy Use 276 kWh/yr
	CLOTHES WASHER	CUSTOM OPTION	Modified Energy Factor 2.47 ft³/kWh*cycle – Annual Energy consumption 247 kWh – Drum's Volume = 42.5 liters ~ 5kg
	CLOTHES DRYER	NONE	CLOTHES LINE
LIGHTING	LIGHTING OPTION	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	100% FLUORESCENT, HARDWIRED Total Energy Use = 1056 kWh/yr
SPACE CONDITIONING	SIMPLE HEATING SYSTEM SETTLED	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	GAS FURNACE – 92.5% AFUE (Annual Fuel Utilization Efficiency)
	AIR CONDITIONER	NONE	
	HYDRONIC	NONE	
	HEAT PUMP	NONE	
	GROUND SOURCE HEAT PUMP	NONE	
	DUCTS	NONE	
	CEILING FANS	NONE	
	DEHUMIDIFIER	NONE	
WATER HEATING	WATER HEATER	CUSTOM OPTION	GAS STANDARD CUSTOM (0.59 ENERGY FACTOR – TANK VOLUME 11 liters)
	DISTRIBUTION	CHOOSEN AMONG THE AVAILABLE BEOPT DEFAULT OPTIONS	UNINSULATED, TrunkBranch, Copper
	SOLAR DHW (Solar Domestic Hot	NONE	
	SDHW AZIMUTH		
	SDHW TILT		
POWER GENERATION	PHOTOVOLTAIC SYSTEM	NONE	
	PV AZIMUTH		
	PV TILT		

Tab. 6.9 – cont: Main Danish model's elements and properties and respective *BEopt* Operation settings

Heat Transfer Contributions' evaluation through the different Building Elements: DANISH MODEL

HEAT TRANSFER'S CONTRIBUTIONS THROUGH THE DIFFERENT BUILDING ELEMENTS (*)					
DENMARK	To be observed with reference to surface's evaluation	U [W/m²*K]	A [m²]	U*A [W/K]	
CEILING	It takes into account the total finished area of the floor	0,37	150,219	55,58	
ROOF	It Includes the two pitches of the BEopt *Gable* Roof Type with a *Rafter* Structure and a Roof Pitch ratio of (9:12)	2,839	187,826	533,238	(***)
EXTERNAL WALLS	It was calculated basing on the data and information provided by *BEopt* (some small different approximation exist while basing the evaluations on *BEopt* walls' height vs. *BEopt* windows' areas deductions)	0,447	130,060	58,166	
WINDOWS	It takes into account the total windows area evaluated as a percentage of the exterior wall area, with a respective distribution into [Front, Back, Left, Right] and including both glazing and framing.	2,799	9,104	25,482	
FOUNDATION SLAB	It takes into account the total finished area of the floor	0,633	150,219	66,096	(**)

Tab. 6.10 Main Danish dwelling model's properties and respective building elements' heat loss

N.B. With reference to the different "asterisks & notes" of above, the same considerations before mentioned with reference to the Italian building model still remain valid.

A further clarification is needed in order to better justify and explain the main criteria which addressed such an assessment, along with the main building elements' evaluation here carried out.
Actually, according to an integrated and "*holistic*" approach for the entire building context (as below summed up in **Fig. 6.39**), two fundamental principles may be adopted into fruitfully planning an overall retrofitting strategy:

- On the one hand, the most powerful **Energy Saving Measures** for reducing the main energy losses before detected must be planned (and, at this regard, the preventive overall building elements' assessment of above would be particularly useful).

- On the other hand, a proper **Energy Delivering Plan** should be defined and implemented as an additional equipments' complex for the reference building of interest.

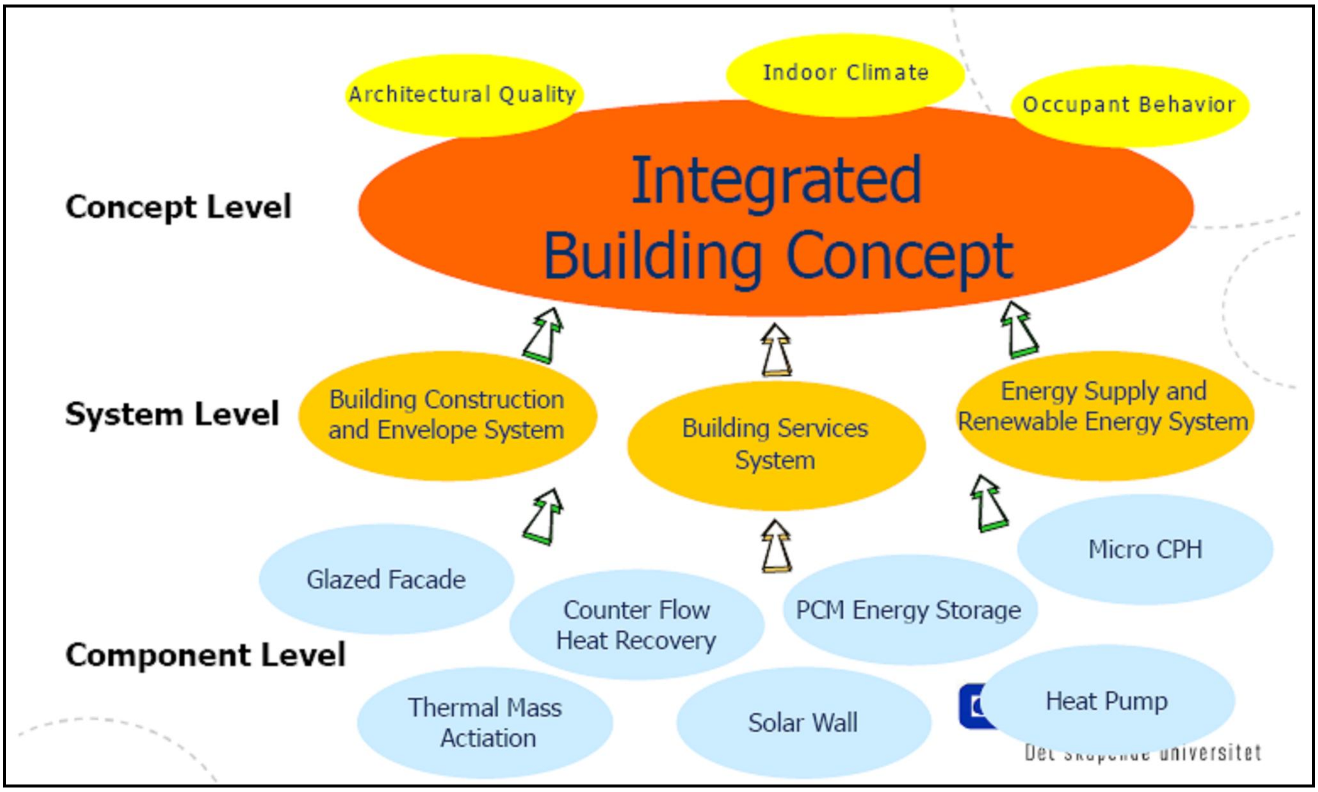


Fig. 6.39 Illustration of the main principles laying behind an *Integrated Building Concept* (as depicted by [*http://www.ides-edu.eu*](http://www.ides-edu.eu) and quoting P. Heiselberg's and Annemie Wyckmans's lecture on *Design Strategies for Energy Demand Reduction*)

Hence, in first instance, a focus on those building elements which reveal the highest heating loss (respectively based on the Tab. 6.7 and Tab. 6.10) is required;

Secondly, it's necessary to plan the main improvements and most opportune retrofit measures to be adopted in order to respect the U-value limits respectively imposed by Italian and Danish Regulations for the different building elements (and still keeping in mind that - for Italy - <u>two main different classes of limits</u> exist, depending on the simple goal to comply with the Law, or also to exploit the economic tax deduction provided by the Italian Revenue Agency).
Furthermore, in the light of the above remarks, also in the retrofitting plans hereinafter detailed a main distinction was applied between ***<u>Energy Saving Measures</u>*** and ***<u>Energy Delivering Actions</u>*.**

6.9 Modeling vs. Improvement: evaluation and results - state of the art – Italian case: design case's Energy Label based on the current Italian Energy Rating Criteria

Before going through the core theme of the analysis, along with the different retrofitting scenarios' evaluation, a fundamental clarification is now needed: actually, with reference to the main Regulations and Labelling/Certification criteria currently in force in Italy, it must be recalled that all the settled limits and reference parameters are valid and applicable only in case of evaluations based on **<u>STATIC</u>** calculations, while instead the software *BEopt* implements a global **<u>DYNAMIC</u>** simulation.

Nevertheless, such remarks and those "ranking criteria" hereinafter applied may be considered still rather interesting and meaningful, since they provide some further information about how the average energy consumption registered for the residential building of reference could be interpreted under a more pragmatic, consistent and contextualized point of view.

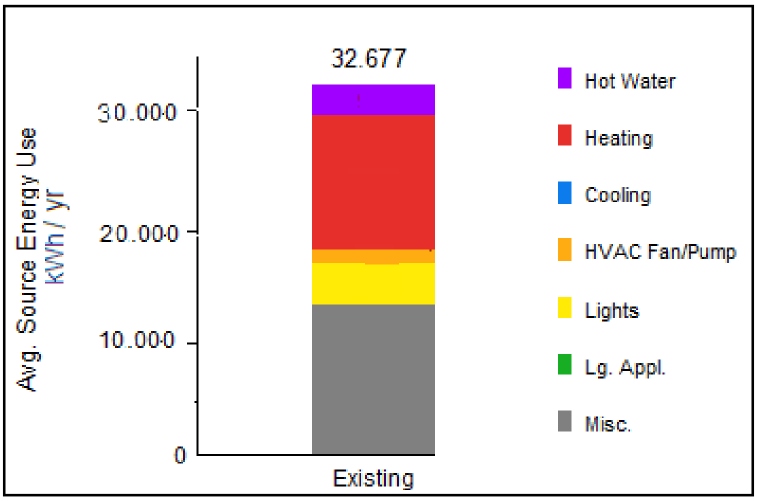
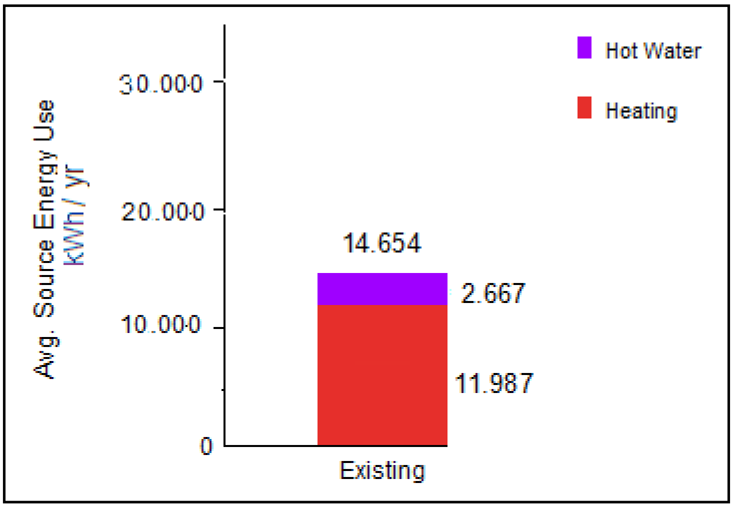


Fig. 6.40 *BEopt* Output: Energy Consumption Design Case - Italy – Olbia CLIMATIC ZONE: "*C*"

Only focusing the attention on the main contributions to be considered for an energetic rating assessment, such output values may be summed up as follows:

Fig. 6.40-bis *BEopt* Output:



Energy Consumption Design Case – Italy – Olbia CLIMATIC ZONE: "*C*"

As below depicted and still recalling all the necessary metric conversions worked out from the ***American Standards*** to the ***European*** and the ***International System Units***, the following summary table may be filled in:

BEOPT OUTPUT ENERGY CONSUMPTION VALUES – DEFAULT CASE – ITALY - OLBIA (CLIMATIC ZONE "C")			
	CONSUMPTION CATEGORIES		
GLOBAL ENERGY CONSUMPTION	DOMESTIC HOT WATER HEATING FAN/PUMP LIGHTS LG. APPL MISCELLANEOUS	32.677 kWh/yr	
ONLY HEATING	HEAT.	11.987 kWh/yr	TOTAL CONSUMPTION: 14.654 kWh/yr (97,69 kWh/m^2*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	2.667 kWh/yr	
		"F" RATING CLASS	

Tab. 6.11 Italian Existing Building – Default Case assessment – Climatic Zone "*C*"

Focusing now the analysis on the secondly most representative Sardinian climatic zone (i.e. the "*D*" zone), the following existing case assessment's results were gathered:

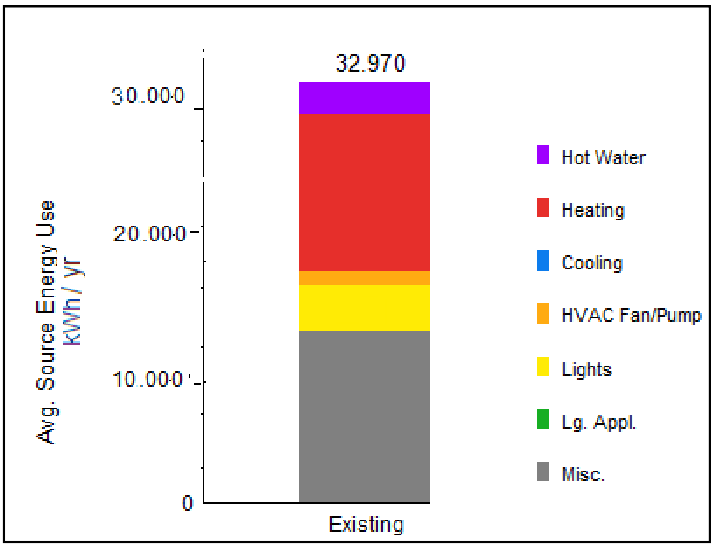


Fig. 6.41 *BEopt* Output: Energy Consumption Design case – Italy - Pozzomaggiore CLIMATIC ZONE: "*D*"

Only focusing the attention on the main contributions to be considered for an energetic rating assessment, such output values may be summed up as follows:

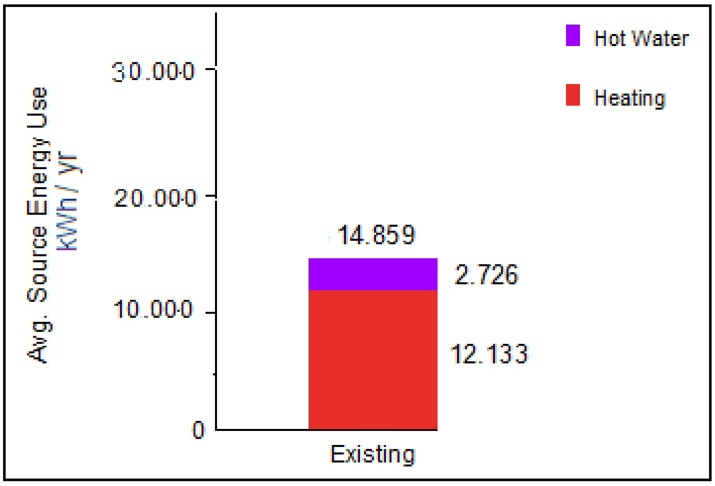


Fig. 6.41-bis *BEopt* Output: Energy Consumption Design case – Italy - Pozzomaggiore CLIMATIC ZONE: "*D*"

BEOPT OUTPUT ENERGY CONSUMPTION VALUES– DEFAULT CASE– ITALY - POZZOMAGGIORE (CLIMATIC ZONE "*D*")			
	CONSUMPTION CATEGORIES		
GLOBAL ENERGY CONSUMPTION	DOMESTIC HOT WATER	32.970 kWh/yr	
	HEATING		
	FAN/PUMP		
	LIGHTS		
	LG. APPL		
	MISCELLANEOUS		
ONLY HEATING	HEAT.	12.133 kWh/yr	TOTAL CONSUMPTION: 14.859 kWh/yr (99 kWh/m^2*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	2.726 kWh/yr	
		***"E"* RATING CLASS**	

Tab. 6.12 Italian Existing Building – Default Case assessment – Climatic Zone "*D*"

Italian Design Case's Assessment: Economic implications

It's now possible adjusting and afterwards analyzing the main running outputs (i.e. the different energy consumptions associated to the Italian Base – Design Case) also under an economical point of view.
Regarding this task and in order to achieve an "instantaneous pan" for a "2012's energy consumption sample", it's important to highlight that the economical and financial fuel escalation rates before settled were temporarily kept aside.

Thence, the utility bills which have been evaluated without any fuel escalation rate (i.e. **with a 0% escalation rate both for the electricity and the natural gas, and for Italy and Denmark as well**) may be depicted by the stacked bar charts of below**:**

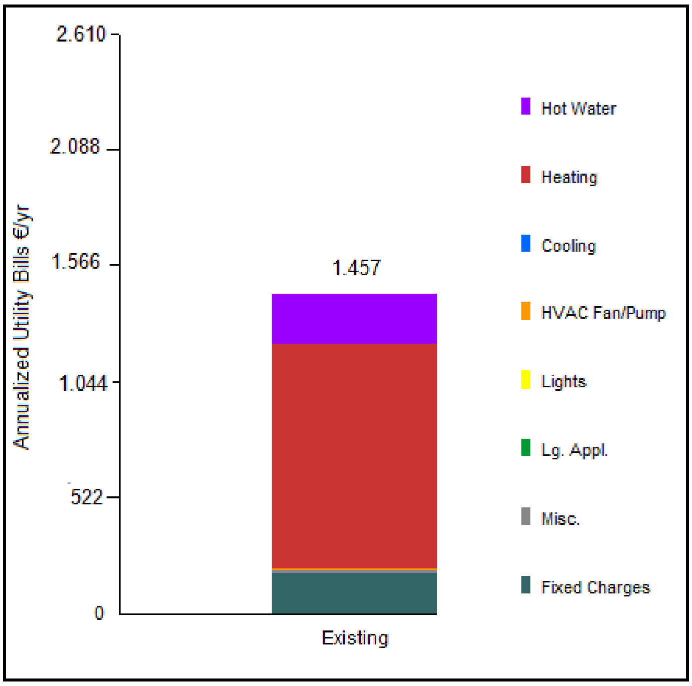


Fig. 6.42 BEopt Output: Utility Bills Design case - Italy – Olbia CLIMATIC ZONE: "*C*"

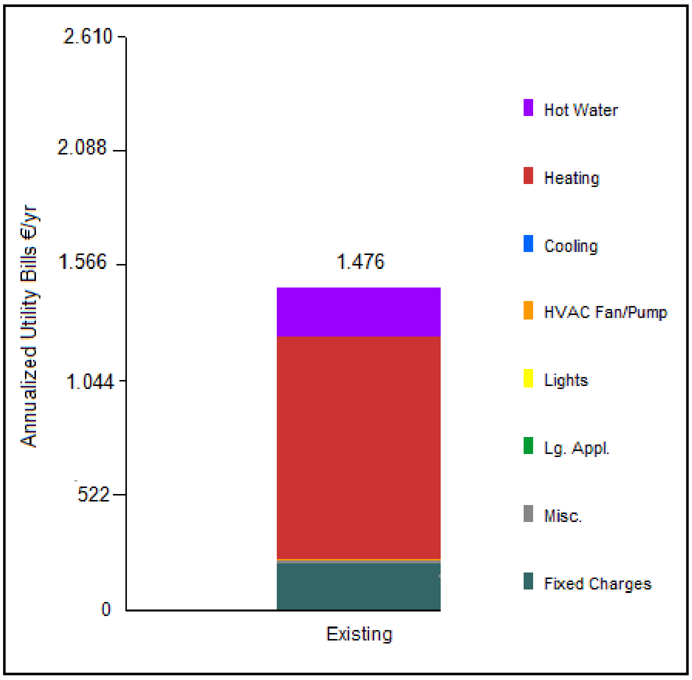


Fig. 6.43 BEopt Output: Utility Bills Design case - Italy – Pozzomaggiore CLIMATIC ZONE: "*D*"

BEOPT OUTPUT ENERGY CONSUMPTION VALUES – ITALY			
OLBIA - C ZONE	CONSUMPTION CATEGORIES		
ONLY HEATING	HEAT.	1.012 €/yr	TOTAL CONSUMPTION (FIXED CHARGES INCLUDED): 1.457 €/yr (~9,7 €/m²*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	226 €/yr	
BEOPT OUTPUT ENERGY CONSUMPTION VALUES – ITALY			
POZZOMAGGIORE- D ZONE	CONSUMPTION CATEGORIES		
ONLY HEATING	HEAT.	1.026 €/yr	TOTAL CONSUMPTION (FIXED CHARGES INCLUDED): 1.476 €/yr (~9,8 €/m²*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	230 €/yr	
BEOPT OUTPUT ENERGY CONSUMPTION VALUES - ITALY- AVERAGE REFERENCES			
Ref. *http://www.casa24.ilsole24ore.com*		*Average Utility Bills evaluated in case of an ITALIAN "F"* RATING CLASS: ~ 11 €/m²*yr	

Tab. 6.13 Italian Existing Building – Default Case assessment – Utility Bills

6.10 Modeling vs. Improvement: evaluation and results - state of the art – Danish case: design case's Energy Label based on the current Danish Energy Rating Criteria

Before the analysis of the different, possible retrofit solutions, along with their respective impact assessment for the entire reference dwelling, it's possible to evaluate as follows the Danish model's energetic asset, based on the fundamental properties previously defined.

Actually, this can be particularly useful to better understand and assess, since the beginning, the main differences and distinctions which may be detected between the Italian and the Danish reference building here adopted.

At this regard, it's also important to highlight that, in order to achieve the most adherent comparison and parallelism between the two different climatic and geographical contexts - as well as between the two different building materials mainly used in such countries - analogous modeling criteria were applied (whenever possible), e.g. for the total finished surfaces, for the main appliances implemented etc…

Focusing now the analysis on the specific parameters and rating criteria which should be adopted into assessing and detecting the effective energy class for the above detached house, the "***EPC - Energy Performance Certification***" scheme (established and evaluated by the "***DEA – Danish Energy Agency***") was applied.

Furthermore, as previously observed with reference to the Italian model's assessment, it must be recalled that, also in this case, all the specific energy consumption levels and global outputs gathered after having launched the software derive from a **DYNAMIC** simulation.

The Implementation of EPBD in Denmark – Certification of Buildings

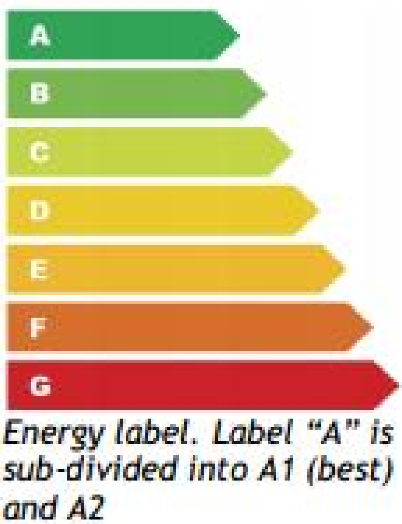
The introduction of National laws meeting the EU regulations, and particularly the ***Energy Performance of Buildings Directive (Directive 2002/91/EC - EPBD)***, has led in Denmark (as well as in Italy and in all the other European Union Members) to the establishment of specific building requirements.
In particular, for Denmark, the implementation of *EPBD* is under the responsibility of the ***DEA*** (***Danish Energy Agency***) and of the ***Danish Enterprise and Construction Authority***.
As previously mentioned, a new secretariat for the daily operations connected to the ***Energy Performance Certification (EPC) Scheme*** has started functioning since May 2010 within *DEA*.

Such a section (***Energieffektive Bygninger - SEEB***) also covers quality assurance and contributions to the future development for the global scheme currently in force, as well as marketing.

The current ***EPC Scheme*** has replaced the mandatory certification schemes existing since 1997 and has been regularly revised over the years in order to update its main requirements, also adapting them to the undergoing continuous and rapid society's evolution.

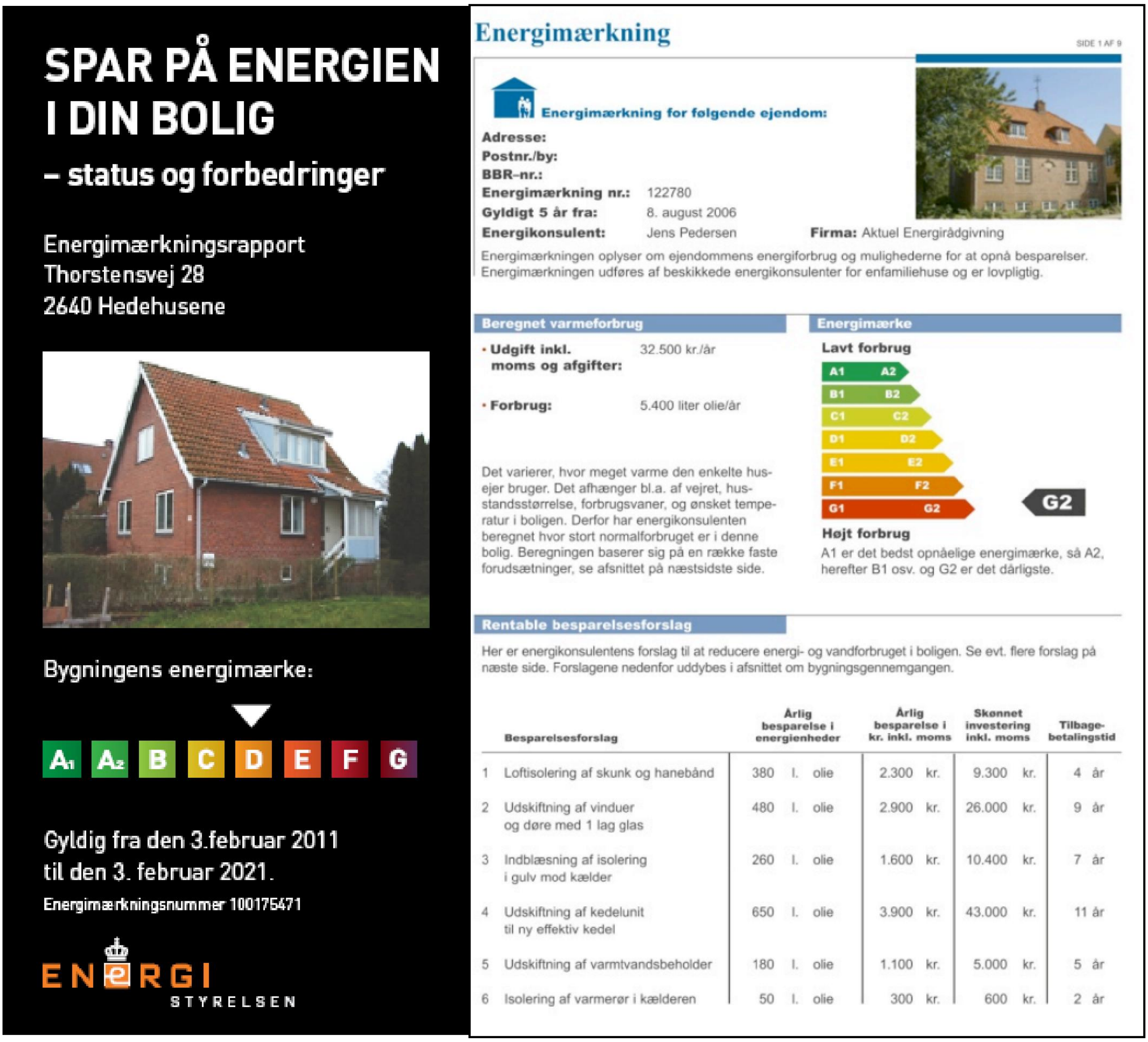
The Danish Energy Performance Certificate

The ***Energy Performance (EP) Certificate*** assigns an energy performance label to almost all the types of buildings and lists cost-effective measures for improving their energy performance. Actually, the energy label allows classifying all the different buildings basing on an efficiency scale ranging from the ***A Class*** (high energy efficiency buildings) to the ***G Class*** (poor efficiency ones).
Moreover, the A Class is divided into further two categories - ***A1*** and ***A2*** – (as below depicted) which identify the two low energy classes defined by the *Building Regulations* since year 2008.
The energy efficiency rating indicates a dwelling's energy consumption and the possibility of achieving respective savings.



Label	Residential	Non-residential
A1	< 35 + 1100/A	< 50 + 1100/A
A2	< 50 + 1600/A	< 70 + 1600/A
B	< 70 + 2200/A	< 95 + 2200/A
C	< 110 + 3200/A	< 135 + 3200/A
D	< 150 + 4200/A	< 175 + 4200/A
E	< 190 + 5200/A	< 215 + 5200/A
F	< 240 + 6500/A	< 265 + 6500/A
G	> 240 + 6500/A	> 265 + 6500/A

Fig. 6.44 *Danish Energy Labelling Scheme*: global rating criteria



Energimærkning

SIDE 1 AF 9

Energimærkning for følgende ejendom:

Adresse:
Postnr./by:
BBR-nr.:
Energimærkning nr.: 122780
Gyldigt 5 år fra: 8. august 2006
Energikonsulent: Jens Pedersen **Firma:** Aktuel Energirådgivning

Energimærkningen oplyser om ejendommens energiforbrug og mulighederne for at opnå besparelser. Energimærkningen udføres af beskikkede energikonsulenter for enfamiliehuse og er lovpligtig.

Beregnet varmeforbrug

- **Udgift inkl. moms og afgifter:** 32.500 kr./år
- **Forbrug:** 5.400 liter olie/år

Det varierer, hvor meget varme den enkelte husejer bruger. Det afhænger bl.a. af vejret, husstandsstørrelse, forbrugsvaner, og ønsket temperatur i boligen. Derfor har energikonsulenten beregnet hvor stort normalforbruget er i denne bolig. Beregningen baserer sig på en række faste forudsætninger, se afsnittet på næstsidste side.

Energimærke

Lavt forbrug
A1 A2
B1 B2
C1 C2
D1 D2
E1 E2
F1 F2
G1 G2
G2
Højt forbrug

A1 er det bedst opnåelige energimærke, så A2, herefter B1 osv. og G2 er det dårligste.

Rentable besparelsesforslag

Her er energikonsulentens forslag til at reducere energi- og vandforbruget i boligen. Se evt. flere forslag på næste side. Forslagene nedenfor uddybes i afsnittet om bygningsgennemgangen.

	Besparelsesforslag	Årlig besparelse i energienheder	Årlig besparelse i kr. inkl. moms	Skønnet investering inkl. moms	Tilbage-betalingstid
1	Loftisolering af skunk og hanebånd	380 l. olie	2.300 kr.	9.300 kr.	4 år
2	Udskiftning af vinduer og døre med 1 lag glas	480 l. olie	2.900 kr.	26.000 kr.	9 år
3	Indblæsning af isolering i gulv mod kælder	260 l. olie	1.600 kr.	10.400 kr.	7 år
4	Udskiftning af kedelunit til ny effektiv kedel	650 l. olie	3.900 kr.	43.000 kr.	11 år
5	Udskiftning af varmtvandsbeholder	180 l. olie	1.100 kr.	5.000 kr.	5 år
6	Isolering af varmerør i kælderen	50 l. olie	300 kr.	600 kr.	2 år

Fig. 6.45 a-b *Danish Energy Labelling Scheme*: energy certification's examples

In the light of all the above enlightenments, the current cost-effectiveness assessment and the analysis of all its respective optimization scenarios, reveals then even more meaningful and pregnant.

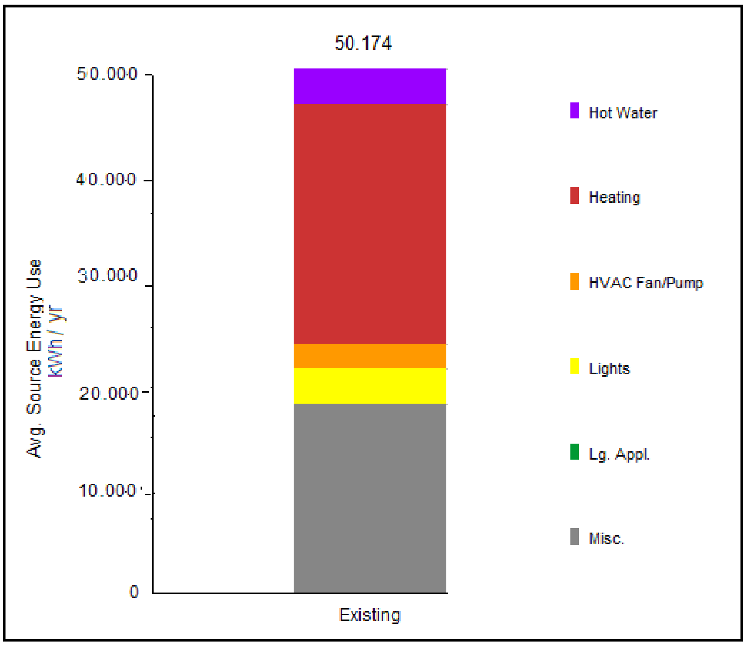


Fig. 6.46 *BEopt* Output: Energy Consumption Design Case – Denmark

Only focusing on those main contributions to be considered for the Energetic Rating assessment, the output values may be summed up as follows:

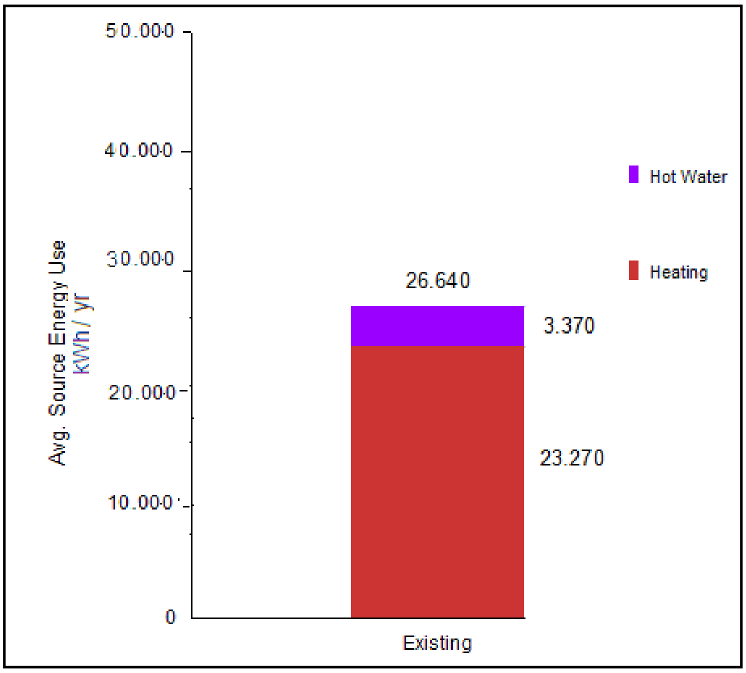


Fig. 6.46-bis *BEopt* Output: Energy Consumption Design Case – Denmark

Also in this case, after having applied all the necessary conversions from *U.S.* metrics to *S.I.* units and recalling that *Danish Building Regulations* and energy rating criteria only take into account (in order to assess the specific energy class for a residential building) the main contributions due to Domestic Hot Water, Heating Consumption and Air Conditioning Systems, it's possible to sum up the following results:

BEOPT OUTPUT ENERGY CONSUMPTION VALUES - DENMARK			
	CONSUMPTION CATEGORIES		
GLOBAL ENERGY CONSUMPTION	DOMESTIC HOT WATER	50.174 kWh/yr	
	HEATING		
	FAN/PUMP		
	LIGHTS		
	LG. APPL		
	MISCELLANEOUS		
ONLY HEATING	HEAT.	23.270 kWh/yr	TOTAL CONSUMPTION: 26.640 kWh/yr (177,6 kWh/m^2*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	3.370 kWh/yr	
		"D" RATING CLASS [*177.6 kWh/m^2*yr* < (150 + 4200/A) = *178 kWh/m^2*yr*]	

Tab. 6.14 Danish Existing Building – Default Case assessment

Danish Design Case's Assessment: Economic implications

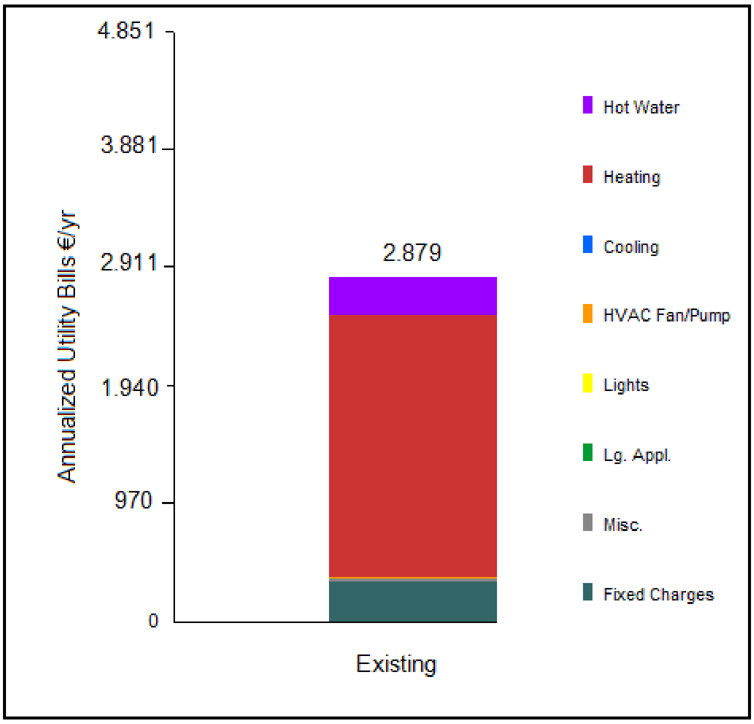


Fig. 6.47 BEopt Output: Utility Bills Design case - Denmark

BEOPT OUTPUT ENERGY CONSUMPTION VALUES - DENMARK			
	CONSUMPTION CATEGORIES		
ONLY HEATING	HEAT.	2.165 €/yr	TOTAL CONSUMPTION (FIXED CHARGES INCLUDED): 2.879 €/yr (~19,2 €/m^2*yr)
ONLY DOMESTIC HOT WATER	D.H.W.	313 €/yr	
BEOPT OUTPUT ENERGY CONSUMPTION VALUES – DENMARK - AVERAGE REFERENCES			
Ref. *http://www.ens.dk/forbruger/boligen/energimaerkning/enfamilieshuse*	*Average Utility Bills evaluated in case of a DANISH "D"* RATING CLASS: ~ 17 €/m^2*yr		

Tab. 6.15 Danish Existing Building – Default Case assessment – Utility Bills

Typisk energiforbrug

I en bolig på 140 m2 koster energien til varme og varmt vand typisk:

Årlig energiudgift	A1/A2	B	C	D	E	F	G
El (1,87 kr./kWh)	8.000	19.500	28.500	41.000	53.500	67.000	75.000
Olie (0,38 kr./kWh)	4.500	10.500	15.500	22.500	29.500	37.000	41.000
Naturgas (8,69 kr./kWh)	3.500	8.000	12.000	17.500	22.500	28.500	31.500
Fjernvarme ex. fast afgift (0,61 kr./kWh)	2.500	6.500	9.500	13.500	17.500	22.000	24.500

Fig. 6.48 Typical energy consumption in a house of 140 m^2: average utility costs based on the different energy classes (cost energy for heating and hot water typically)

17.500 DKK/140 m^2

125 DKK/ m^2*yr → ~ 17 €/m^2*yr

In the light of the above assessments and summary tables it was hence possible verifying the strictly reliability and trustworthiness of the results until now obtained (for Italy and Denmark as well), also exploiting them in order to properly plan the several improvement and testing scenarios to be evaluated.

6.11 Modeling vs. Improvement: main focus on the key-elements to be considered for the global retrofit assessment; Italy vs. Denmark

For the main purpose of better understanding and justifying the specific methodologies expressly adopted into dealing with such a renovating process for Italy and Denmark, the following remarks and distinctions reveal themselves necessary and particularly meaningful.

- Actually, before going through the core optimization scenarios' analysis, some further clarifications are required: in first instance it must be specified that, in order to avoid taking into account the main replacement costs connected with the different **Building Appliances** (e.g. refrigerator, washing machine etc…) while planning the future "Retrofit Scenarios" for the default case, they have been settled as "None". And when this hadn't been possible (e.g. for the lighting group typologies), very low/infinitesimal energy consumption values have been settled in order to avoid any software's alert and/or error log.
- A particular, further specification and requirement should be highlighted, only for the Danish retrofitting background and when assessing the different possible windows' retrofit solutions: as a matter of fact, according to the *Danish Building Regulations*, when replacing existing windows with new ones, the following parameter – i.e. the ***Net Energy Gain Factor*** - has to be evaluated and verified.

  In general, the net energy gain for windows may be defined as the solar gain minus the heat loss integrated over the heating season. Hence, the net energy gain expresses in a simple way the energy performance of windows.

  Regarding the introduction of the Directive on the Energy Performance of Buildings in EU, a shift from 'heat loss' to 'used energy' in the characterization of buildings with respect to the energy performances must be highlighted (ref. Svendsen S., Kragh J., Laustsen J., in "*Energy performance of windows based on net energy gain*").

  In particular, the used net energy gain equation is described in Nielsen T.R., Duer K. and Svendsen S., and it applies to Danish conditions without considering the specific air permeability: such a parameter is useful into quantifying the energy performance of windows and, as mentioned above, it may be calculated by adopting the formulation of below.

  $$E = g_w * I - U_w * D \quad [kWh/m^2]$$

  Where:

  I is the solar radiation calculated for a reference house;
  D is referred to the degree hour number during the heating season in Denmark;
  U_w expresses the total thermal transmittance;
  g_w is the total solar energy transmittance of the window.

  It must be recalled that the net energy gain will be negative when energy is lost.
  For Denmark, the above parameters' values may be specified as follows:

  $I = 196{,}40\ kWh/m^2$
  $D = 90{,}36\ kKh$

  In particular, the current Regulations for new windows in Denmark require that the ***E factor*** is higher than (-33) kWh/m^2/year.

  Thence:

E= (g_w*196,40 - U_w*90,36) > (- 33) kWh/m²/year

In addition, it must be also highlighted that, in order to respect the **U_W limit** of **1,4 kWh/m²/year** established by the *Danish Building Regulations,* an even more strictly defined retrofitting framework is therefore outlined.
Furthermore, all the clarifications mentioned above are going to be particularly meaningful to properly deal with all the available new windows solutions provided by the *BEopt* interface (also addressing and steering the retrofit project when selecting a *High* or *Low Solar Heat Gain Coefficien*t, a *Higher* or *Lower glass emissivity* etc….).

Main retrofit costs' definition: assumption and remarks – Italy vs. Denmark

As stated above, in order to properly define the main retrofitting assumptions and costs in function of the specific context to be assessed, a complete revision and customization of the *BEopt Cost Setting Schedule* (and its respective integration with new cost entries and item prices) was necessary.
Actually, for the purpose of adapting the standard *BEopt* template in function of the most common and performing energy-retrofitting solutions adopted in Italy and Denmark (and generally in Europe), new materials were introduced, along with their average economic evaluation.

Nevertheless, a main distinction must be highlighted when dealing with such a task for the Italian or the Danish background: indeed, if on the one hand for Italy a wider reference costs database, distinguished in function of the specific materials to be adopted, as well as based on the specific technique to be applied (e.g. when planning an additional insulation for any building element) was available, on the other hand a more limited field of action was possible with reference to the Danish context.
As an example, some of the main references and databases exploited while customizing (through several *ad hoc* spreadsheets) the different retrofit measures to be assessed for the Italian context may be following listed:

- ***http://www.regione.sardegna.it - Prezzario dei Lavori Pubblici*** (Institutional Framework for Public Works);
- Besides, also other ***Italian Regional Official Price Bulletins*** were considered, also resorting to the more complete, several price lists implemented and available within the ***ACCA – PRIMUS – UNICUM - DCF*** software (a special program expressly developed for evaluating building works' global costs);
- Furthermore, also different small-medium enterprises and construction companies price lists were analyzed, in order to properly define and take into account the specific labour costs contributions.

Definitely, a huge difference between Denmark and Italy is once again recognizable also with reference to the main average retrofit costs to be estimated for the different building elements: and such a phenomenon is only partially ascribable to the different methodologies here adopted into assessing these prices.
Moreover, another important factor to be considered is related to the quite high variability of the insulating layer thicknesses, as well as to the wide range of materials to be assessed: actually, while the evaluation criterion adopted for the Italian context allows distinguishing among different materials (along with the respective retrofit prices), for the Danish context it's only possible to associate different retrofit costs to different layers' thicknesses, but without any further specification about the respective, specific materials.

Finally, still with reference to the main assessing procedures hereinafter adopted (for Italy and Denmark as well) into gathering the main financial budgets globally required for a specific retrofit project, the following, fundamental clarification is needed.
As a matter of fact, the current assessment has only taken into account the **specific costs' increases due to the higher performance technologies to be adopted:** that is, it only considered the **specific extra cost voices** necessary for achieving better insulating standards and energy performance levels when replacing and/or renovating the different building elements.
Such extra-costs were therefore expressly defined and extrapolated.

CEILING FIBERGLASS BATTS - 8CM				
PG 327 -VOL 3 BIS - SEMILAVORATI / ANALISI DEI PREZZI (MAIN VOICE)				
		QUANT	IMPORTO-EURO	TOT
[B.0001.0001.0001] - OPERAIO SPECIALIZZATO VOL 3 ...PG 1...	ORA	0.18	25.82	4.65
[B.0001.0001.0003] - OPERAIO COMUNE ...		0.18	21.97	3.95
[B.0004.0003.0006] - GRU A TORRE ad azionamento ele ...VOL 3 ...PG 75		0.00381	34.3913	0.13
B.0045.0003.0018-VOL 3 BIS- PG 335 -PANNELLO ISOLANTE TERMOACUSTICO PER PARETI PERIMETRALI E DIVISORIE, IN FIBRE DI VETRO TRATTATE CON RESINE TERMOINDURENTI, CON UNA FACCIA RIVESTITA DA UN FOGLIO DI CARTA KRAFT impermeabilizzata, con funzione di barriera	M2	1.01	15.14	15.29
Collante premiscelato		4	0.42	1.68
Stucco a spatola		0.6	9.08	5.45
Tasselli plastici per fissaggi meccanici		6	0.22	1.32
Rete fibra di vetro per rinforzo intonaco		1.05	1.63	1.71
D.0013.0004.0063 INTONACHINO DI FINITURA IN MALTA PREMISCELATA, a base				
di □ore di calce, cemento bianco, inerti calcarei selezionati di diversa granulometria e				
di ossidi sintetici colorati, applicato su super□ci intonacate, gi□a predisposte, spianato				
a mano con cazzuola americana e lisciato con frattazzo, spessore □nito 3 mm, dato				
in opera su super□ci piane o curve, □no a m 4.00 di altezza dal sottostante piano				
di appoggio delle pareti, compreso il ponteggio e il tiro in alto su super□ci interne				
verticali		1	6.39	6.39
Sommano euro:				40.57
Spese generali 15% euro:				6.09
Sommano euro:				46.66
Utili d'impresa 10% euro:				4.67
TOTALE euro/metri quadri:				51.33

Tab. 6.16 Single retrofitting costs' evaluation - custom spreadsheet of reference (excerption) based on:

http://www.regione.sardegna.it-Prezzario dei Lavori Pubblici (Institutional Framework for Public Works)

N.B.

The coefficient "1,01" of the above table (instead of the simple value of "1") was introduced in order to take into account also any possible waste and/or scrapping material occurred during the main working processes.

Main retrofit costs' definition: additional charge required (*VAT*) – Italy vs. Denmark
As previously specified, ad hoc retrofit costs were expressly defined for all the different building elements to be replaced and/or renovated: in particular, such an assessment also involved and took into account the ***VAT – Value Added Tax*** further contribution, whose value has been respectively established as follows for the two main countries of interest:

- **Italy**: + 10 % (a.k.a. ***IVA***);
- **Denmark** : + 25 % (a.k.a. ***MOMS***)

Roof's average retrofit cost assessment: main criteria and key-methodology applied for the Danish context

Regarding this task, it's possible to recall the calculations worked out by the ***Danish Building Research Institute***, based on an average score of untapped attics and flat roofs.
According to the available information, and adopting the same assessment criterion assumed when dealing with the Italian scenarios (i.e. only considering the **specific costs' increasing due to the higher performance technologies to be achieved**), for this single building element it's necessary to budget a marginal retrofit cost settled in 50 DKK (6,70 €) per m^2 of roof plus 1 DKK (0,13 €) per mm of insulation.
Furthermore, also the additional cost ascribable to the *VAT* ("*MOMS*"=25%) contribution must be considered.

External walls' average retrofit cost assessment: main criteria and key-methodology applied for the Danish context.

As already noticed when planning the roof's retrofit, also for the exterior walls' improvement an adequate economic assessment is needed in order to complete the *BEopt* Cost Settings Template and its User's Library with the new exterior walls' configuration's parameters.
Regarding this task, it's possible to recall once again the main calculations performed by the ***Danish Building Research Institute***, also considering the several reports published by this agency in collaboration with the ***Aalborg University***.
Actually, one of these reports declares that there are two different evaluation criteria which can be followed in order to calculate the external walls' renovation costs along with their respective improvements:

1) Every kind of exterior walls' renovation (independently of its specific characteristics) provides for the following cost's voices:
   - an upfront cost of 1.500 DKK (201,15 €) per each m^2 of outer wall;
   - an additional charge of 7 DKK (0,94 €) per each mm of insulation added to the outer wall;

2) Furthermore, in order to assess the specific marginal costs connected to the implementation of energy saving measures in conjunction with any other already planned renovation for the exterior walls, the following reference points must be assumed (also in this case independently of their specific typology):
   - the initial costs of 200 DKK (26,82 €) per each m^2 of outer wall after its insulation;
   - an additional charge of 7 DKK (0,94 €) per each mm of insulation added to the outer wall;

Hence recalling that, when dealing with the "Danish Case", it was chosen to adopt (as much as possible) the same working hypotheses already assumed for the "Italian Case" analysis, the specific outer walls insulation's prices were calculated according to the second criterion.
Moreover, also in this case, the price's increasing due to the VAT ("*MOMS*"=25%) contribution has to be considered.

Windows' average retrofit cost assessment: main criteria and key-methodology applied for the Danish context.

Quoting the main indications provided at this reference by the "***SBi 2010:56 Danske bygningers energibehov i 2050***" – section "***Økonomi – Vinduer***" (windows), it's possible to define, as the main windows replacement costs' assessment criterion, the following key-cost-voices:

- An upfront cost of 2.900 DKK (389 €) per each m^2 of window to be renovated;
- In addition, in order to assess any possible marginal cost referable to the renovation of this building element, it is assumed that the price of energy windows with a U-value of 1,0 W/m²K and extra-cost replacement for energy efficient windows will decrease over time.
  It must be therefore assumed an average marginal cost of DKK 400 per m² of window over the entire analysis period.
  While instead, in case of lower expectations for energy efficiency of windows in the renovated building (i.e. if they are similar to the existing low quality glazing) a 0 DKK marginal cost due to the windows' replacement has to be considered.

Main retrofit limits and prescriptive requirements: overall framework – Italy vs. Denmark

Recalling the main changes and variations occurred in these latest years - also based on the specific statements recently established by the Italian Government - the following remarks are necessary and, most of all, the global summary tables of below (**Tab. 6.17 a-b**) reveal quite useful, also providing an exhaustive, overall legislative scheme.

Actually, on the 25th June 2009 the ***D.P.R. 59/2009*** became legally binding and thence the less restrictive limits which had been fixed in **2005** (by the ***D.Lgs. 192/2005*** - limits valid from the 1st January 2006) were definitely replaced - from the 1st January 2010 - by more stringent maximum transmittance values.

Besides, even more restrictive limits were established, according to the ***D.M. 26/01/2010*** (and with effect from 14th March 2010), in order to allow joining the benefits related to the so called ***"Tax cut - Public Incentives"***.

However, a further scenario (the most restrictive of all) can also be defined and assessed: it was established in **2012** and is referred to the so called *"**Conto Termico**"* (lit. *"Thermal Account"*, established by means of the ***D.M. 28/12/2012*** and recently updated on 4th December 2013) issued in order to subsidize thermal energy output from renewable sources, also developing buildings energy efficiency through requalification projects.

In the light of such remarks it's therefore quite meaningful summing up all these different values and reference limits by means of a global assessment (as hereinafter depicted), along with all the several building elements to which it should be applied, therefore providing a more clear working framework.

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE: ref. OLBIA – ZONE C	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. FLOORS upward not heated zones or exterior)
STARTING PERIMETER CONDUCTANCE	1,33 W/m*K
CURRENT SLAB U-VALUE	0,633 W/m^2*K
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE C – valid from 1st January 2006	0,55W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE C	0,49W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	0,42W/m^2*K
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0,40 W/m^2*K
"CONTO TERMICO" LIMIT ITALIAN CLIMATIC ZONE C	0,33W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: EXTERNAL WALLS	OPAQUE VERTICAL SURFACES
U-VALUE STARTING VALUE	0,42 W/m^2*K
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE C – valid from 1st January 2006	0,57 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE C	0,46 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	0,40 W/m^2*K
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0,34 W/m^2*K
"CONTO TERMICO" LIMIT ITALIAN CLIMATIC ZONE C	0,28 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: CEILING	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	2,989 W/m^2*K
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE C – valid from 1st January 2006	0,55 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE C	0,42 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	0,38 W/m^2*K
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0,32 W/m^2*K
"CONTO TERMICO" LIMITS ITALIAN CLIMATIC ZONE C	0,27 W/m^2*K

Tab. 6.17-a: Main prescription and transmittance limits to be respected for the single building elements in the Italian climatic *Zone C* (specific loc. *Olbia*)

BUILDING ELEMENT TO BE IMPROVED: WINDOWS	TRANSPARENT OPENABLE VERTICAL SURFACES (i.e. WINDOWS including PANES and FRAME)
U-VALUE STARTING VALUE	2,799 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE C – valid from 1st January 2006	3,30 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE C	3,00 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	2,60 $W/m^2{*}K$
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	2,10 $W/m^2{*}K$
"CONTO TERMICO" LIMITS ITALIAN CLIMATIC ZONE C	1,75 $W/m^2{*}K$

Tab. 6.17-a (cont): Main prescription and transmittance limits to be respected for the single building elements in the Italian climatic *Zone C* (specific loc. *Olbia*)

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE: ref. POZZOMAGGIORE – ZONE D	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. FLOORS upward not heated zones or exterior)
STARTING PERIMETER CONDUCTANCE	1,33 W/m*K
CURRENT SLAB U-VALUE	0,633 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE D – valid from 1st January 2006	0,46 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE D	0,41 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	0,36 $W/m^2{*}K$
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0,34 $W/m^2{*}K$
"CONTO TERMICO" LIMIT ITALIAN CLIMATIC ZONE D	0,28 $W/m^2{*}K$
BUILDING ELEMENT TO BE IMPROVED: EXTERNAL WALLS	OPAQUE VERTICAL SURFACES
U-VALUE STARTING VALUE	0,42 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE D – valid from 1st January 2006	0,50 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE D	0,40 $W/m^2{*}K$
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	0,36 $W/m^2{*}K$
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0,29 $W/m^2{*}K$
"CONTO TERMICO" LIMIT ITALIAN CLIMATIC ZONE D	0,24 $W/m^2{*}K$

Tab. 6.17-b: Main prescription and transmittance limits to be respected for the single building elements in the Italian climatic *Zone D* (specific loc. *Pozzomaggiore*)

BUILDING ELEMENT TO BE IMPROVED: CEILING	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	2.989 W/m^2*K
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE D – valid from 1st January 2006	0.46 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE D	0.35 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	0.32 W/m^2*K
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	0.26 W/m^2*K
"CONTO TERMICO" LIMITS ITALIAN CLIMATIC ZONE D	0.22 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: WINDOWS	TRANSPARENT OPENABLE VERTICAL SURFACES (i.e. WINDOWS including PANES and FRAME)
U-VALUE STARTING VALUE	2.799 W/m^2*K
REGULATIONS' U_{REF} LIMIT (D.Lgs. 192/05) ITALIAN CLIMATIC ZONE D – valid from 1st January 2006	3.10 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2008 ITALIAN CLIMATIC ZONE D	2.80 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	2.40 W/m^2*K
FINANCIAL TAX CUT U_{REF} LIMIT (Decree 11/03/2008 – Coord. Decr. 26/01/2010) – (Decree 19/02/2007, as amended by Decr. 26/10/2007 and coord. Decr. 07/04/2008 and Decr. 06/08/2009)	2.00 W/m^2*K
"CONTO TERMICO" LIMITS ITALIAN CLIMATIC ZONE D	1.67 W/m^2*K

Tab. 6.17-b (cont): Main prescription and transmittance limits to be respected for the single building elements in the Italian climatic *Zone D* (specific loc. *Pozzomaggiore*)

Furthermore, in order to complete the global overview and boundary conditions' framework to be considered when dealing with the Italian and the Danish retrofitting background, it's important to recall the main Danish Building Regulations nowadays in force, as well as the respective, current transmittance limits and reference values.

Actually, the ***Danish Building Regulations "BR10"*** came into force in July 2010, with a transition period of 6 months, meaning that all new building permits issued after the 1st January 2011 must comply the *BR10*. They established a general tightening by 25% of the energy performance frameworks and insulation requirements for components and building elements compared with the previous ***BR08.***

In order to encourage the development of more energy-efficient constructions, the *BR10* also includes a definition for the ***Low Energy Buildings*** class, called ***'Class 2015'***.

In particular, a building may be classified as ***Class 2015*** when "*the total demand for energy supply for heating, ventilation, cooling and domestic hot water, as well as lighting (and except for dwellings) is no more than approximately 75% of the maximum permissible energy consumption in general construction*".

Besides, also the main requirements for air tightness in ***low energy buildings*** have been tightened up.

Moreover, it has to be also highlighted that Denmark has been so far the only European country which has expressly settled an *ad hoc* definition for a *"**Nearly Zero**" Energy Building*.

In addition, it's important to recall that a building fulfils those specific requirements settled by the ***BR10*** if the total demand for ***energy supply*** (kWh/m^2 of heated floor area per year) necessary to ***cover heat loss, ventilation, cooling, domestic hot water and lighting*** (except for dwellings) doesn't exceed the reference limits depicted by the **Table 6.18** of below.

Energy performance framework (kWh/m2 floor area per year)	Dwellings	Other buildings
BR10	52,5 + 1650/A	71,3 + 1650/A
Lavenergiklasse 2015	30 + 1000/A	41 + 1000/A
Bygningsklasse 2020	20	25

Tab. 6.18 Main prescriptions and energy performance framework according to the *Danish Regulations* (ref. *http://www.paroc.dk*)

N.B.

- The application of *low energy classes* has been in principle voluntary, but from year 2015 it is expected to form the basis for even more strict energy requirements by the *Danish Building Regulations*.
- In addition, a further building class called "***Class 2020***" (with even lower energy consumption levels) is expected to become compulsory for all new buildings at the end of year 2020 and for new public buildings starting from the end of 2018.
- For existing dwellings, specific requirements for individual building components were established, as also previously mentioned with reference to the Italian context and even though the reference values are clearly markedly different.

At this regard, the following **Table 6.19** provides an overview of the fundamental Transmittance - U value requirements, as established by the ***Danish Building Regulations - BR10*** at Chapter 7 (Table 7.4.2(2)).

REFERENCE CASE: DANISH SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. FLOORS upward not heated zones or exterior)
STARTING PERIMETER CONDUCTANCE	1.33 W/m*K
CURRENT SLAB U-VALUE	0.633 W/m^2*K
REGULATIONS' U_{REF} LIMIT according to BR 10	0.12 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: EXTERNAL WALLS	OPAQUE VERTICAL SURFACES
U-VALUE STARTING VALUE	0.447 W/m^2*K
REGULATIONS' U_{REF} LIMIT according to BR 10	0.20 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: CEILING	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	0.37 W/m^2*K
REGULATIONS' U_{REF} LIMIT according to BR 10	0.15 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: ROOF	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	2.839 W/m^2*K
REGULATIONS' U_{REF} LIMIT according to BR 10	0.15 W/m^2*K
BUILDING ELEMENT TO BE IMPROVED: WINDOWS	TRANSPARENT OPENABLE VERTICAL SURFACES (i.e. WINDOWS including PANES and FRAME)
U-VALUE STARTING VALUE	2.799 W/m^2*K
REGULATIONS' U_{REF} LIMIT according to BR 10	1.65 W/m^2*K

Tab. 6.19: Main prescription and transmittance limits to be respected for the single building elements according to the *Danish Building Regulations* currently in force (a.k.a. *BR10*)

- The above U value requirements should be adopted as reference limits in case of "*Specific Measures*" like *conversions, maintenance and replacements* (as specified in the *BR10* at Chapter 7).
- Moreover, it's also important to recall that such values are expressly applied in case of conversions with the retrofit insulation of existing building elements, providing that the work is **cost-effective** (at this purpose, cost-effective energy improvements for existing buildings are described in the *Appendix 6* to *BR10*).
  If the building element is going instead to be totally replaced, the reference limits still remain valid, but **regardless of the cost-effectiveness** task.
- Beside the above remarks, and once again in order to properly plan a fruitful retrofitting project (targeted in function of the two different boundary contexts of interests), the overall reference framework provided by the following maps (see **Fig.6.49-a,b**) reveals markedly meaningful.

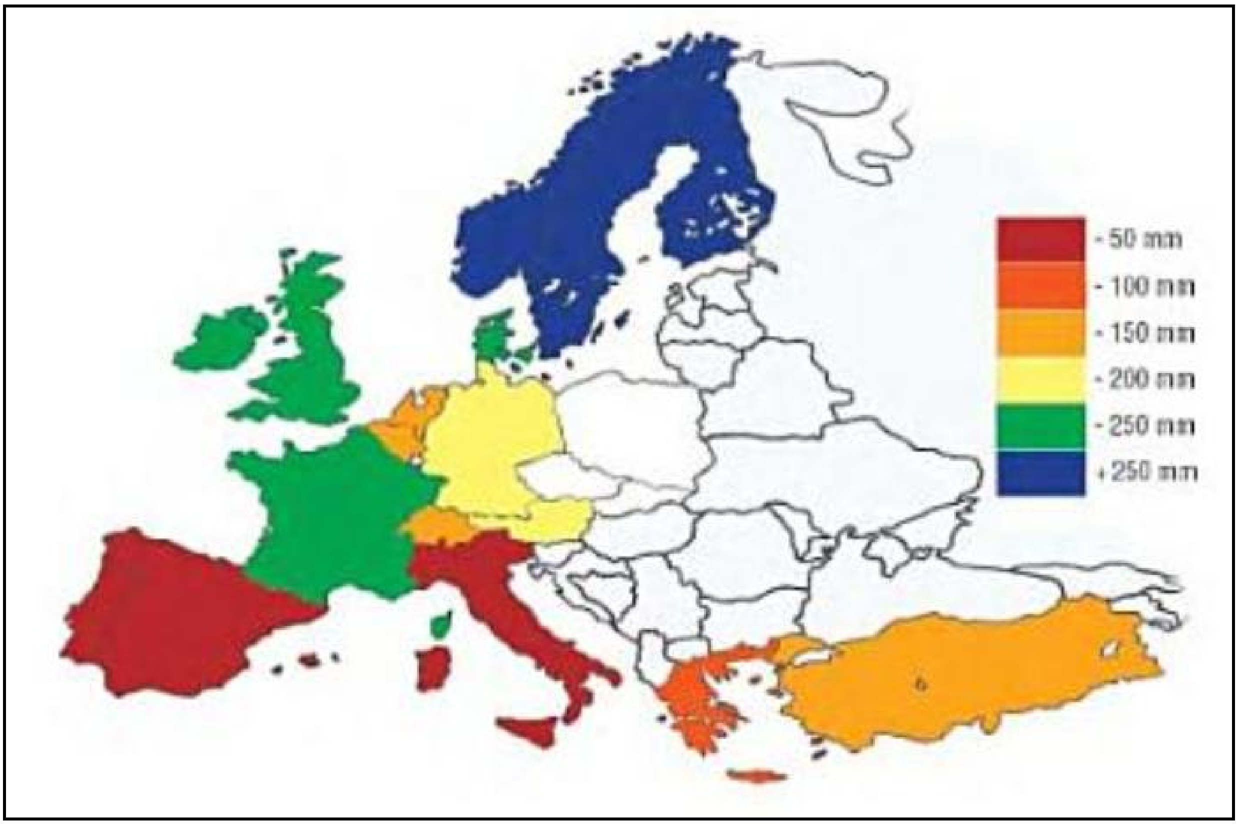


Fig. 6.49-a Average insulation thickness for <u>Roofs</u> in Europe: overall assessment – year 2001 (Source *EURIMA - European Insulation Manufacturers Association*)

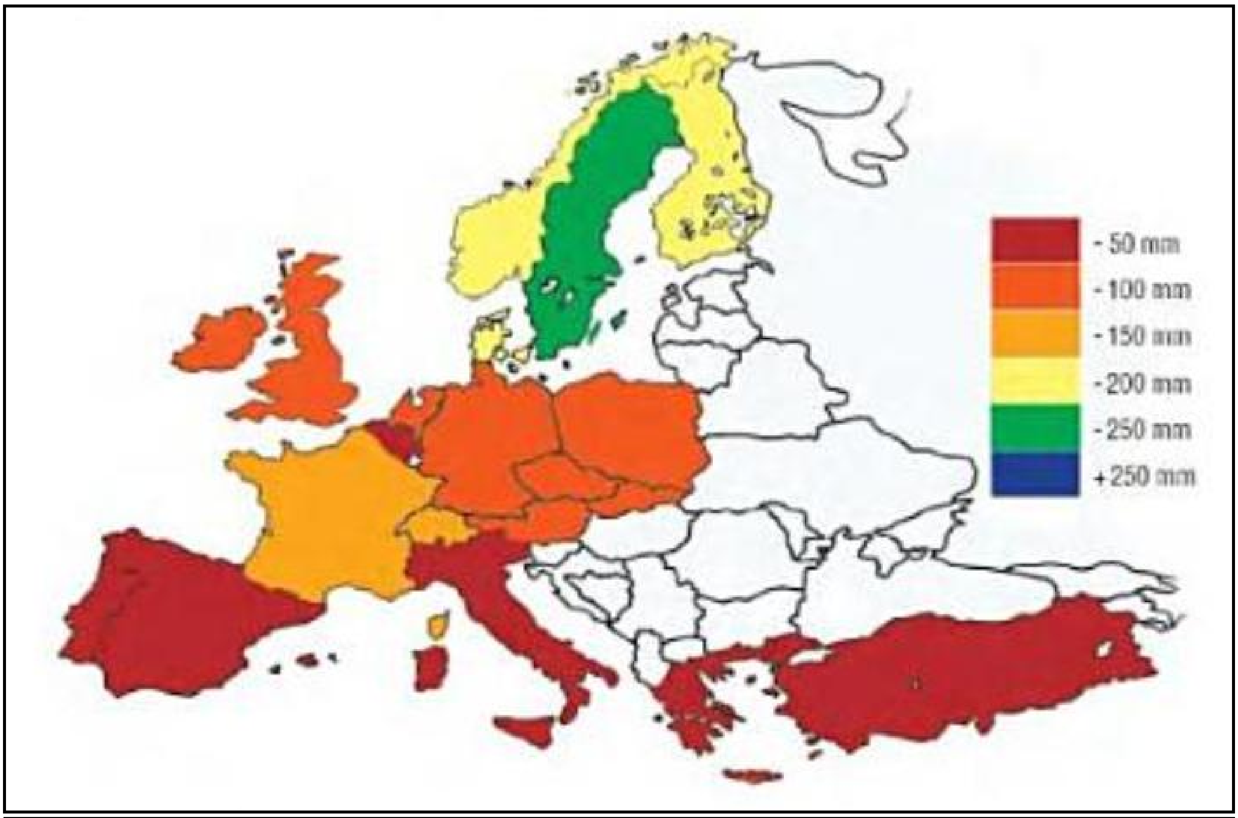


Fig. 6.49-b Average insulation thickness for <u>Walls</u> in Europe: overall assessment – year 2001 (Source *EURIMA - European Insulation Manufacturers Association*)

6.12 Retrofit results and optimization tasks
Retrofit scenarios and respective evaluation – Italy: *C Zone & D Zone*
Ceiling retrofit

• ***C Zone*** **(ceiling retrofit)**

The assessment started initially focusing the attention on the retrofit analysis for each single building element: actually, all of them were assessed by means of several, independent retrofitting sessions. The main different insulation/improvement solutions were therefore evaluated, along with the respective costs, in function of the several necessary thicknesses/properties required in order to meet the regulation limits currently in force

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: CEILING	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	2,839 W/m²*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	0,38 W/m²*K

Tab. 6.20

RETROFIT DESIGN CASE A:
GLASS-WOOL INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING FIBERGLASS BATTS TERMOK8*	
THICKNESS OF CEILING'S INSULATION: GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K): 10 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): 2,70 m²*K/W
R-VALUE OF CEILING 'S INSULATION (GLASS-WOOL with λ= 0,036 W/m*K): 2,70 m²*K/W	
U-VALUE OF CEILING INSULATION (GLASS-WOOL with 0,036 W/m*K): 0,37 W/ m²*K	CEILING RESPECTIVE U-VALUE: 0,358 W/m²*K
0,358 W/m²*K < 0,38 W/m²*K	

Tab. 6.20-A

RETROFIT DESIGN CASE B:
XPS-Expanded Extruded Polystyrene INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING XPS-Expanded Extruded Polystyrene*	
THICKNESS OF CEILING'S INSULATION (XPS with λ= 0.037 W/m*K): 10 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): 2,78 m^2*K/W
R-VALUE OF CEILING 'S INSULATION (XPS with λ= 0.037 W/m*K): 2,70 m^2*K/W	
U-VALUE OF CEILING INSULATION INSULATION (XPS with λ= 0,037 W/m*K): 0,37 W/ m^2*K	CEILING RESPECTIVE U-VALUE: 0,36 W/m^2*K
0,36 W/m^2*K < 0,38 W/m^2*K	

Tab. 6.20-B

RETROFIT DESIGN CASE C:
STONE-WOOL INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING STONEWOOL INSULATION*	
THICKNESS OF CEILING'S INSULATION (Rockwool with λ= 0,035 W/m*K): 10 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): 2,91 m^2*K/W
R-VALUE OF CEILING 'S INSULATION (Rockwool with λ= 0,035 W/m*K): 2,85 m^2*K/W	
U-VALUE OF CEILING INSULATION (Rockwool with λ= 0,035 W/m*K): 0,35 W/ m^2*K	CEILING RESPECTIVE U-VALUE: 0,34 W/m^2*K
0,34 W/m^2*K < 0,38 W/m^2*K	

Tab. 6.20-C

RETROFIT DESIGN CASE D:
CORK PAN-TECNOSUGH INSULATION

<table>
<tr><th colspan="2">CEILING’S INSULATION</th></tr>
<tr><td colspan="2">CUSTOM OPTION:
CEILING CORK-BATT-CORK PAN insulation</td></tr>
<tr><td>THICKNESS OF CEILING’S INSULATION (TECNOSUGH with λ= 0,039 W/m*K):
10 cm</td><td rowspan="2">CEILING NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION):
2,68 m^2*K/W</td></tr>
<tr><td>R-VALUE OF CEILING ‘S INSULATION (TECNOSUGH with λ= 0,039 W/m*K):
2,56 m^2*K/W</td></tr>
<tr><td>U-VALUE OF CEILING INSULATION (TECNOSUGH with λ= 0,039 W/m*K):
0,39 W/ m^2*K</td><td>CEILING RESPECTIVE U-VALUE:
0,37 W/m^2*K</td></tr>
<tr><td colspan="2">0,37 W/m^2*K < 0,38 W/m^2*K</td></tr>
</table>

Tab. 6.20-D

RETROFIT DESIGN CASE E:
MINERALIZED-WOODFIBER-BATTS INSULATION

<table>
<tr><th colspan="2">CEILING’S INSULATION</th></tr>
<tr><td colspan="2">CUSTOM OPTION:
CEILING MINERALIZED WOODFIBER BATTS insulation</td></tr>
<tr><td>THICKNESS OF CEILING’S INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0.04 W/m*K):
12,5 cm</td><td rowspan="2">CEILING NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION):
3,08 m^2*K/W</td></tr>
<tr><td>R-VALUE OF CEILING ‘S INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0.04 W/m*K):
2,90 m^2*K/W</td></tr>
<tr><td>U-VALUE OF CEILING INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0.04 W/m*K):
0,345 W/ m^2*K</td><td>CEILING RESPECTIVE U-VALUE:
0,32 W/m^2*K</td></tr>
<tr><td colspan="2">0,32 W/m^2*K = 0,32 W/m^2*K < 0,38 W/m^2*K</td></tr>
</table>

Tab. 6.20-D

Hence, as mentioned above, after having introduced the fundamental corrections and the necessary adjustments which should be applied in order to achieve a reliable evaluation, the software was launched through three different analysis' sessions, comparing the several ceiling's improvements by adopting the respective approaches following depicted:

1) The first one has evaluated all the different scenarios one-by-one, keeping each retrofit solution separated from the other ones: the results were obtained launching the software in a ***"Design Mode"*** and were thence consequently compared.

2) The second (and more representative) one has made a global comparison among all the different thicknesses and insulating materials customized through the *BEopt Option Manager*: the results were obtained launching the software in a ***"Parametric Mode"*** and may be summed up through the following output table' s excerption:

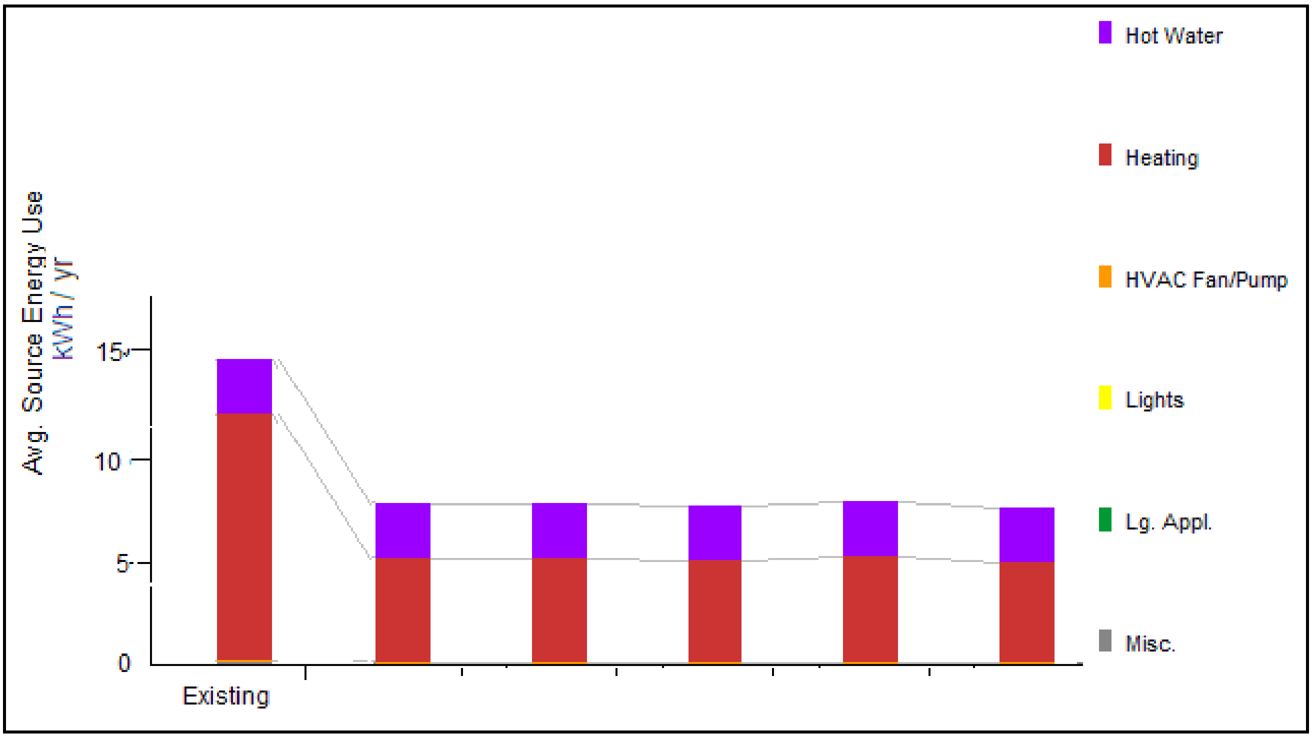


Fig. 6.50 Comparative – Parametric - Analysis results

As it's possible to gather looking at the above table and considering the main net energy savings achievable, no significant differences are outwardly detectable - at a macroscopic level - among the different retrofit solutions assessed.

3) Afterwards, for the purpose of better exploiting the optimization and cost-optimal resources provided by BEopt and still applying its main potentialities "*step by step → building element by building element*", an ***"Optimization Mode"*** session was finally launched, reaching the key-results below depicted **(see Fig. 6.51)** in correspondence with the *max savings–min retrofit costs point* (i.e. with reference to the Ceiling-Stone Wool insulation layer solution).

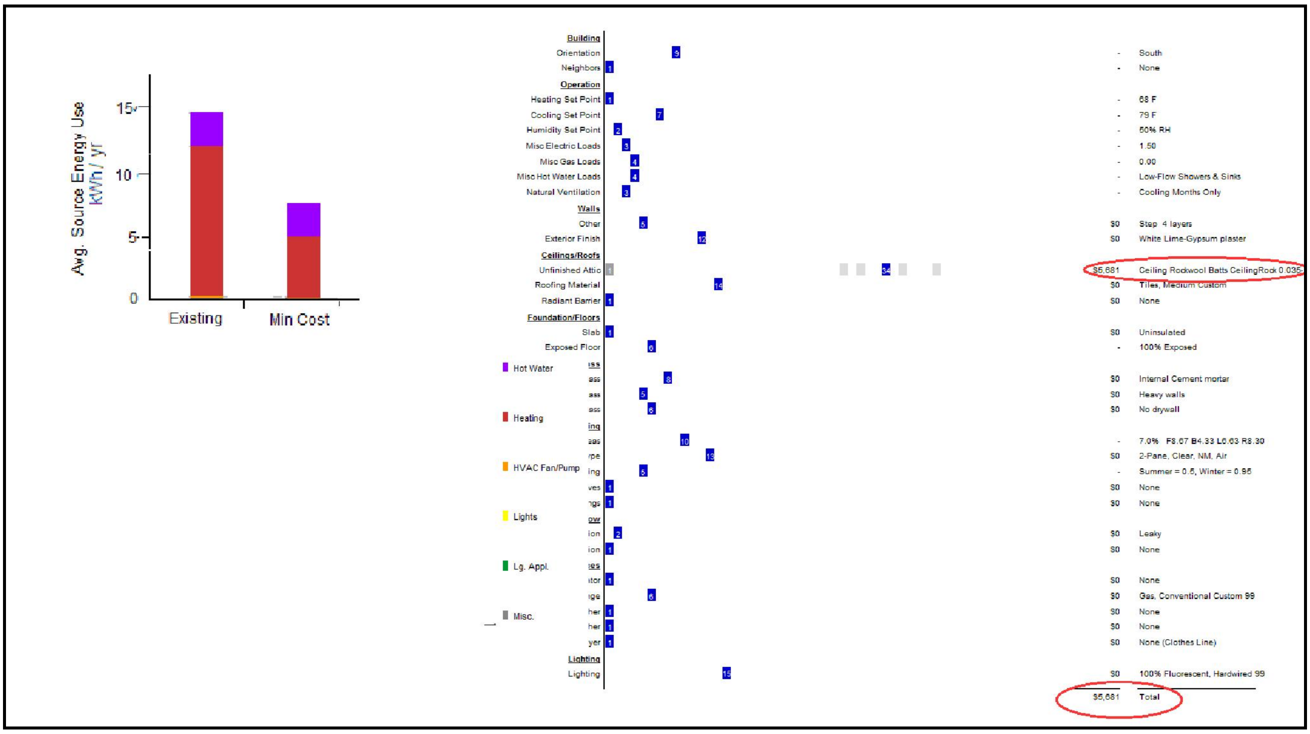


Fig. 6.51 Optimization Analysis results (Max Savings – Min costs Point) – CLIMATIC ZONE C Global Savings estimated in 6.858 kWh/yr and respective Retrofit Costs evaluated in 4.131 €

Implementing now an overall comparison among the different assessments until now carried out (and still remembering all the differences which affect the respective final results) it's possible to report the summary table hereinafter shown (see **Tab. 6.21**).

At this regard and for such a purpose, the Enea Report assessment carried out during year 2009 has been assumed as the most representative one and may be therefore recalled as follows.

Furthermore, another clarification is needed with reference to the retrofit costs reported by Enea and assessed on the average: actually, if on the one hand (i.e. through the *Beopt* interface) the average retrofit costs were evaluated with reference to a dwelling with a surface of 150 m^2, no certain information are available with reference to the average retrofit costs reported by Enea.

Hence this represents a further uncertainty and unpredictability element to be considered while dealing with such a task.

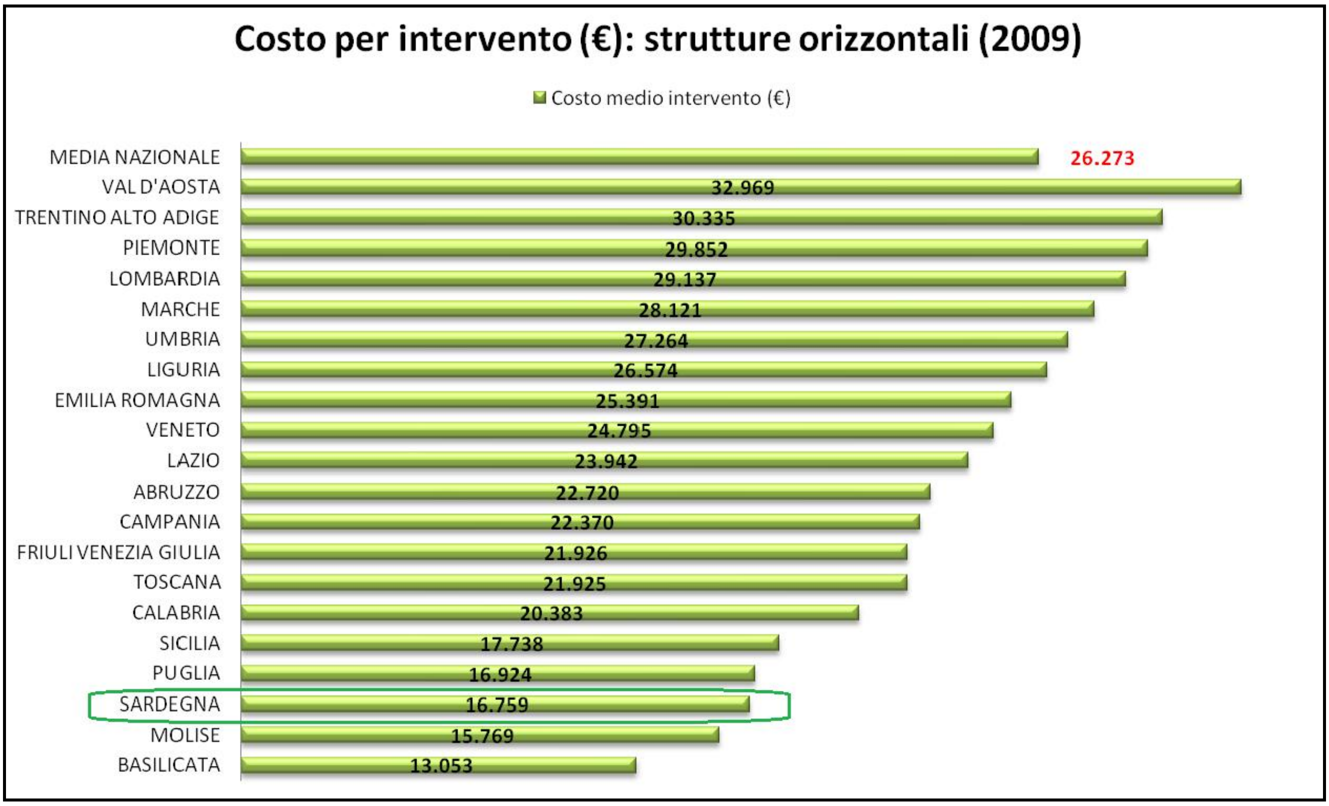


Fig. 6.52-a Enea Report's excerption (ref. year 2009)

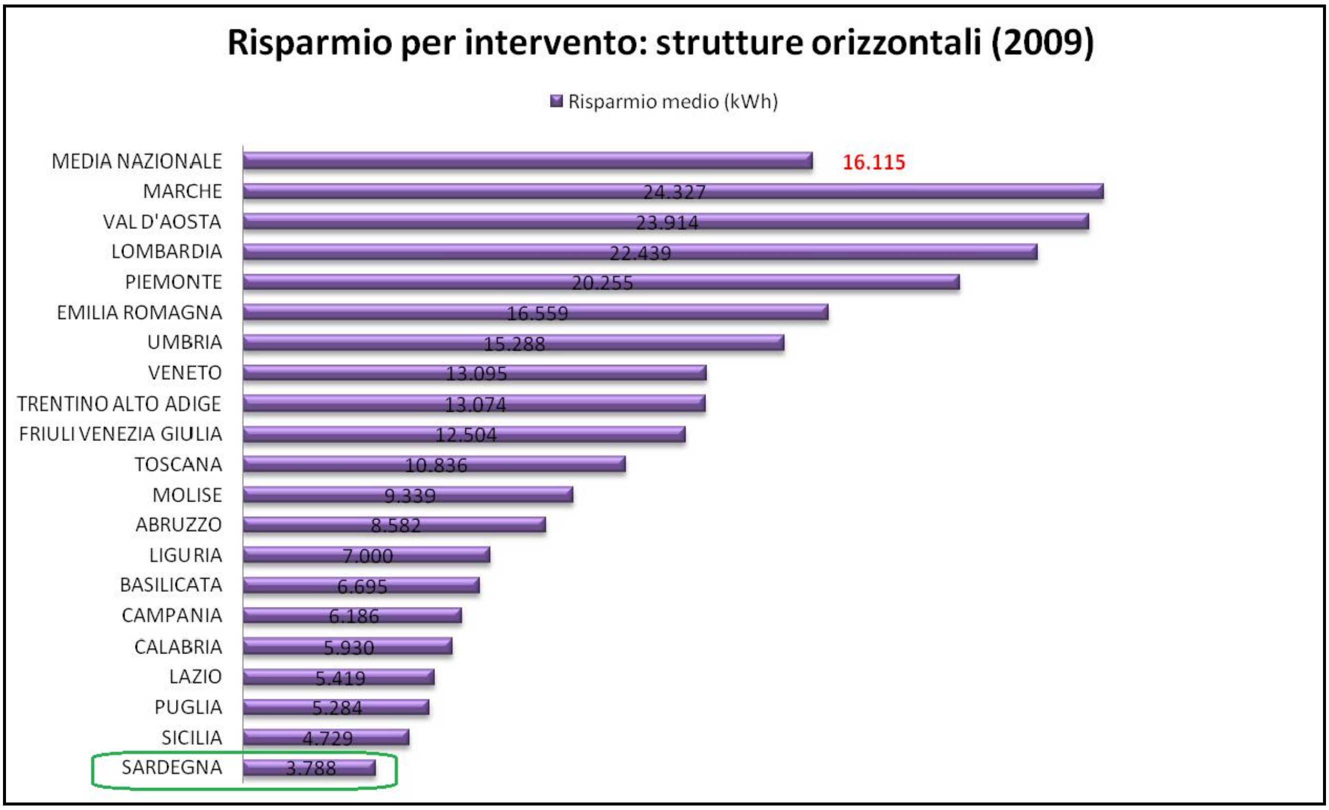


Fig. 6.52-b Enea Report's excerption (ref. year 2009)

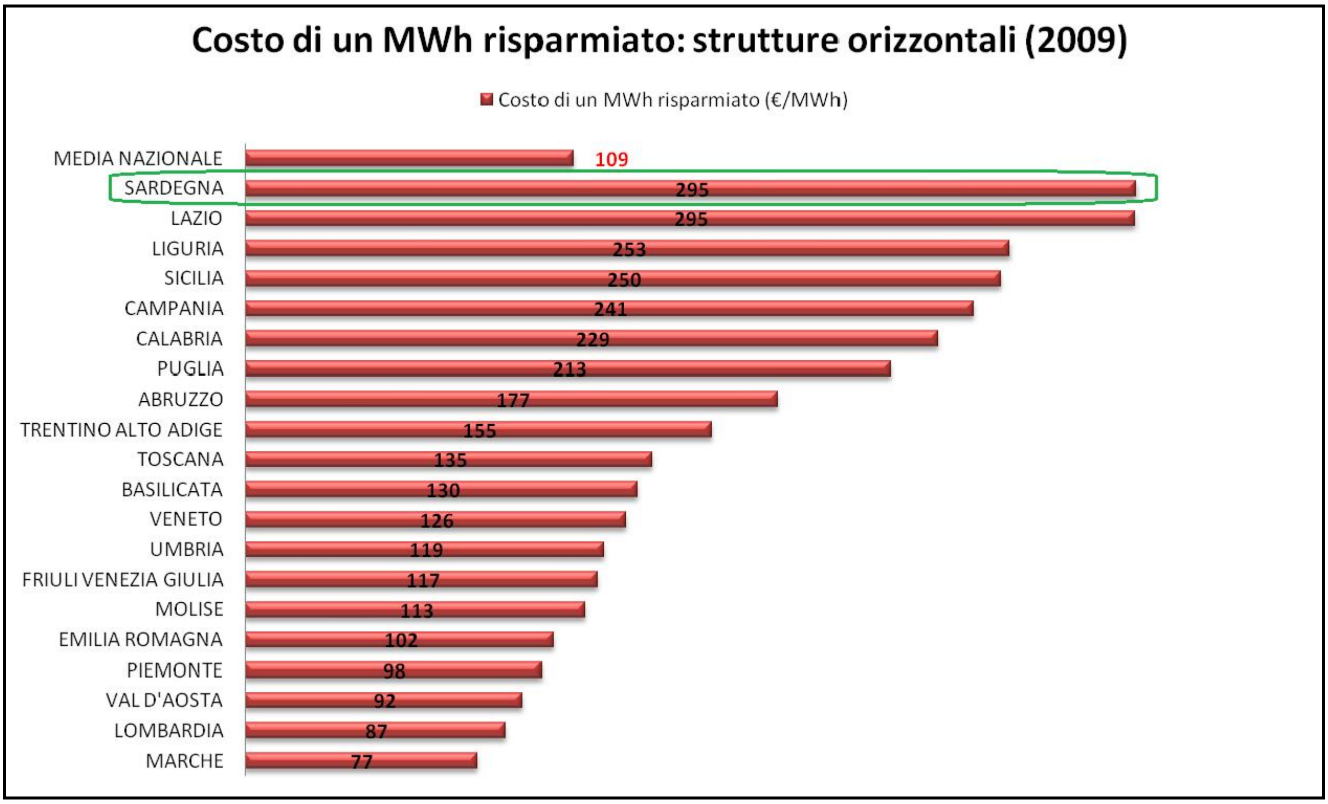


Fig. 6.52-c Enea Report's excerption (ref. year 2009)

RETROFIT'S ACTION TYPE: ENERGY SAVING						
BUILDING ELEMENT TO BE IMPROVED: CEILING (i.e. *OPAQUE HORIZONTAL SURFACES* - simplex variables)	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)		BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)		ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	3.788		6.858			
RETROFIT COSTS [€]	16.759		4.131			
ASSUMED LIFESPAN [yr]	ENEA REF.	20	ENEA REF.	20		
COSTS SAVED [€/KWh*yr]	0,22		0,030		0,579	0,487
COSTS SAVED [€/MWh*yr]	220		30 →		57,86	48,68

Tab. 6.21 Global Comparative Framework: Ceiling retrofit (exploiting the BEopt *C Zone* results)

- ***D Zone*** **(ceiling retrofit)**

Still maintaining the same working hypotheses and retrofitting assumptions before applied while dealing with the *Climatic C Zone*, also for the most representative Sardinian *Climatic D Zone*'s location (i.e. Pozzomaggiore), analogous, further improvements sessions were settled and hence assessed. Actually, recalling the different and more stringent transmittance limits required for this climatic zone, slightly different final results were reached (as hereinafter depicted).

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: CEILING	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. CEILINGS under not heated zones and ROOFS)
U-VALUE STARTING VALUE	2,839 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	0,32 W/m^2*K

Tab. 6.22

RETROFIT DESIGN CASE I:
GLASS-WOOL INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING FIBERGLASS BATTS TERMOK8*	
THICKNESS OF CEILING'S INSULATION: GLASS-WOOL (FIBERGLASS BATTS with λ= 0,036 W/m*K): 12 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): (3,33 m^2*K/W)
R-VALUE OF CEILING 'S INSULATION (GLASS-WOOL with λ= 0,036 W/m*K): 3,20 m^2*K/W	
U-VALUE OF CEILING INSULATION (GLASS-WOOL with 0.036 W/m*K): 0,31 W/ m^2*K	CEILING RESPECTIVE U-VALUE: (0,30 W/m^2*K)
0.30 W/m^2*K < 0.32 W/m^2*K	

Tab. 6.23-I

RETROFIT DESIGN CASE II:
XPS-Expanded Extruded Polystyrene INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING XPS-Expanded Extruded Polystyrene*	
THICKNESS OF CEILING'S INSULATION (XPS with λ= 0.037 W/m*K): 12 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): (3.33 m^2*K/W)
R-VALUE OF CEILING 'S INSULATION (XPS with λ= 0.037 W/m*K): 3,20 m^2*K/W	
U-VALUE OF CEILING INSULATION INSULATION (XPS with λ= 0,037 W/m*K): 0,313 W/ m^2*K	CEILING RESPECTIVE U-VALUE: (0,30 W/m^2*K)
0,30 W/m^2*K < 0,32 W/m^2*K	

Tab. 6.23-II

RETROFIT DESIGN CASE III: STONE-WOOL INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING STONEWOOL INSULATION*	
THICKNESS OF CEILING'S INSULATION (Rockwool with λ= 0,035 W/m*K): 12 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): (3,5 m^2*K/W)
R-VALUE OF CEILING 'S INSULATION (Rockwool with λ= 0,035 W/m*K): 3,40 m^2*K/W	
U-VALUE OF CEILING INSULATION (Rockwool with λ= 0,035 W/m*K): 0,29 W/ m^2*K	CEILING RESPECTIVE U-VALUE: (0,29 W/m^2*K)
0,29 W/m^2*K < 0,32 W/m^2*K	

Tab. 6.23-III

RETROFIT DESIGN CASE IV: CORK PAN-TECNOSUGH INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING CORK-BATT-CORK PAN insulation*	
THICKNESS OF CEILING'S INSULATION (TECNOSUGH with λ= 0.039 W/m*K): 12 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): (3,22 m^2*K/W)
R-VALUE OF CEILING 'S INSULATION (TECNOSUGH with λ= 0,039 W/m*K): 3,077 m^2*K/W	
U-VALUE OF CEILING INSULATION (TECNOSUGH with λ= 0,039 W/m*K): 0,325 W/ m^2*K	CEILING RESPECTIVE U-VALUE: (0,31 W/m^2*K)
0,31 W/m^2*K < 0,32 W/m^2*K	

Tab. 6.23-IV

RETROFIT DESIGN CASE V: MINERALIZED-WOODFIBER-BATTS INSULATION

CEILING'S INSULATION	
CUSTOM OPTION: *CEILING MINERALIZED WOODFIBER BATTS insulation*	
THICKNESS OF CEILING'S INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0.04 W/m*K): 15 cm	CEILING NOMINAL R - ASSEMBLY (*BEopt* AUTOMATIC EVALUATION): (3,68 m^2*K/W)
R-VALUE OF CEILING 'S INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0,04 W/m*K): 3,50 m^2*K/W	
U-VALUE OF CEILING INSULATION (URSA WOODFIBER SANDWICH BATTS with λ= 0,04 W/m*K): 0,286 W/ m^2*K	CEILING RESPECTIVE U-VALUE: (0,27 W/m^2*K)
0,27 W/m^2*K < 0,32 W/m^2*K	

Tab. 6.23-V

As it's possible to notice considering such global results, also in this case the last ***Optimization Mode*** run by *BEopt* has led to the *max savings–min retrofit costs* configuration corresponding to the Ceiling-Stone Wool insulation retrofit (even though now with a thicker layer of 12 cm due to more stringent requirements established by Law with reference to the climatic *D Zone*).

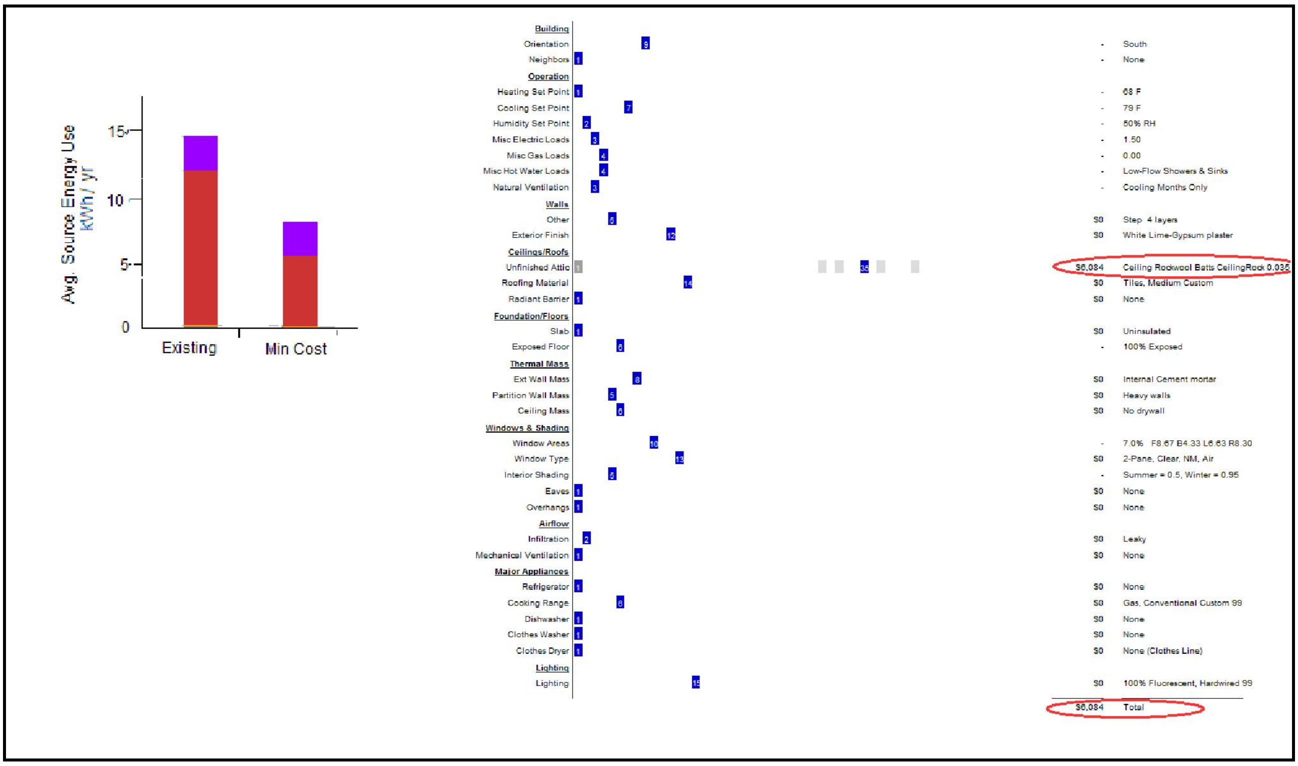


Fig. 6.53 Optimization Analysis results (Max Savings – Min costs Point) – CLIMATIC ZONE D Global Savings estimated in 6.711 kWh/yr and respective Retrofit costs evaluated in 4.417 €

<table>
<tr><th colspan="7">RETROFIT'S ACTION TYPE: ENERGY SAVING</th></tr>
<tr><td>BUILDING ELEMENT TO BE IMPROVED: <u>CEILING</u> (i.e. <u>OPAQUE HORIZONTAL SURFACES</u> - simplex variables)</td><td colspan="2">ENEA STATISTICAL DATA <u>STATIC</u> ASSESSMENT

(<u>SARDINIA</u>)</td><td colspan="2">BEOPT <u>DYNAMIC</u> OPTIMIZATION ASSESSMENT

(<u>CLIMATIC ZONE D</u>)</td><td rowspan="4">ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the <u>ENTIRE ITALY and for ALL the different kinds of building retrofit</u>)</td><td rowspan="4">SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the <u>ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit</u>)</td></tr>
<tr><td>ENERGY SAVINGS [KWh/yr]</td><td colspan="2">3.788</td><td colspan="2">6.711</td></tr>
<tr><td>RETROFIT COSTS [€]</td><td colspan="2">16.759</td><td colspan="2">4.417</td></tr>
<tr><td>ASSUMED LIFESPAN [yr]</td><td>ENEA REF.</td><td>20</td><td>ENEA REF.</td><td>20</td></tr>
<tr><td>COSTS SAVED [€/KWh*yr]</td><td colspan="2">0,22</td><td colspan="2">0,033</td><td>0,579</td><td>0,487</td></tr>
<tr><td>COSTS SAVED [€/MWh*yr]</td><td colspan="2">220</td><td colspan="2">33 →</td><td>57,86</td><td>48,68</td></tr>
</table>

Tab. 6.24 Global Comparative Framework: Ceiling retrofit (exploiting the *BEopt D Zone* results)

6.13 Retrofit results and optimization tasks
Retrofit scenarios and respective evaluation – Italy: *C Zone* & *D Zone*
Exterior walls retrofit

• ***C Zone*** **(exterior walls retrofit)**

Going ahead and continuing the current assessment, the analysis has been therefore focused onto one of the other main building elements to be improved, such as the exterior dwelling's walls.
Also in this case an analogous approach was adopted, along with the evaluation of different retrofitting and insulating solutions.

In particular, it was planned to evaluate the impact of adding a further, exterior layer for the existing wall - i.e. a ***Thermal Insulation Coating*** - with the characteristics and the retrofit investments costs depicted as follows (see the retrofit design scenarios respectively shown by **Tab. 6.26-A,B**)

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: EXTERIOR WALLS	OPAQUE VERTICAL SURFACES
U-VALUE STARTING VALUE	0,42 W/m^2*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE C	0,40 W/m^2*K

Tab. 6.25

PRE - RETROFIT DESIGN CASE ASSET:

BUILDING ELEMENTS	EXISTING ELEMENTS' PROPERTIES	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIAL EVALUATED VALUES	
EXTERIOR WALLS	"MURATURA A CASSETTA"	External walls: "STEP 4 LAYERS			
	4 LAYERS	4 LAYERS			
	ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER				
	LAYER 1: BRICKS	LAYER 1: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m^3 SPECIF.HEAT: 840 J/kg*K THERMAL CONDUCT: 0,3 W/m*K		GLOBAL R ASSEMBLY VALUE (resultant from the sum of the 2 differents BEOPT customizing sections):
	LAYER 2: RENDERING / ROCK DASH	LAYER 2: RENDER CEMENT MORTAR	LAYER WIDTH: 1 cm DENSITY: 2000 kg/m^3 SPECIF.HEAT: 670 J/kg*K THERMAL CONDUCT: 1,4 W/m*K	GLOBAL R ASSEMBLY VALUE (FOR THE ONLY 4 LAYERS SETTLED): 2,36 m^2*K/W -- ---	(2,36 + 0,035) m^2*K/W = 2,395 m^2*K/W ---
	LAYER 3: INSULATION	LAYER 3: GLASS WOOL (FIBERGLASS) BOARD INSULATION	LAYER WIDTH: 5 cm DENSITY: 30 kg/m^3 SPECIF.HEAT: 800 J/kg*K THERMAL CONDUCT: 0.039 W/m*K		
	LAYER 4: BRICKS	LAYER 4: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m^3 SPECIF.HEAT: 840 J/kg*K THERMAL CONDUCT: 0.3 W/m*K	CONSEQUENT U VALUE: 0,424 W/m^2*K	CONSEQUENT U VALUE to be considered for the exterior walls: 0,42 W/m^2*K
EXT. WALLS – EXTERIOR FINISH	WHITE LIME-GYPSUM PLASTER	WHITE LIME-GYPSUM PLASTER	LAYER WIDTH: 2 cm	RESULTANT R VALUE (FOR THE ONLY EXTERIOR FINISH LAYER): (0.035 m^2*K/W)	
			DENSITY: 1400 kg/m^3		
			SPECIF.HEAT: 1010 J/kg*K		
			THERMAL CONDUCT: 0.7 W/m*K		
			ABSORPTIVITY (solar radiation absorptance of the exterior finish - fraction: 0.2		
			INFRARED EMISSIVITY - fraction: 0.91		

Tab. 6.26-A

(Current Transmittance assessed in 0,42 W/m^2*K > 0, 40 W/m^2*K)

POST - RETROFIT DESIGN CASE ASSET:

BUILDING ELEMENT	POST-RETROFIT ELEMENTS' PROPERTIES	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIAL EVALUATED VALUES	
EXTERIOR WALLS	"THERMAL INSULATION	"THERMAL INSULATION			GLOBAL R ASSEMBLY VALUE (resultant from the sum of the 2 differents BEOPT customizing sections): (4.42 + 0.035) m²*K/W = 4.455 m²*K/W ------------------------ CONSEQUENT U VALUE to be considered for the exterior walls: 0.22 W/m²*K
	5 LAYERS ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER LAYER 1: EXT. THERMAL INSULATION COATING – 8 CM FIBERGLASS BATTS – GLASSWOOL	5 LAYERS LAYER 1: EXT. THERMAL INSULATION COATING– 8CM	LAYER WIDTH: 8 cm DENSITY: 30 kg/m³ SPECIF.HEAT: 800 J/kg* K THERMAL CONDUCT: 0,039 W/m* K	GLOBAL R ASSEMBLY VALUE (FOR THE ONLY 5 LAYERS SETTLED): (4.42 m²*K/W) ------------------------ CONSEQUENT U VALUE: (0.23 W/m²*K)	
	LAYER 2: BRICKS	LAYER 2: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m³ SPECIF.HEAT: 840 J/kg* K THERMAL CONDUCT: 0.3 W/m* K		
	LAYER 3: RENDERING / ROCK DASH	LAYER 3: RENDER CEMENT MORTAR	LAYER WIDTH: 1 cm DENSITY: 2000 kg/m³ SPECIF.HEAT: 670 J/kg* K THERMAL CONDUCT: 1.4 W/m* K		
	LAYER 4: INSULATION	LAYER 4: GLASS WOOL (FIBERGLASS) BOARD INSULATION	LAYER WIDTH: 5 cm DENSITY: 30 kg/m³ SPECIF.HEAT: 800 J/kg* K THERMAL CONDUCT: 0,039 W/m* K		
	LAYER 5: BRICKS	LAYER 5: BRICKS	LAYER WIDTH: 12 cm DENSITY: 717 kg/m³ SPECIF.HEAT: 840 J/kg* K THERMAL CONDUCT: 0.3 W/m* K		
EXT. WALLS – EXTERIOR FINISH	WHITE LIME-GYPSUM PLASTER	WHITE LIME-GYPSUM PLASTER	LAYER WIDTH: 2 cm DENSITY: 1400 kg/m³ SPECIF.HEAT: 1010 J/kg* K THERMAL CONDUCT: 0.7 W/m* K ABSORPTIVITY (solar radiation absorptance of the exterior finish - fraction: 0.2 INFRARED EMISSIVITY - fraction: 0.91	RESULTANT R VALUE (FOR THE ONLY EXTERIOR FINISH LAYER): 0.2 h*ft²*°F/Btu (0.035 m² K/W) ------------------------ CONSEQ. U VALUE: 10 (28.6 W/m²*K)	

Tab. 6.26-B

(Final Transmittance assessed in 0,22 W/m²*K < 0, 40 W/m²*K)

Since (as it's possible to gather analyzing the above detailed insulation layers' scheme) the thermal **insulation coating of 8 cm** was able to widely fulfill the exterior walls Italian requirements, it's also possible to design and consider other thinner (and thence also cheaper) insulation layers, still fulfilling the transmittance limits currently in force (see the following summary table **Tab. 6.26-C**).

POST-RETROFIT: (6 cm of GLASSWOOL INSULATION COATING)	**RESPECTIVE U-VALUE:** **0,25 W/m^2*K < 0,40 W/m^2*K**
POST-RETROFIT: (4 cm of GLASSWOOL INSULATION COATING)	**RESPECTIVE U-VALUE:** **0,29 W/m^2*K < 0,40 W/m^2*K**
POST-RETROFIT: (8 cm of ROCKWOOL-STONEWOOL INSULATION COATING)	**RESPECTIVE U-VALUE:** **0,21 W/m^2*K < 0,40 W/m^2*K**
POST-RETROFIT: (4 cm of EPS - INSULATION COATING)	**RESPECTIVE U-VALUE:** **0,28 W/m^2*K < 0,40 W/m^2*K**

Tab. 6.26-C (All the Final Transmittance values assessed fulfill the maximum limit established)

N.B. Since the ***BEopt Cost Selector*** requires distinguishing the retrofit costs connected both to the exterior finish improvements, as well as those ones related to the external walls retrofitting, an "artifice" has been necessary while customizing the *BEopt User Library*. Actually, through the above calculations, a unique, global renovation cost has been evaluated with reference to the exterior walls and hence, in order to fill in the retrofit schedule in a correct way, the **exterior finish** retrofit prices were artificially settled as *"none-zero"* and the entire estimated budget for exterior walls' retrofit costs has been entirely ascribed ("by fudging a unique value") to the **external walls' improvement**.

According to the parametric assessment - as well as considering the consequent optimization results - the energy saving level now achieved seems to be rather low compared to the default case and even lower considering the previous retrofit assessed scenario: actually the energy savings achievable through the single exterior walls improvements now tested aren't sufficient to balance their respective retrofit costs within a short-term investigation period.

However, in the light of such results and also considering the different average retrofit costs (along with the main *Annualized Energy Related Costs* reported by the output screen), it's possible to detect as the most profitable solution the one associated to **Point 5**: i.e. the solution associated to a thermal insulation coating with 8 cm of stone wool, as hereinafter detailed.

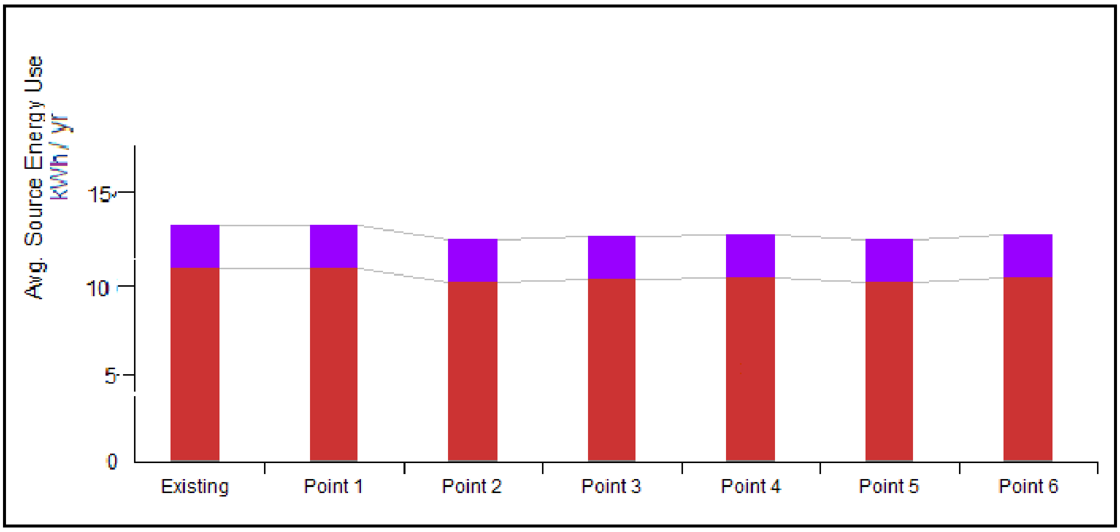


Fig. 6.54 Comparative-Parametric-Analysis results - CLIMATIC ZONE C
Global Savings estimated in 733 kWh/yr and respective Retrofit costs evaluated in 3.163 €

Recalling also in this case the assessment carried out by Enea with reference to the Opaque Vertical Surfaces building retrofits and focusing the attention on the single Sardinian Region, it's possible to recall the following summary graphs.

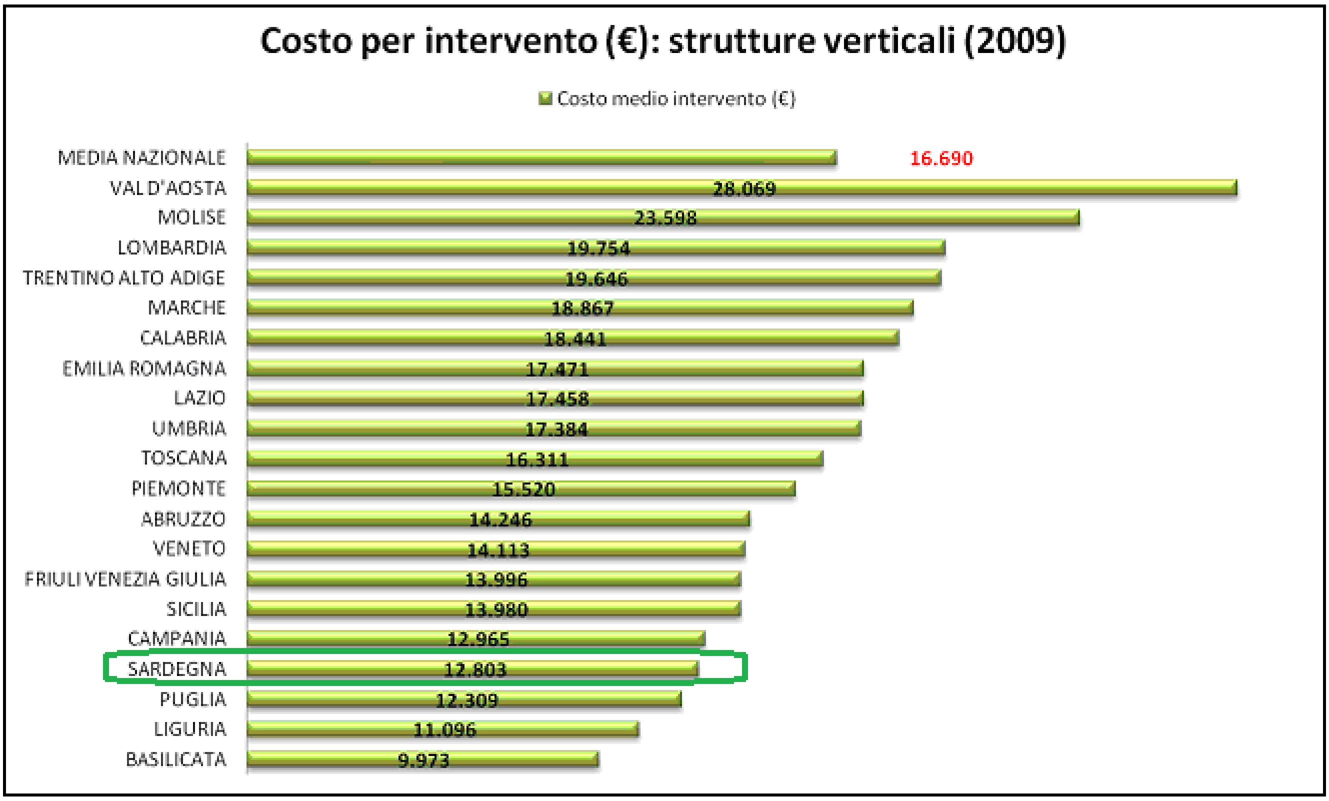


Fig. 6.55-a Enea Report's excerption (ref. year 2009)

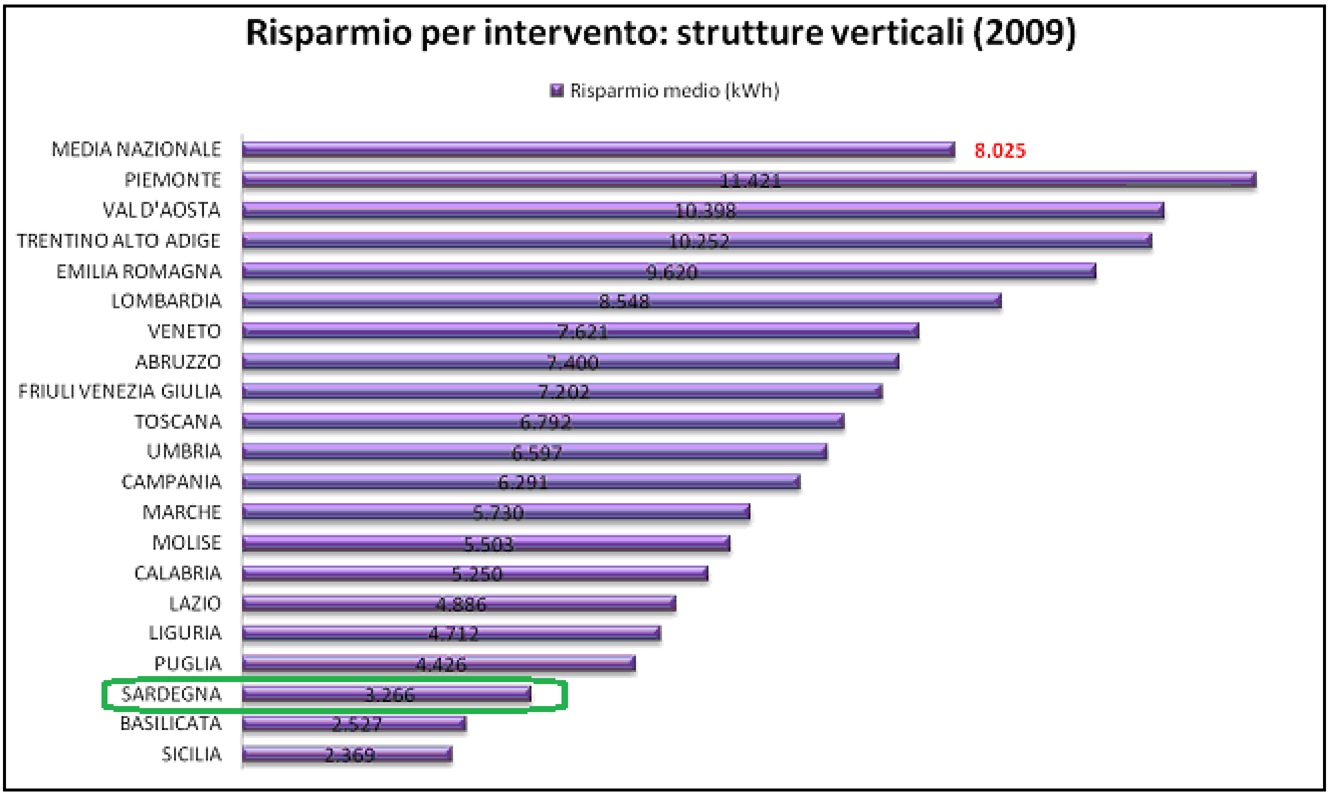


Fig. 6.55-b Enea Report's excerption (ref. year 2009)

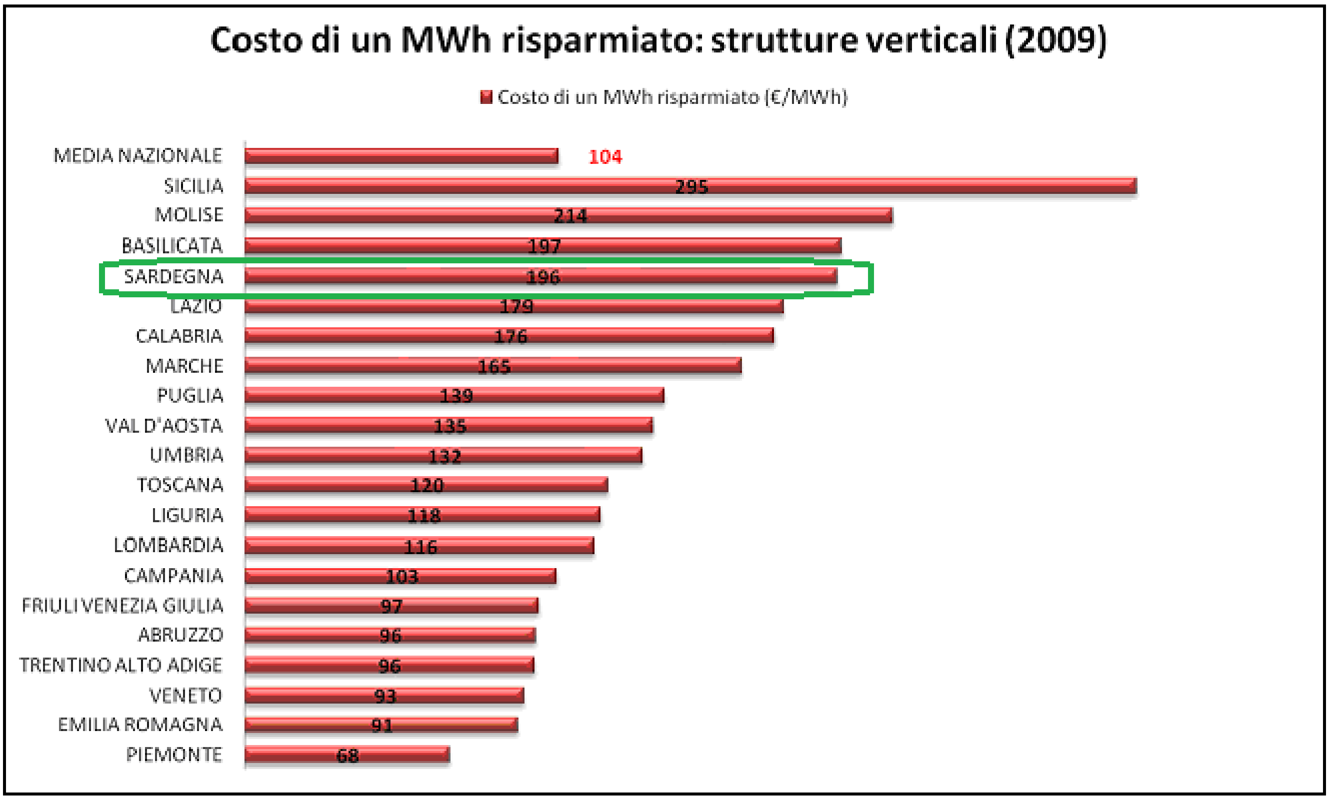


Fig. 6.55-c Enea Report's excerption (ref. year 2009)

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: EXTERIOR WALLS (i.e. *OPAQUE VERTICAL SURFACES* - simplex variables)	**ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)**	**BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)**	**ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)**	**SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)**
ENERGY SAVINGS [KWh/yr]	**3.266**	**733**		
RETROFIT COSTS [€]	**12.803**	**3.163**		
ASSUMED LIFESPAN [yr]	**ENEA REF. 15**	**ENEA REF. 15**		
COSTS SAVED [€/KWh*yr]	**0,261**	**0,288**	**0,579**	**0,487**
COSTS SAVED [€/MWh*yr]	**261**	**← 288**	**57,86**	**48,68**

Tab. 6.27 Global Comparative Framework: Exterior Walls retrofit (exploiting the BEopt *C Zone* results)

• ***D Zone*** **(exterior walls retrofit)**

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: EXTERIOR WALLS	OPAQUE VERTICAL SURFACES
U-VALUE STARTING VALUE	0,42 W/m²*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE D	0,36 W/m²*K

Tab. 6.28

Despite the more stringent requirements established for the current climatic zone (as above depicted), also for this location it's possible to evaluate the same improving solutions previously analyzed. Actually, all such retrofit measures are widely respectful of the maximum transmittance limit here allowed (i.e. **0,36 W/m²*K**).
The only main variation currently detectable is in fact associated to the post-retrofit energy saving levels (even though just slightly different) now registered.
Once again, focusing the attention on the retrofit solution represented by a thermal insulation coating with 8 cm of stone wool, the following summary table (**Tab. 6.29)** has been therefore filled in.

CLIMATIC *ZONE D* - Global Savings estimated in 820 kWh/yr - Retrofit costs evaluated in 3.163 €

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: EXTERIOR WALLS (i.e. *OPAQUE VERTICAL SURFACES* - simplex variables)	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)	BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE D)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	3.266	820		
RETROFIT COSTS [€]	12.803	3.163		
ASSUMED LIFESPAN [yr]	ENEA REF. 15	ENEA REF. 15		
COSTS SAVED [€/KWh*yr]	0,261	0,257	0,579	0,487
COSTS SAVED [€/MWh*yr]	261	← 257	57,86	48,68

Tab. 6.29 Global Comparative Framework: Exterior Walls retrofit (exploiting the BEopt *D Zone* results)

6.14 Retrofit results and optimization tasks

Retrofit scenarios and respective evaluation – Italy: *C Zone* & *D Zone*

Windows replacement

• ***C Zone*** **(windows replacement)**

Considering the windows and glazing (actually quite weak and outdated) which characterize the default existing building in both Italy and Denmark (as hereinafter analyzed), it must be considered what following reported:

- The existing windows (*2 Pane-Clear Windows* with non metal frames and air filled) are associated to a high transmittance value of **0,493 Btu/hr*ft^2 °F = 2,8 W/m^2*K** and to a *Solar Heat Gain Factor - SHGC* of **0,564**. It's then clear that is necessary providing for a huge renovation in order to allow their thermal properties fulfilling the National Italian limits (respectively **2,60 W/m^2*K** and **2,40 W/m^2*K** for the Climatic Zone *C* and *D*) as well as the Danish ones (i.e. **1,65 W/m^2*K**);

- Besides, they are responsible for a too much high ***Airflow-Infiltration Rate*** (***Leaky - 0,78 ACH***- Annual Average Changes for Hour as settled for the existing building) and it's then necessary bringing it back to a more suitable rate, compliant with the Italian - and Danish - standards (as we will see: ***0,30 ACH*** or a ***Tight*** Infiltration Rate of ***0,40 ACH***).
  Actually, when dealing with the analysis of the default case, a ***Leaky*** infiltration option had been selected. That's because the main source of air leakage (according to a "European standard house structure") is generally ascribable to the window building element - in this case quite crummy - despite an external walls' and/or roof's improvement would also reduce infiltrations and heat losses through the building envelope.

Windows' replacement will therefore significantly affect the air tightness of the entire building and for this reason (along with the existing glazing and window frames' improvement) a reduction of infiltration rate was contextually planned.

The above goals are only achievable by means of a substantial change of the global, crummy, existing windows' performances: thence it has been planned to entirely remove and replace them with new ones, characterized by higher performance levels

.

EXISTING WINDOWS	2 PANE	U-Value: 2,799 W/m^2*K
	CLEAR GLASS	SHGC – Solar Heat Gain Coefficient: 0,564
	NON METAL FRAME	E_{value} = -142,15 kW/m^2*yr

Tab. 6.30 Existing windows' main properties

The replacement solutions selected and tested within the current assessment consist in the ones depicted by the summary table of below (**Tab. 6.31**).
In particular, it must be recalled that, beside the most representative **default windows types** already available in *BEopt* (even though adapted according to the Italian average installation costs), also **new custom windows** were *ex novo* introduced and evaluated.

<table>
<tr><th colspan="2">ITALY – CLIMATIC ZONE C</th></tr>
<tr><td colspan="2"><u>RETROFIT SOLUTION A</u></td></tr>
<tr><td colspan="2">3 PANE
LOW EMISSIVITY
INSULATED – ARGON FILLED
HIGH SHGC</td></tr>
<tr><td>U-Value: 1,033 W/m^2*K</td><td>SHGC – Solar Heat Gain Coefficient: 0,402</td></tr>
<tr><td colspan="2">1,033 W/m^2*K <u><2,60 W/m^2*K</u></td></tr>
<tr><td colspan="2"><u>RETROFIT SOLUTION B</u></td></tr>
<tr><td colspan="2">3 PANE
LOW EMISSIVITY
INSULATED – ARGON FILLED
LOW SHGC</td></tr>
<tr><td>U-Value: 0,943 W/m^2*K</td><td>SHGC – Solar Heat Gain Coefficient: 0,266</td></tr>
<tr><td colspan="2">0,943 W/m^2*K <u><2,60 W/m^2*K</u></td></tr>
<tr><td colspan="2"><u>RETROFIT SOLUTION C</u></td></tr>
<tr><td colspan="2">3 PANE
LOW EMISSIVITY
THERMAL BREAK- METAL - AIR-FILLED
2 DIFFERENT SHGC</td></tr>
<tr><td rowspan="2">U-Value: 2,6 W/m^2*K</td><td>HIGH SHGC – Solar Heat Gain Coefficient: 0,528</td></tr>
<tr><td>MEDIUM SHGC – Solar Heat Gain Coefficient: 0,437</td></tr>
<tr><td colspan="2">1,033 W/m^2*K <u><2,60 W/m^2*K</u></td></tr>
<tr><td colspan="2"><u>RETROFIT SOLUTION D</u></td></tr>
<tr><td colspan="2">3 PANE
LOW EMISSIVITY
INSULATED - AIR-FILLED
HIGH SHGC</td></tr>
<tr><td>U-Value: 1,17 W/m^2*K</td><td>SHGC – Solar Heat Gain Coefficient: 0,402</td></tr>
<tr><td colspan="2">1,17 W/m^2*° K <u><2,60 W/m^2*K</u></td></tr>
<tr><td colspan="2"><u>RETROFIT SOLUTION E</u> : BEOPT DEFAULT OPTION</td></tr>
<tr><td colspan="2">3 PANE
LOW EMISSIVITY
INSULATED - AIR-FILLED
LOW SHGC</td></tr>
<tr><td>U-Value: 1,09 W/m^2*K</td><td>SHGC – Solar Heat Gain Coefficient: 0.266</td></tr>
<tr><td colspan="2">1,09 W/m^2*K <u><2,60 W/m^2*K</u></td></tr>
</table>

Tab. 6.31 The main windows' retrofit solutions assessed and their respective characteristics

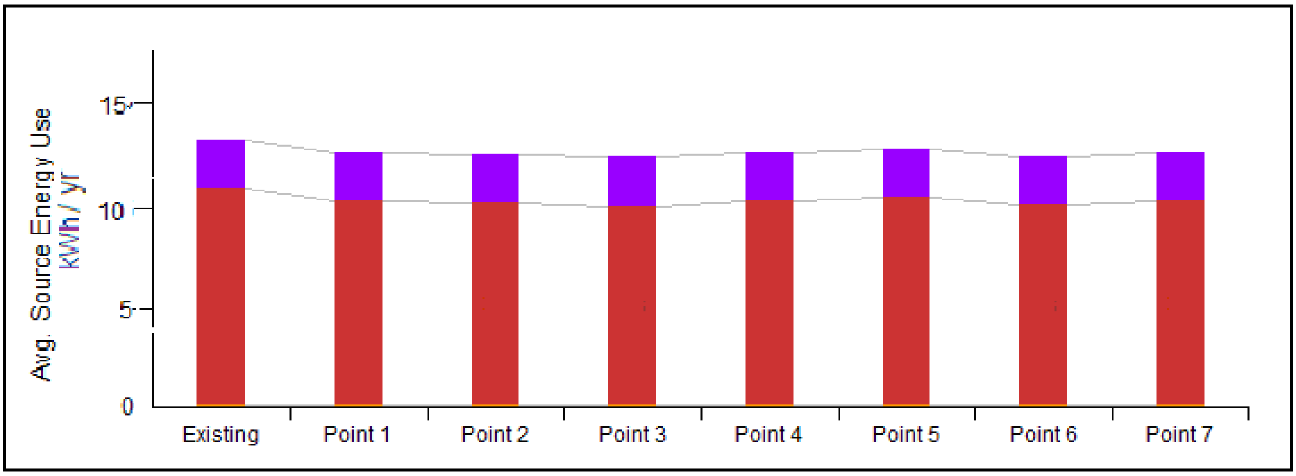


Fig. 6.56 Analysis results (Max Savings – Min costs Point) – CLIMATIC ZONE C
Global Savings estimated in 1.114 kWh/yr & respective Retrofit costs evaluated in 230 €/m^2 of windows
Total windows area assumed as 7% of exterior walls area - Exterior walls area 130,060 m^2
Consequent Windows retrofit costs evaluated in 2.094 €

Considering the final energy savings level achievable through an infiltration rate's reduction, along with the improvements provided by the most profitable windows replacement solution, it's possible to detect, as the most profitable retrofit measure (also according to the main *BEopt* outputs and balance assessment), the ***"C"*** configuration: i.e. ***3 PANE - LOW EMISSIVITY - THERMAL BREAK – METAL – AIR FILLED - MEDIUM SHGC*** represented by the *Output Point 4*.
Also in this case, recalling the assessment carried out by Enea with reference to windows' replacements and focusing the attention on the single Sardinian Region, it's possible to recall the following summary graphs:

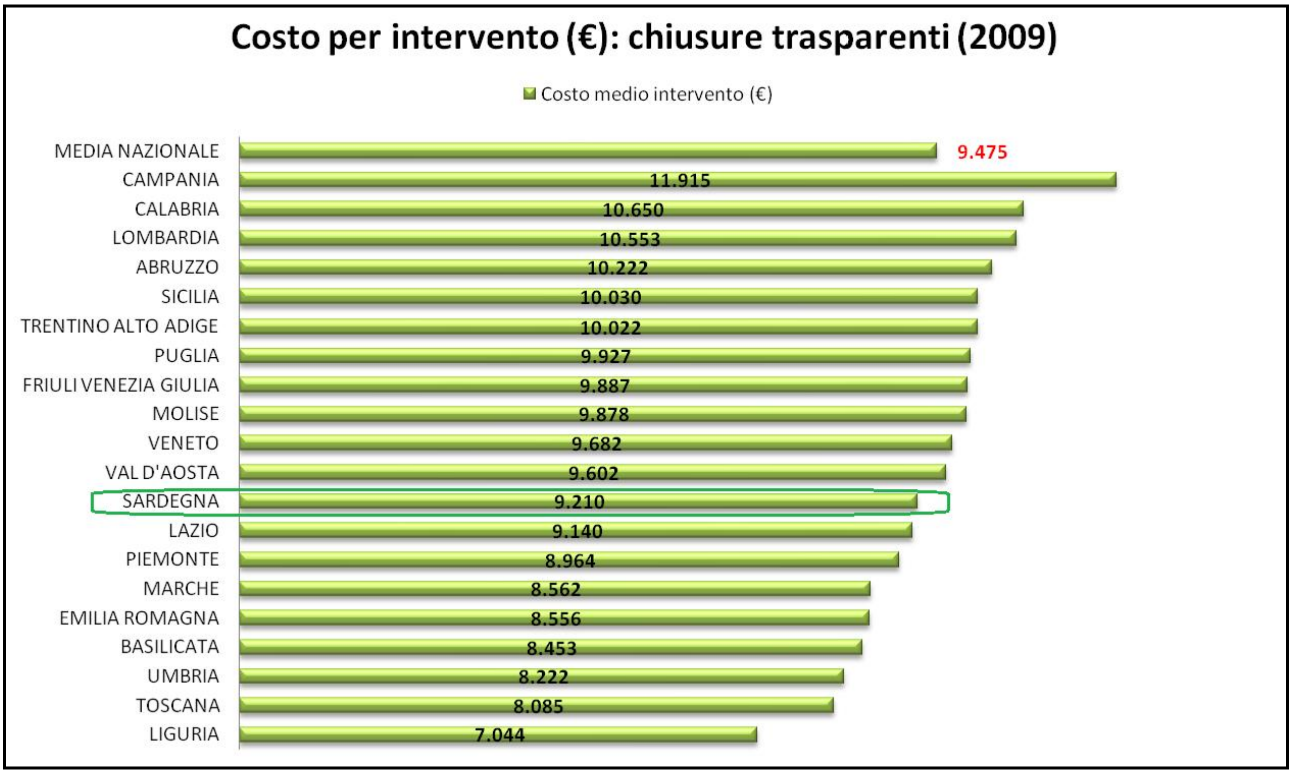


Fig. 6.57- a Enea Report's excerption (ref. year 2009)

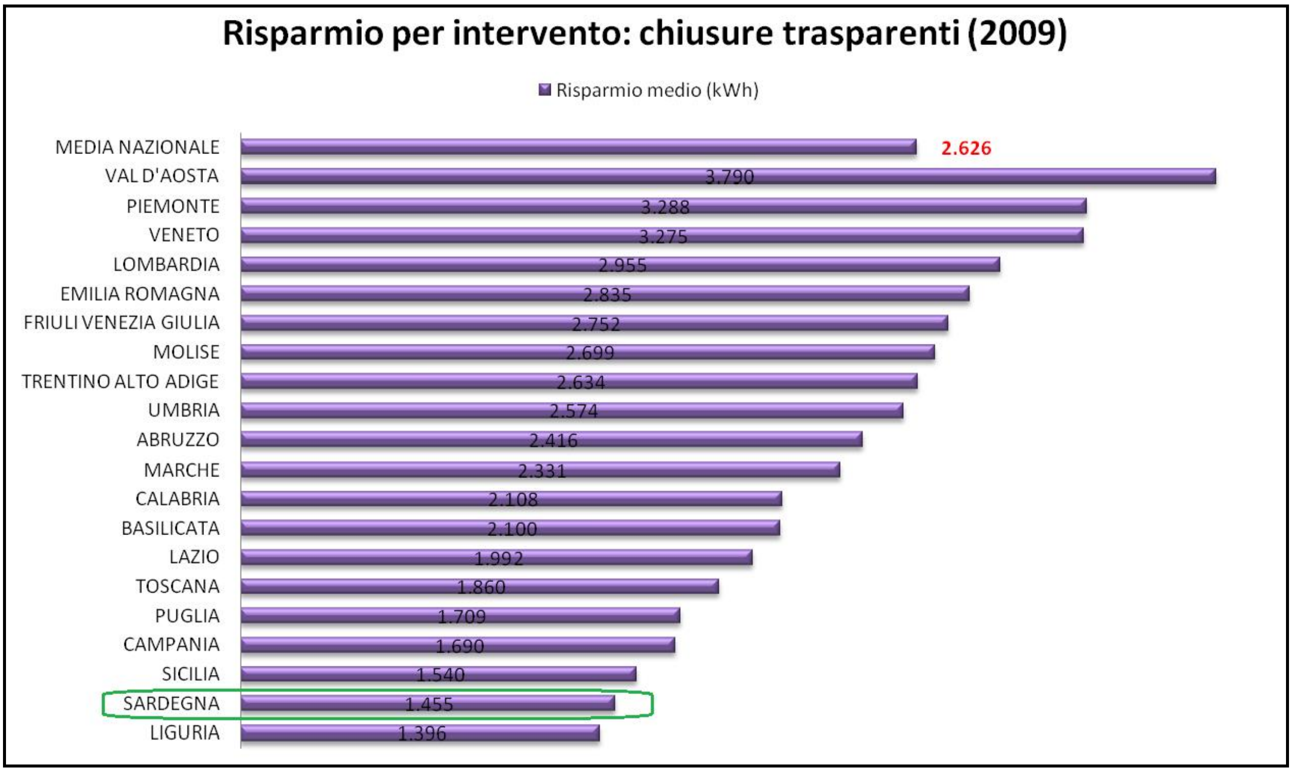


Fig. 6.57- b Enea Report's excerption (ref. year 2009)

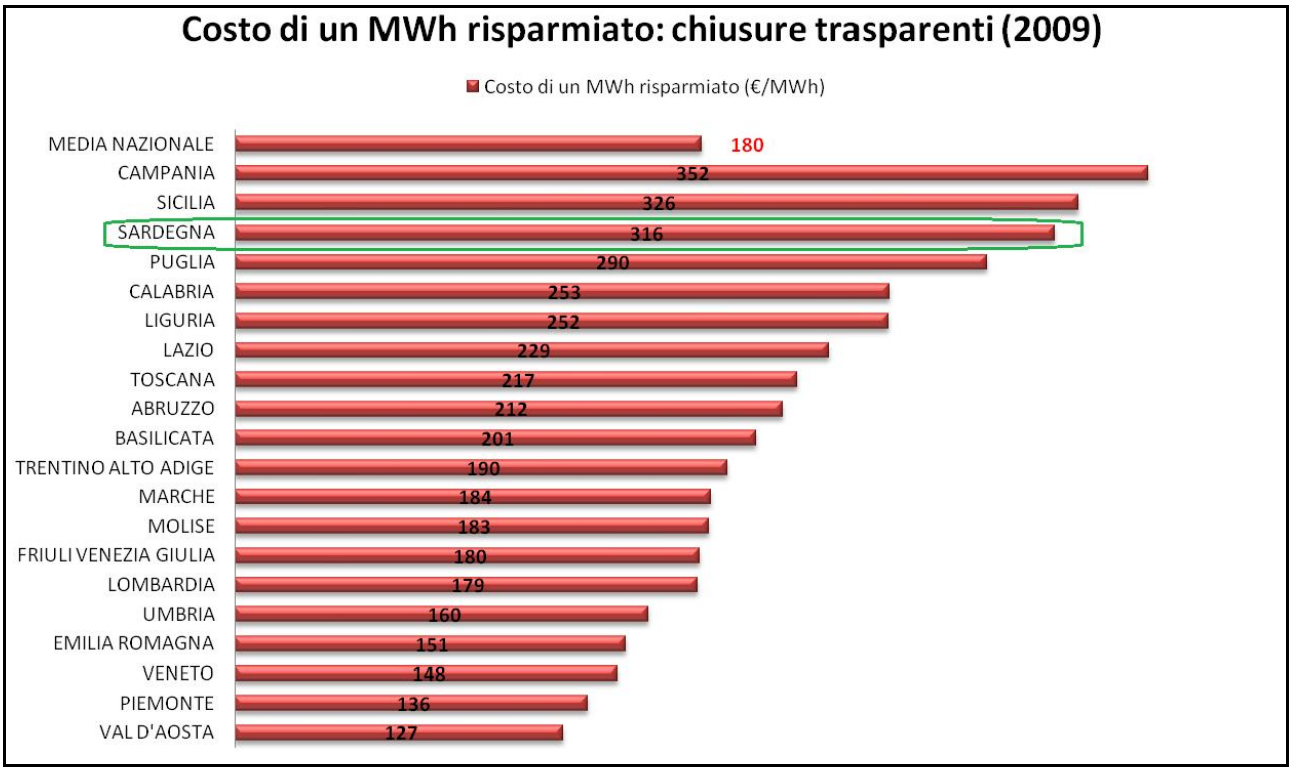


Fig. 6.57- c Enea Report's excerption (ref. year 2009)

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: <u>WINDOWS</u>	ENEA STATISTICAL DATA <u>STATIC</u> ASSESSMENT (<u>SARDINIA</u>)	BEOPT <u>DYNAMIC</u> OPTIMIZATION ASSESSMENT (<u>CLIMATIC ZONE C</u>)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the <u>ENTIRE ITALY and for ALL the different kinds of building retrofit</u>)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the <u>ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit</u>)
ENERGY SAVINGS [KWh/yr]	1.455	1.114		
RETROFIT COSTS [€]	9.210	2.094		
ASSUMED LIFESPAN [yr]	ENEA REF. 20	ENEA REF. 20		
COSTS SAVED [€/KWh*yr]	0,316	0,094	0,579	0,487
COSTS SAVED [€/MWh*yr]	316	94 →	57,86	48,68

Tab. 6.32 Global Comparative Framework: Windows replacement (exploiting the BEopt *C Zone* results)

- ***<u>D Zone</u>*** **(windows replacement)**

Launching once again *BEopt*, initially in a *Parametric Mode* and finally exploiting the *Optimization Mode*, the same retrofit solutions previously assessed were tested, since they are widely respectful of the maximum transmittance limit ($U_{gl} < 2,4$ W/m^2*K) required for the current climatic zone.
And if on the one hand the same most profitable improvement solution before assessed also for the *C Zone* has been detected, on the other hand - in this case - higher levels of energy savings were registered compared to the previous case (see below).

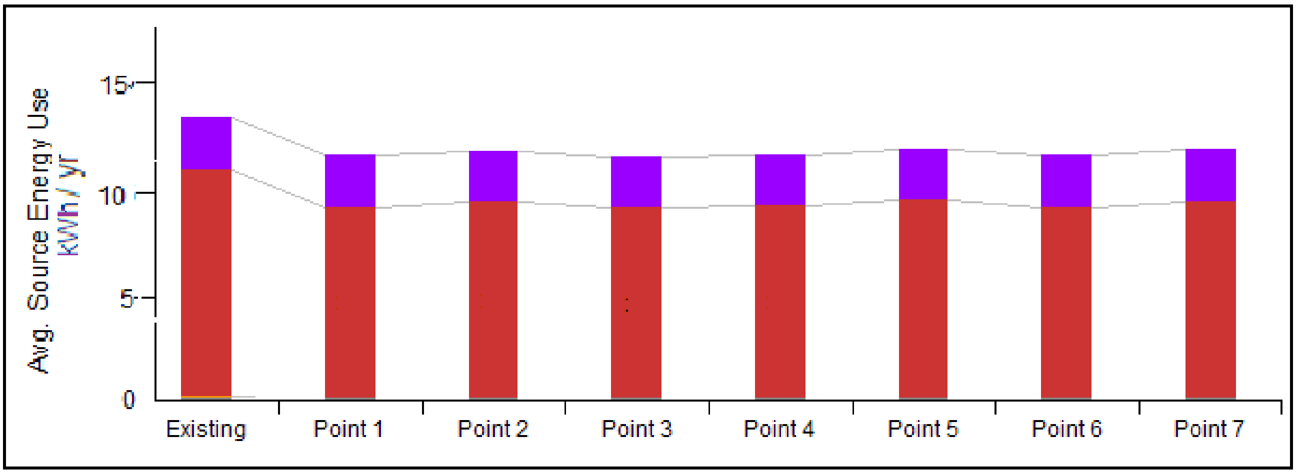


Fig. 6.58 Analysis results (Max Savings – Min costs Point) – CLIMATIC ZONE D
Global Savings estimated in 1.788 kWh/yr and respective Retrofit costs evaluated in 230 €/m^2 of windows
Total windows area assumed as 7% of exterior walls area - Exterior walls area 130,060 m^2
Consequent Windows retrofit costs evaluated in 2.094 €

Recalling once again the assessment carried out by Enea with reference to windows replacements and focusing the attention on the single Sardinian Region, it's possible depicting the following summary table (**Tab. 6.33**) also for the climatic zone *D* and still with reference to the retrofit measure represented by *3 PANE - LOW EMISSIVITY - THERMAL BREAK – METAL – AIR FILLED - MEDIUM SHGC*.

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: WINDOWS	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)	BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	1.455	1.788		
RETROFIT COSTS [€]	9.210	2.094		
ASSUMED LIFESPAN [yr]	ENEA REF. 20	ENEA REF. 20		
COSTS SAVED [€/KWh*yr]	0,316	0,059	0,579	0,487
COSTS SAVED [€/MWh*yr]	316	59 →	57,86	48,68

Tab. 6.33 Global Comparative Framework: Windows replacement (exploiting the BEopt *D Zone* results)

6.15 Retrofit results and optimization tasks

Retrofit scenarios and respective evaluation – Italy: *C Zone* & *D Zone*

Foundation slab retrofit

Also this building element, as already mentioned, is not respectful of the transmittance limits currently in force: actually its U-value, assessed in **0,633 W/m²*K**, is higher than the maximum transmittance values respectively allowed for the Climatic Zone *C* (i.e. **0,42W/m²*K**) and *D* (i.e. **0,36 W/m²*K**).

REFERENCE CASE: ITALIAN SINGLE DETACHED HOUSE	
RETROFIT'S ACTION TYPE: ENERGY SAVING	
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB	OPAQUE SURFACES HORIZONTAL OR SLOPING (i.e. FLOORS upward not heated zones or exterior)
U-VALUE STARTING VALUE	0,633 W/m²*K
REGULATIONS' U_{REF} LIMIT valid from 1st January 2010 – ITALIAN CLIMATIC ZONE *D*	0,42 W/m²*K

Tab. 6.34

While dealing with such an issue, the retrofit solution following shown has been defined and consequently assessed through the exploitation and the implementation of the main potentialities and powerful tools provided by *BEopt*:

SLAB'S INSULATION
SLAB'S INSULATION: BEOPT OPTION *"4 ft. R20 Exterior" – default option N. 11* 60 cm FOUNDATION WALL INSULATION'S DEPTH
FOUNDATION INSULATION DEPTH 1,2 m
R-VALUE OF SLAB INSULATION: 3,522 m^2*K/W
EFFECTIVE U-VALUE PER FOOT OF THE CARPETED PERIMETER OF THE SLAB *(Slab Carpet Perimeter Conduction):* 0,519 W/m*K
EFFECTIVE U-VALUE PER FOOT OF THE BARE PERIMETER OF THE SLAB *(Slab Bare Perimeter Conduction):* 0,692 W/m*K

Tab. 6.35

N.B. Since for the current building model a *100% Exposed Floor* (i.e. an *Uncarpeted Slab*) has been settled, the distinction between *Carpeted/Uncarpeted (Bare) perimeter* doesn't affect - in this case - the final effective transmittance.

Recalling once again the main assumptions above mentioned (see **Part 6.7**) stated by the *Winklemann* article and being also aware of the main hypotheses and approximations adopted by *BEopt* for its evaluations, the only profitable kind of slab retrofitting action would be an **Exterior Perimeter Insulation**, as shown by the above summary table (**Tab. 6.35**) and as also hereinafter detailed.

R20 Exterior Slab Insulation - BEopt default option

Effective Slab Resistance: * $R_{eff} = A/(F2 * P_{exp}) = 1617/(\mathbf{0{,}30}*164) = 32{,}87$ hr*ft^2*F/Btu

(where ***F2*** is the Perimeter Conduction Factor for Concrete Slab-on-Grade as reported by ***Table 1*** of the *Winkelmann Article* – recalling "Y.J. Huang, L.S. Shen, J.C. Bull, L.F. Goldberg, *Whole-house Simulation of Foundation Heat Flows Using the DOE-2.1C Program, ASHRAE Transactions 94 (2) (1988)*").

Effective Slab U-value:

$U_{eff}=1/R_{eff}=1/32{,}87=0{,}030$ Btu/hr*ft^2*F=**0,176 W/m^2*K**

* Despite the current study case analyzes an uninsulated, **uncarpeted** slab, the value of **0,30** is gathered form the right column (hp. Slab **carpeted**) of the above ***Table 1*** since the percentage of carpeted/uncarpeted slab surface is automatically evaluated by the software in proportion with the floor exposure percentage selected through the *Exposed Floor Category* of *BEopt*.
As it's possible to notice while observing the above results, such a slab retrofit has led to a **final Effective Slab U-value of 0,176 W/m^2*K**, hence widely respectful of both the limits settled by Italian Regulations for this building element.

After having launched BEopt for the two climatic zones of interest, the following main results were obtained (with an average renovation cost estimated in **~ 47 €/m²**

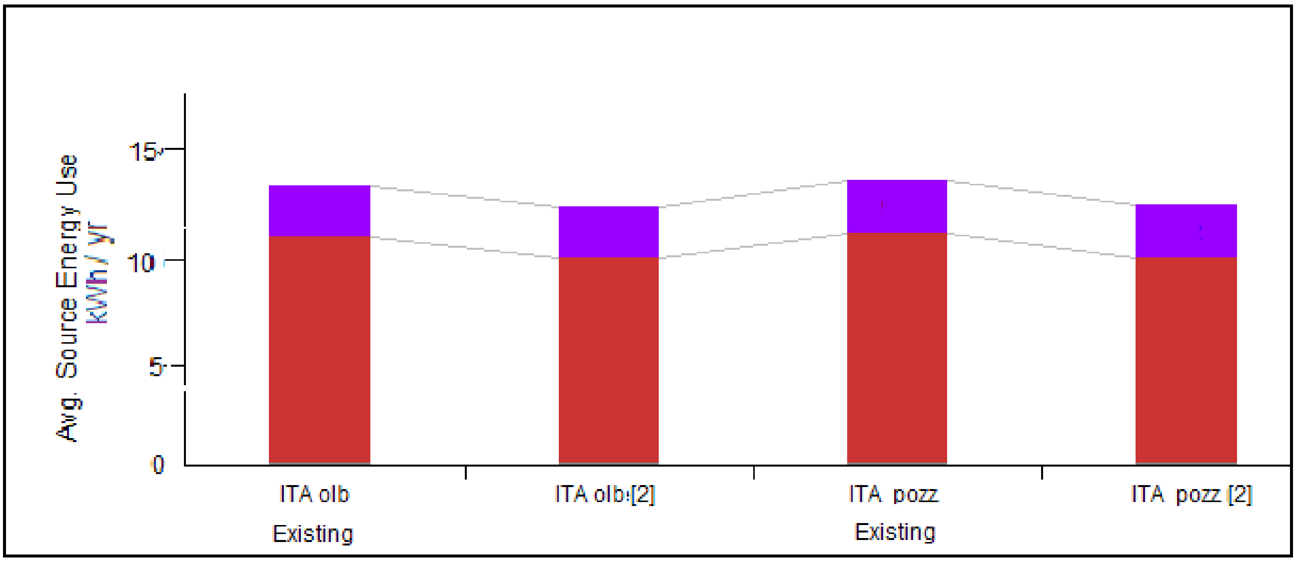


Fig. 6.59 Analysis results: CLIMATIC ZONE *C* (*"olb"*) vs CLIMATIC ZONE *D* (*"pozz"*)

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB (i.e. *OPAQUE HORIZONTAL SURFACES* - simplex variables)	**ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)**	**BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)**	**ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)**	**SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)**
ENERGY SAVINGS [KWh/yr]	3.788	967		
RETROFIT COSTS [€]	16.759	7.050		
ASSUMED LIFESPAN [yr]	ENEA REF. 20	ENEA REF. 20		
COSTS SAVED [€/KWh*yr]	0,221	0,365	0,579	0,487
COSTS SAVED [€/MWh*yr]	221	← 365	57,86	48,68

Tab. 6.36 Global Comparative Framework: Foundation slab's retrofit (exploiting the BEopt *C Zone* results)

RETROFIT'S ACTION TYPE: ENERGY SAVING				
BUILDING ELEMENT TO BE IMPROVED: FOUNDATION SLAB (i.e. *OPAQUE HORIZONTAL SURFACES* - simplex variables)	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)	BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	3.788	1.172		
RETROFIT COSTS [€]	16.759	7.050		
ASSUMED LIFESPAN [yr]	ENEA REF. 20	ENEA REF. 20		
COSTS SAVED [€/KWh*yr]	0,221	0,301	0,579	0,487
COSTS SAVED [€/MWh*yr]	221	← 301	57,86	48,68

Tab. 6.37 Global Comparative Framework: Foundation slab's retrofit (exploiting the BEopt *D Zone* results)

6.16 Retrofit results and optimization tasks

Retrofit scenarios and respective evaluation – Italy: *C Zone* & *D Zone*

Energy delivering actions (heating): thermal plant replacement

Changing now the main retrofitting "***Energy Saving***" approach until now adopted and hence dealing with the most fruitful retrofit actions which may be ascribed to the so called "***Energy delivering measures***", it's possible to report the following key-results.

Also in this case, a further investigation was necessary in order to adjust the main appliances' references and the respective energy efficiency factors from the *U.S. System* to the *European standards*.

At this reference, the different sections depicted in the several tables hereinafter shown provide a global overview about the available and most consistent default *BEopt* options (see **Tab. 6.38 - a, b, c, d, e, f, g, h, i**).

CATEGORIES	MAIN INFORMATION	AVAILABLE VALUES (specified as follows only in those cases for which some customization's and/or specification's problems have been encountered)	FURTHER COMMENTS
REFRIGERATOR	Total annual energy consumption - The Capacity given is the fresh volume capacity and does not include freezer volume of 5 ft3.	With the Default options: The annual Electric Use may vary from a minimum of 374 kWh/year (ENERGY STAR-TOP MOUNT FREEZER with a volume of 18 ft3) until 815 kWh/year (OLD - SIDE BY SIDE FREEZER) with a volume of 25 ft3) & 19 years of lifetime	..in the lack of specific and relating further information...(but other kinds of configuration and settings can be chosen and customized)
COOKING RANGE		With the Default options: The annual Electric Use may vary from a minimum of 80 kWh/year (GAS CONVENTIONAL with a Gas use of 29 therms/year & 15 years of lifetime) until 500 kWh/year (ELECTRIC CONVENTIONAL with a Gas use of 0 therms/year & 13 years of lifetime)	..in the lack of specific and relating further information...(but other kinds of configuration and settings can be chosen and customized)
DISHWASHER	"Annual Energy" is the annual energy used by the dishwasher, under test conditions, from the EnergyGuide label.For dishwasher with boost heating elements, the dishwasher water heating depends on the water heater set point.In the case where all hot water is heated internally (dishwashers with cold-water connection only), energy consumption for dishwasher water heating depends on mains water temperature and is location-dependent, and the impact on water heater energy consumption is zero.	With the Default options: The annual Electric Use may vary from a minimum of 290 kWh/year (ENERGY STAR with a lifetime of 11 years) until 318 kWh/year (STANDARD with a lifetime of 11 years)	..in the lack of specific and relating further information...(but other kinds of configuration and settings can be chosen and customized) - Actually, in order to define the current "custom type", further details and information has been specified (the number of place-settings for the unit, the use of a cold water connection or not etc...)
CLOTHES WASHER	Options of varying energy, water use and water removal efficiency are available for washers. Cold Only options refer to operating the clothes washer with cold water. The Modified Energy Factor is a measure of energy efficiency that considers the energy used by the washer, the energy used to heat the water, and the energy used to run the dryer.	With the Default options: The Modified EF [ft3/kW-cycle] may vary from a minimum of 1.41 STANDARD with a lifetime of 14 years and a volume of 3.50 ft3) until 2.47 (ENERGY STAR with a lifetime of 14 years and a volume of 3.68 ft3)	..in the lack of specific and relating further information...(but other kinds of configuration and settings can be chosen and customized) - Actually, in order to define the current "custom type", further details and information has been specified (the volume of the washer drum, the use of the only cold cycle or not etc...)
CLOTHES DRYER	Clothes dryer energy consumption depends on the characteristics of both the dryer (moisture removal efficiency) and the washer (remaining moisture in clothes).	Also available an ELECTRIC DRYER, or a GAS DRYER	

Tab. 6.38-a Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION
AIR CONDITIONER	SEER values shown are nominal rated values; actual performance will vary depending on climate. For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. If a building requires larger than a 5-ton unit, 2 air conditioners of similar size will be used for costing. High SEER air-conditioners tend to decrease in efficiency as the rated capacity increases. This trend has been included for the SEER 18, SEER 21, and SEER 24.5 options using manufacturer data but can be modified by creating a User-Defined option. EER multipliers are applied to the rated EER for 1.5, 2, 3, 4, and 5 ton air-conditioners. The BEopt auto-sized result is used to interpolate between multipliers. For units larger than 5 tons, 2 equally sized units are assumed when adjusting the EER.
FURNACE	AFUE values shown are nominal rated values; actual performance will vary depending on climate. For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes.
HYDRONIC HEATING	Hydronic heating is distributed through baseboard heaters in the zone. AFUE values shown are nominal rated values; actual performance will vary depending on climate. For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. For condensing boilers, the default control has no Outdoor Air Temperature Reset. User can go to the Option Editor and switch on the reset control with user defined reset temperature bounds.
HEAT PUMP	SEER and HSPF values shown are nominal rated values; actual performance will vary depending on climate. For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. If a building requires larger than a 5-ton unit, 2 heat pumps of similar size will be used for costing. High SEER/HSPF heat pumps tend to decrease in efficiency as the rated capacity increases. This trend has been included for the SEER 18/HSPF 9.3, SEER 19/HSPF 9.5, and SEER 22/HSPF 10.0 options using manufacturer data but can be modified by creating a User-Defined option. EER and COP multipliers are applied to the rated EER for 1.5, 2, 3, 4, and 5 ton heat pumps. The BEopt auto-sized result is used to interpolate between multipliers. For units larger than 5 tons, 2 equally sized units are assumed when adjusting the EER and COP.
GROUND SOURCE HEAT PUMP	Vertical bore field configuration. With proper (auto) ground heat exchanger sizing, thermally enhanced grout or high ground thermal conductivity will result in less heat exchanger bore length (bore depth times number of bores) with similar energy savings, but reduced first cost and annual energy related cash flow.For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. If a building requires larger than a 5-ton unit, 2 heat pumps of similar size will be used for costing.The lifetime is an effective value averaged across representative continental climates feasible for GSHP, adjusting for the unequal timing of indoor heat pump and ground heat exchanger replacements, based on fixed, assumed values of: HP life = 15 yrs, ground heat exchanger age = 50 yrs, period of analysis = 30 yr, real discount rate = 3%, and cash only. For different user-selected values, the annualized cost results would not be valid. BEopt auto adjusts ground heat exchanger pumping power, and indoor fan powe

Tab. 6.38-b Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	AVAILABLE OPTIONS	OUTPUT AUTOMATICALLY EVALUATED VALUES			
			SEER (Seasonal Energy Efficiency Ratio)	EER (Energy Efficiency Ratio) [kBtu/kWh]	COMPRESSOR	LIFETIME [years]
AIR CONDITIONER	SEER values shown are nominal rated values; actual performance will vary depending on climate.	SEER 8, 15 years old (Seldom Maintened)	5.1	4.6	1 Stage	19
		SEER 8, 15 years old (Frequently Maintened)	6.9	6.3	1 Stage	19
		SEER 10, 10 years old (Seldom Maintened)	7.4	6.5	1 Stage	19
		SEER 10, 10 years old (Frequently Maintened)	9.0	8.1	1 Stage	19
	For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. If a building requires larger than a 5-ton unit, 2 air conditioners of similar size will be used for costing.	SEER 13, at Wear Out	13.0	11.1	1 Stage	19
		SEER 13	13.0	11.1	1 Stage	19
		SEER 14	14.0	12.0	1 Stage	19
		SEER 15	15.0	13.0	1 Stage	19
		SEER 16	16.0	13.9	1 Stage	19
	High SEER air-conditioners tend to decrease in efficiency as the rated capacity increases. This trend has been included for the SEER 18, SEER 21, and SEER 24.5 options using manufacturer data but can be modified by creating a User-Defined option. EER multipliers are applied to the rated EER for 1.5, 2, 3, 4, and 5 ton air-conditioners. The BEopt auto-sized result is used to interpolate between multipliers. For units larger than 5 tons, 2 equally sized units are assumed when adjusting the EER.	SEER 16 (2 Stage)	16.0	13.5 - 12.4	2 Stage	19
		SEER 17	17.0	14.4 - 13.2	2 Stage	19
		SEER 18	18.0	15.2 - 14	2 Stage	19
		SEER 21	21.0	17.7 - 15.3	2 Stage	19
		SEER 24.5	24.5	[multiple]	Var. Speed	19

Tab. 6.38-c Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	AVAILABLE OPTIONS	OUTPUT AUTOMATICALLY EVALUATED VALUES	
			AFUE (Annual Fuel Utilization Efficiency) [Btu/Btu]	LIFETIME [years]
FURNACE	AFUE values shown are nominal rated values; actual performance will vary depending on climate.	Gas, AFUE 78%, 20 years old (Seldom Maintened)	0.577	20
		Gas, AFUE 78%, 20 years old (Frequently Maintened)	0.706	20
		Gas, AFUE 78%, 10 years old (Seldom Maintened)	0.671	20
		Gas, AFUE 78%, 10 years old (Frequently Maintened)	0.742	20
		Gas, AFUE 78%	0.780	20
	For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes.	Gas, AFUE 92.5%	0.925	20
		Fuel Oil, AFUE 78%	0.780	15
		Fuel Oil, AFUE 95%	0.950	15
		Propane, AFUE 78%	0.780	20
		Propane, AFUE 94%	0.940	20
		Electric, AFUE 98%	0.980	20

Tab. 6.38-d Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	AVAILABLE OPTIONS	OUTPUT AUTOMATICALLY EVALUATED VALUES			
			SEER (Seasonal energy efficiency ratio) [kBtu/kWh]	HSPF (Heating Seasonal Performance Factor) - (*) [kBtu/kWh]	COMPRESS OR	LIFETIME [years]
HEAT PUMP (Air Source Heat Pumps.)	SEER and HSPF values shown are nominal rated values; actual performance will vary depending on climate.	SEER 8, HSPF 6.0, 15 years old (Seldom Maintened)	5.1	4.1	1 Stage	16
	For new construction or for autosizing within retrofit analysis, a calculation consistent with ACCA's Manual J 8th Edition is performed to auto-size the equipment for the annual simulation. The auto-sized result is then rounded up to a discrete size for costing purposes. If a building requires larger than a 5-ton unit, 2 heat pumps of similar size will be used for costing.	SEER 8, HSPF 6.0, 15 years old (Frequently Maintened)	6.9	5.3	1 Stage	16
		SEER 10, HSPF 6.2, 10 years old (Seldom Maintened)	7.4	4.8	1 Stage	16
		SEER 10, HSPF 6.2, 10 years old (Frequently Maintened)	9.0	5.7	1 Stage	16
		SEER 10, HSPF 6.2	10.0	6.2	1 Stage	16
	High SEER/HSPF heat pumps tend to decrease in efficiency as the rated capacity increases. This trend has been included for the SEER 18/HSPF 9.3, SEER 19/HSPF 9.5, and SEER 22/HSPF 10.0 options using manufacturer data but can be modified by creating a User-Defined option. EER and COP multipliers are applied to the rated EER for 1.5, 2, 3, 4, and 5 ton heat pumps. The BEopt auto-sized result is used to interpolate between multipliers. For units larger than 5 tons, 2 equally sized units are assumed when adjusting the EER and COP.	SEER 13, HSPF 7.7	13.0	7.7	1 Stage	16
		SEER 14, HSPF 8.2	14.0	8.2	1 Stage	16
		SEER 15, HSPF 8.5	15.0	8.5	1 Stage	16
		SEER 16, HSPF 8.6	16.0	8.6	2 Stage	16
		SEER 17, HSPF 8.7	17.0	8.7	2 Stage	16
		SEER 18, HSPF 9.3	18.0	9.3	2 Stage	16
		SEER 19, HSPF 9.5	19.0	9.5	2 Stage	16
		SEER 22, HSPF 10	22.0	10.0	Var. Speed	16

Tab. 6.38-e Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION
WATER HEATER	BEoptE+ only: "% Unmet shwrs" is an estimate of the percent of annual showering time with water leaving the HPWH below 110 deg F. The first value is using the Benchmark shower flow rate (2.25 gpm) and the second value is using low-flow showerheads (1.5 gpm). This metric is meant to assist users in selecting HPWH options that maintain an acceptable level of hot water delivery. It is a function of HPWH tank volume, setpoint, climate, and number of bedrooms; and it assumes the HPWH is in conditioned space. This metric does not account for the effect that some BEopt options (e.g. demand recirc. or clothes washer options) might have on hot water draw volume or mixed water temperature. The metric is sensitive to the timing of hot water use and thus real world values will vary considerably from one set of occupants to the next.
DISTRIBUTION	Hot water distribution systems impact the volume of hot water from the water heater required to meet the delivered hot water loads at the fixtures, internal heat gains to the building, and possibly recirculation pump energy (based on Table 18 in the 2009 Building America Benchmark). Insulated options assume the pipe is completely insulated and that there are no gaps along the pipe or at elbows and tees. Timer recirculation control assumes 16 hours of daily pump operation from 6am to 10pm. Demand recirculation controls assume push button control at all non-appliance fixtures with 100% ideal control (button pushed for every draw event, no false signals, and immediate use of hot water when it arrives at the fixture). User options not covered by the BA Benchmark House Simulation Protocols will be modeled as the Benchmark distribution system.
SOLAR DOMESTIC HOT WATER	Solar DHW systems provide pre-heated water to a conventional water heater specified in the Water heating / Water heater category. BEopt only: ICS (Integral Collector Storage) systems may not be suitable for cold climates due to potential problems with pipe freezing. Closed loop systems include anti-freeze, flatplate collector(s), and a solar storage tank (80 or 120 gal).
SDHW AZIMUTH	Options of type 'Relative' imply degrees relative to the Orientation of the front of the house (e.g. house azimuth + 90 degrees), while options of type 'Absolute' imply the actual azimuth (e.g. 90 degrees). An absolute azimuth of 0 degrees is south-facing.
SDHW TILT	Options of type Pitch imply degrees relative to the roof pitch (e.g. roof pitch + 10 degrees), options of type Absolute imply the actual tilt (e.g. 40 degrees), and options of type Latitude imply degrees relative to the location's latitude (e.g. Phoenix latitude + 15 degrees). An absolute tilt of 0 degrees is horizontal and an absolute tilt of 90 degrees is vertical. If a building has multiple roofs with different pitches, the pitch of the top roof will be used for options of type Pitch.

Tab. 6.38-f Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	AVAILABLE OPTIONS	OUTPUT AUTOMATICALLY EVALUATED VALUES			
			EF (Energy Factor)	Tank Volume [L]	% Unmet Showers [standard, low-flow]	LIFETIME [years]
WATER HEATER	*BEopt E+ only: "% Unmet Showers"* is an estimate of the percent of annual showering time with water leaving the HPWH below 110 deg F (43.33 °C). The first value is using the Benchmark shower flow rate (2.25 gpm) and the second value is using low-flow showerheads (1.5 gpm). This metric is meant to assist users in selecting HPWH options that maintain an acceptable level of hot water delivery. It is a function of HPWH tank volume, setpoint, climate, and number of bedrooms; and it assumes the HPWH is in conditioned space. This metric does not account for the effect that some BEopt options (e.g. demand recirc. or clothes washer options) might have on hot water draw volume or mixed water temperature. The metric is sensitive to the timing of hot water use and thus real world values will vary considerably from one set of occupants to the next.	Electric Standard, 10 years old (Seldom Maintened)	0.90	189.27	///	13
		Electric Standard, 10 years old (Frequently Maintened)	0.91	189.27	///	13
		Electric Standard, 5 years old (Seldom Maintened)	0.91	189.27	///	13
		Electric Standard, 5 years old (Frequently Maintened)	0.92	189.27	///	13
	The %Unmet Showers metric is only available for 50 or 80 gal HPWHs	Electric Standard	0.92	189.27	///	13
	** The Energy Factor is not listed for HPWH options since it is not necessarily a good indicator of annual performance for HPWHs. The HPWH options are based on generic models illustrating different performance levels possible with HPWH technology. ------ Details of compressor efficiency, control logic etc. are available via the Options Editor. ------ For HPWH performance evaluation results, see *Sparn B., Hudon K., Christensen D., "Laboratory Performance Evaluation of Residential Integrated Heat Pump Water Heaters"* - NREL/TP-5500-52635. September 2011	Electric Premium	0.95	189.27	///	13
		Gas Standard	0.59	151.42	///	13
		Gas Premium	0.67	151.42	///	13
		Gas Tankless	0.82	///	///	20
		Gas Tankless, Condensing	0.96	///	///	20
		Fuel Oil Standard	0.62	151.42	///	13
		Fuel Oil Premium	0.68	151.42	///	13
		Propane Standard	0.59	151.42	///	13
		Propane Premium	0.67	151.42	///	13
		HPWH, 50 gal, 130 F (54.44 °C)	**	189.27	1.8 %, 0.0 %	10
		HPWH, 50 gal, 140 F (60.0 °C)	**	189.27	0.0 %, 0.0 %	10
		HPWH, 80 gal, 130 F (54.44 °C)	**	302.83	0.0 %, 0.0 %	10
		HPWH, 80 gal, 140 F (60.0 °C)	**	302.83	0.0 %, 0.0 %	10

Tab. 6.38-g Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	AVAILABLE OPTIONS	OUTPUT AUTOMATICALLY EVALUATED VALUES			
			Primary Location	R-Value [m2 K / W]	Recirc. Control	LIFETIME [years]
DISTRIBUTION	Hot water distribution systems impact the volume of hot water from the water heater required to meet the delivered hot water loads at the fixtures, internal heat gains to the building, and possibly recirculation pump energy (based on Table 18 in the 2009 Building America Benchmark).	Uninsulated, TrunkBranch, Copper	Interior	0	None	99
	Insulated options assume the pipe is completely insulated and that there are no gaps along the pipe or at elbows and tees. Timer recirculation control assumes 16 hours of daily pump operation from 6am to 10 pm. Demand recirculation controls assume push button control at all non-appliance fixtures with 100% ideal control (button pushed for every draw event, no false signals, and immediate use of hot water when it arrives at the fixture). User options not covered by the BA Benchmark House Simulation Protocols will be modeled as the Benchmark distribution system.	Uninsulated, TrunkBranch, PEX	Interior	0	None	99
		Uninsulated, HomeRun, PEX	Interior	0	None	99
		R2, TrunkBranch, Copper	Interior	0.35	None	99
		R2, TrunkBranch, PEX	Interior	0.35	None	99
	N.B. Any recirculation pump energy will appear in the Miscellaneous Electric Loads end use	R2, HomeRun, PEX	Interior	0.35	None	99
		R2, TrunkBranch, Copper, Timer	Interior	0.35	Timer	20
		R2, TrunkBranch, PEX, Timer	Interior	0.35	Timer	20
		R2, TrunkBranch, Copper, Demand	Interior	0.35	Demand	20
		R2, TrunkBranch, PEX Demand	Interior	0.35	Demand	20
		R5, TrunkBranch, Copper, Timer	Interior	0.88	Timer	20
		R5, TrunkBranch, PEX, Timer	Interior	0.88	Timer	20

Tab. 6.38-h Major appliances available in BEopt and respective details and main properties

CATEGORIES	MAIN INFORMATION	FURTHER COMMENTS
PHOTOVOLTAIC AZIMUTH	Options of type 'Relative' imply degrees relative to the Orientation of the front of the house (e.g. house azimuth + 90 degrees), while options of type 'Absolute' imply the actual azimuth (e.g. 90 degrees). An absolute azimuth of 0 degrees is south-facing.	PV options are in kW DC (Solar PV systems are usually rated in peak kilowatts DC (Direct Current, like a battery). This is the peak DC power generated under full sun. However, in order to utilize this energy under normal circumstances, it is necessary to convert the DC power into AC (Alternating Current) power, using a device called an inverter. Modern inverters do a very good job of DC to AC conversion, but the losses in the inverter will be about 5%, yielding an efficiency of 95%. Furthermore, additional losses in the cabling,connections, etc. will bring the total system losses to approximately 15%. This yields a total system efficiency of about 85%. Actual conversion efficiency will vary system to system, based on the specific components selected and the physical layout, etc. (information downloaded from the following website: http://www.atas.com/ATAS/files/36/365421f2-4ea9-4538-b423-4c0ec83a702b.pdf)
PHOTOVOLTAIC TILT	Options of type Pitch imply degrees relative to the roof pitch (e.g. roof pitch + 10 degrees), options of type Absolute imply the actual tilt (e.g. 40 degrees), and options of type Latitude imply degrees relative to the location's latitude (e.g. Phoenix latitude + 15 degrees). An absolute tilt of 0 degrees is horizontal and an absolute tilt of 90 degrees is vertical. If a building has multiple roofs with different pitches, the pitch of the top roof will be used for options of type Pitch.	

Tab. 6.38-i Major appliances available in BEopt and respective details and main properties

The specific energy delivering measure designed and evaluated while dealing with this part of the analysis has led to the assessment hereinafter detailed.

Energy delivering strategies: Heating – Heat Pumps

While dealing with such an issue, It was planned to replace the former **Gas Furnace** (characterized by a 92,5 % *AFUE - Annual Fuel Utilization Efficiency*) with a **Heat Pump**.
As shown by the previous summary tables and by the "*BEOPT INSTALLAT_DETAILS*" spreadsheet of above, the *BEopt* default available options for heat pump systems are catalogued in function of their respective *SEER* values.

With reference to this topic, it must be highlighted that, while until the 31th December 2012 the former **Directive n.2002/31/CE** had been in force, starting instead from the 1st January 2013 and according to the ***European Directive ERP - Energy Related Products***, new rating criteria have to be applied for labelling and classifying new appliances' energy efficiency (including the ***SCOP*** parameter for heating and the ***SEER*** factor for cooling).

The evaluation of the specific energy power required by the building here analyzed has led (by means of an assessment-dimensioning calculation procedure) to the size of 14 kW for the principal external machine and, after a review about the main appliances currently available (as well as an interpolation in order to establish the exact *SEER* value to be settled), the following option has been introduced and settled.
As a matter of fact, when replacing the existing standard gas furnace a new heating system was defined and its specific typology is characterized by the main properties herein depicted: a ***14 kW Heating Unit - Conter Hyper DC Inverter – Mitsubishi*** (or similar ones) with a respective installation cost assessed in **5.068 €/unit (~ 6.967 $/unit).**
The *BEopt Cost Selector* has been consequently customized and balanced, assuming to install **1 heating device "*14 kW unit custom*".**

HEAT PUMP
14 kW UNIT CUSTOM
HP Cooling *SEER* (Seasonal Energy Efficiency Ratio): 14,00 kBtu/kWh
1 Stage Compressor
HP Cooling *HSPF* (Heating Seasonal Performance Factor): 8,2 kBtu/kWh

Tab. 6.39 Heat Pump System introduced and assessed: main properties and technical characteristics

And after having launched *BEopt* for the two climatic zones of interest according to the retrofit hypotheses above specified, the following results were obtained (see **Fig. 6.60**).

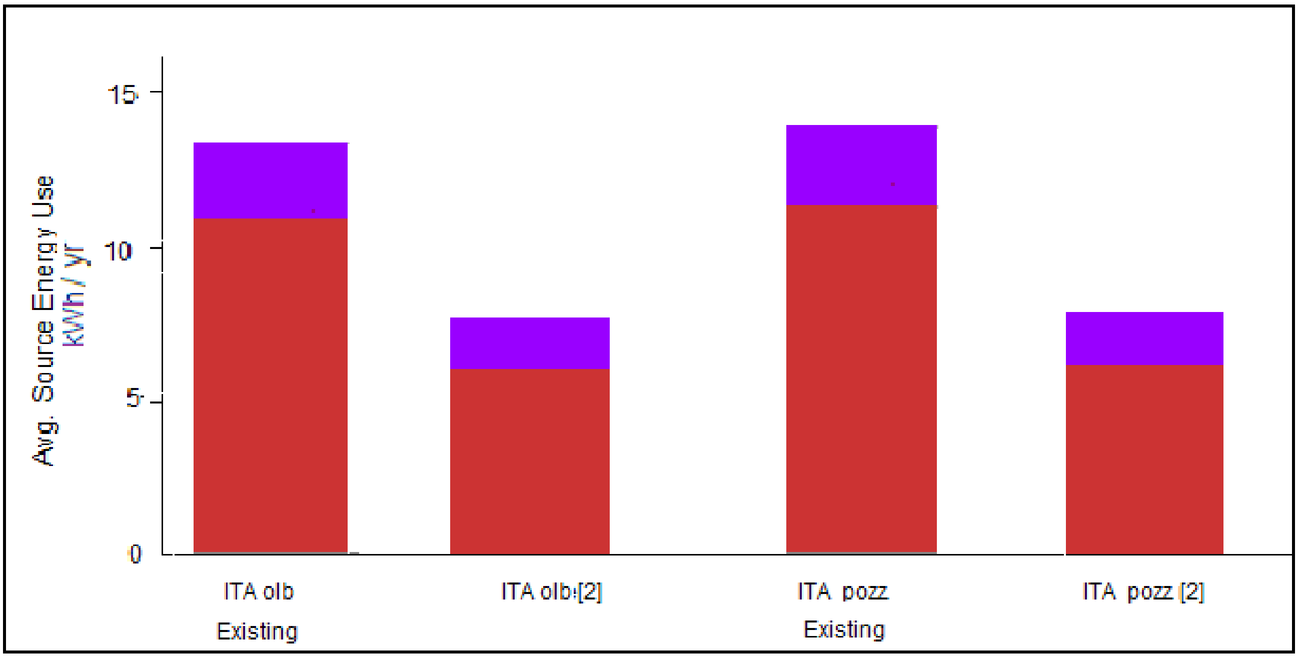


Fig. 6.59 Analysis results: climatic *ZONE C ("olb")* vs. climatic *ZONE D ("pozz")*

Also in this regard, recalling the assessment performed by Enea with reference to the thermal plants' replacements and focusing the attention on the single Sardinian Region, it's possible to point out the following summary graphs:

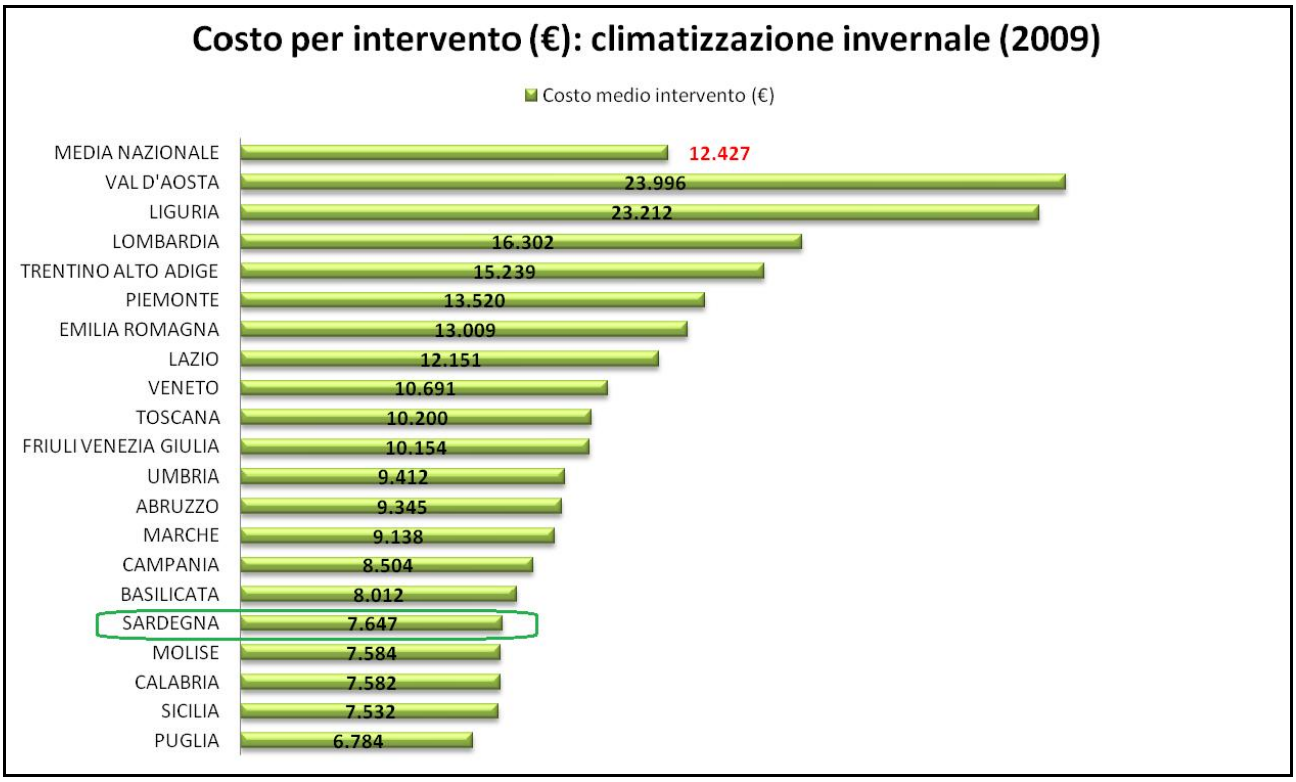


Fig. 6.61-a Enea Report's excerption (ref. year 2009)

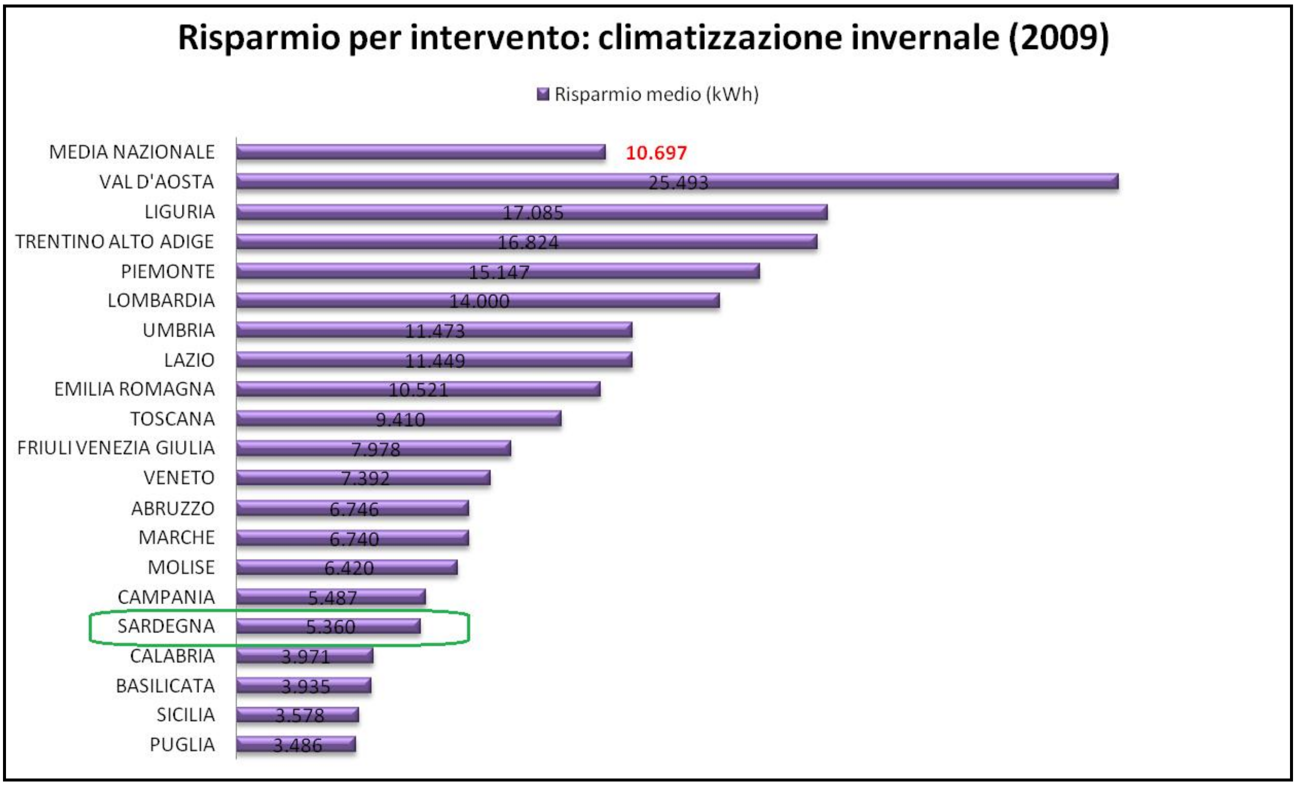


Fig. 6.61-b Enea Report's excerption (ref. year 2009)

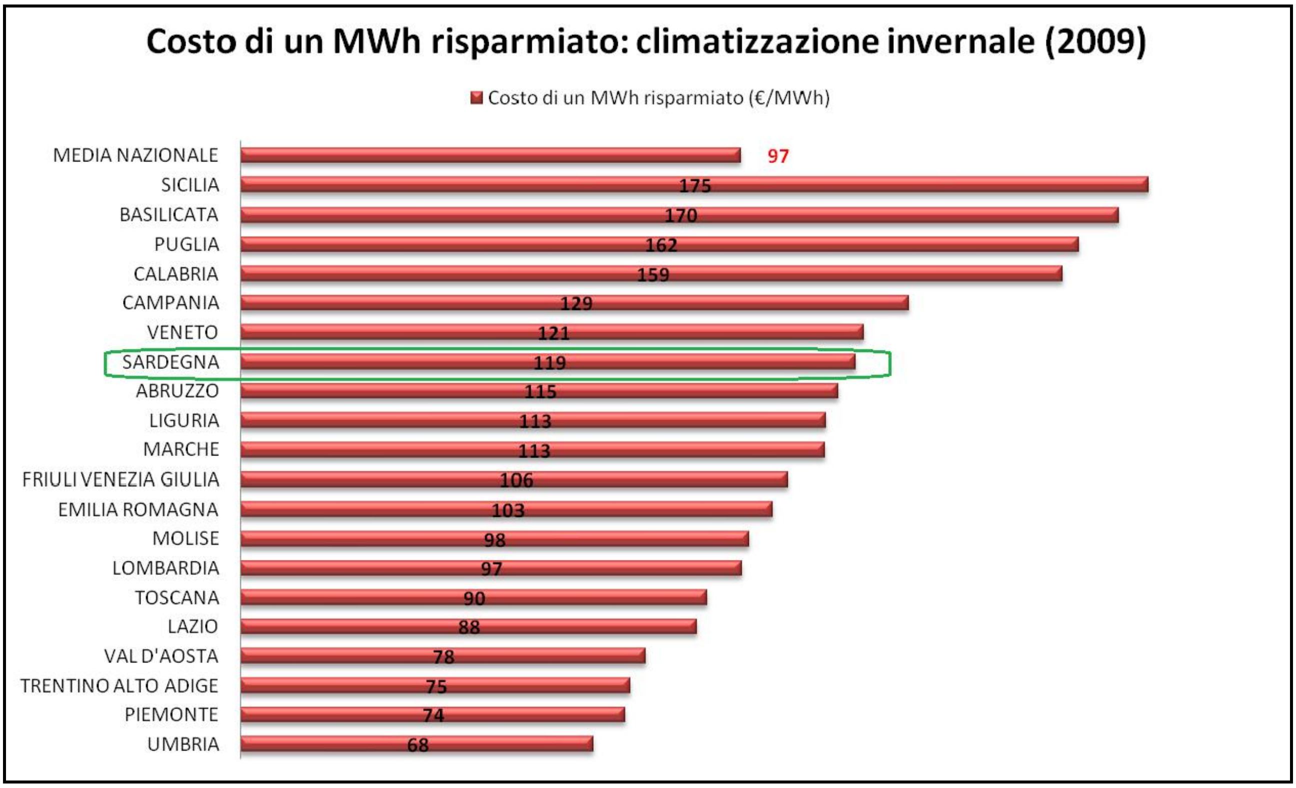


Fig. 6.61-c Enea Report's excerption (ref. year 2009)

RETROFIT'S ACTION TYPE: ENERGY DELIVERING				
BUILDING ELEMENT/APPLIANCE TO BE RETROFITTED: FURNACE REPLACEMENT (i.e. *THERMAL PLANT* - simplex variables)	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)	BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	5.360	2.169		
RETROFIT COSTS [€]	7.647	5.068		
ASSUMED LIFESPAN [yr]	ENEA REF. 12	ENEA REF. 12		
COSTS SAVED [€/KWh*yr]	0,119	0,195	0,579	0,487
COSTS SAVED [€/MWh*yr]	119	← 195	57,86	48,68

Tab. 6.40 Global Comparative Framework: Thermal Plant replacement (exploiting the BEopt *C Zone* results)

RETROFIT'S ACTION TYPE: ENERGY DELIVERING				
BUILDING ELEMENT/APPLIANCE TO BE RETROFITTED: FURNACE REPLACEMENT (i.e. *THERMAL PLANT* - simplex variables)	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)	BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)	ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	5.360	2.139		
RETROFIT COSTS [€]	7.647	5.068		
ASSUMED LIFESPAN [yr]	ENEA REF. 12	ENEA REF. 12		
COSTS SAVED [€/KWh*yr]	0,119	0,197	0,579	0,487
COSTS SAVED [€/MWh*yr]	119	← 197	57,86	48,68

Tab. 6.41 Global Comparative Framework: Thermal Plant replacement (exploiting the BEopt *D Zone* results)

6.17 Retrofit results and optimization tasks
Retrofit Scenarios and respective evaluation - Italy: *C Zone* & *D Zone*
Energy delivering actions: solar panels' installation

With reference to this issue, an average surface of **6 m^2 (~ 54 ft^2)** has been assumed for the solar panels to be installed and consequently assessed: a new-custom voice has been therefore *ex novo* defined and introduced into the *BEopt Library Manager* and *Cost Selector* sections (ref. Italian average price lists).
Besides, it was designed to settle the panels facing them **South** (*BEopt-Azimuth* option), also providing for an **orientation of 45°** (*BEopt-Tilt* option).
The new configuration assigned to the domestic hot water supplying system, after its integration with such solar panels, (and providing for a proper orientation and slope of solar collectors, strictly connected to the Italian Latitude), may be therefore described as follows (see **Tab. 6.42**).

SOLAR DHW DOMESTIC HOT WATER
CLOSED LOOP (including anti-freeze, flatplate collectors and a solar storage tank)
SDHW Collectors' Area: 6 m^2
SDHW Azimuth : South
SDHW Tilt : 45° (Custom Option)
LIFETIME : 20 YEARS (Custom Option – actually the default lifetime assumed by BEopt for this appliance is 15 years)

Tab. 6.42 Solar Thermal Panels *ex-novo* defined and introduced: main properties and technical characteristics

Afterwards, in order to gather how this latest improvement would reflect its impact on the global dwelling's consumption and its overall asset, it's possible to launch once again the program in a *Parametric Mode*, analyzing both the climatic zones until now considered. Such a latest retrofit hypothesis has led to the main results globally summarized by the **Tab. 6.43** and **Tab. 6.44** hereinafter reported. Moreover, also in this case it's possible recalling the assessment carried out by Enea for the Solar Panels installations, just focusing the attention on the only Sardinian Region.

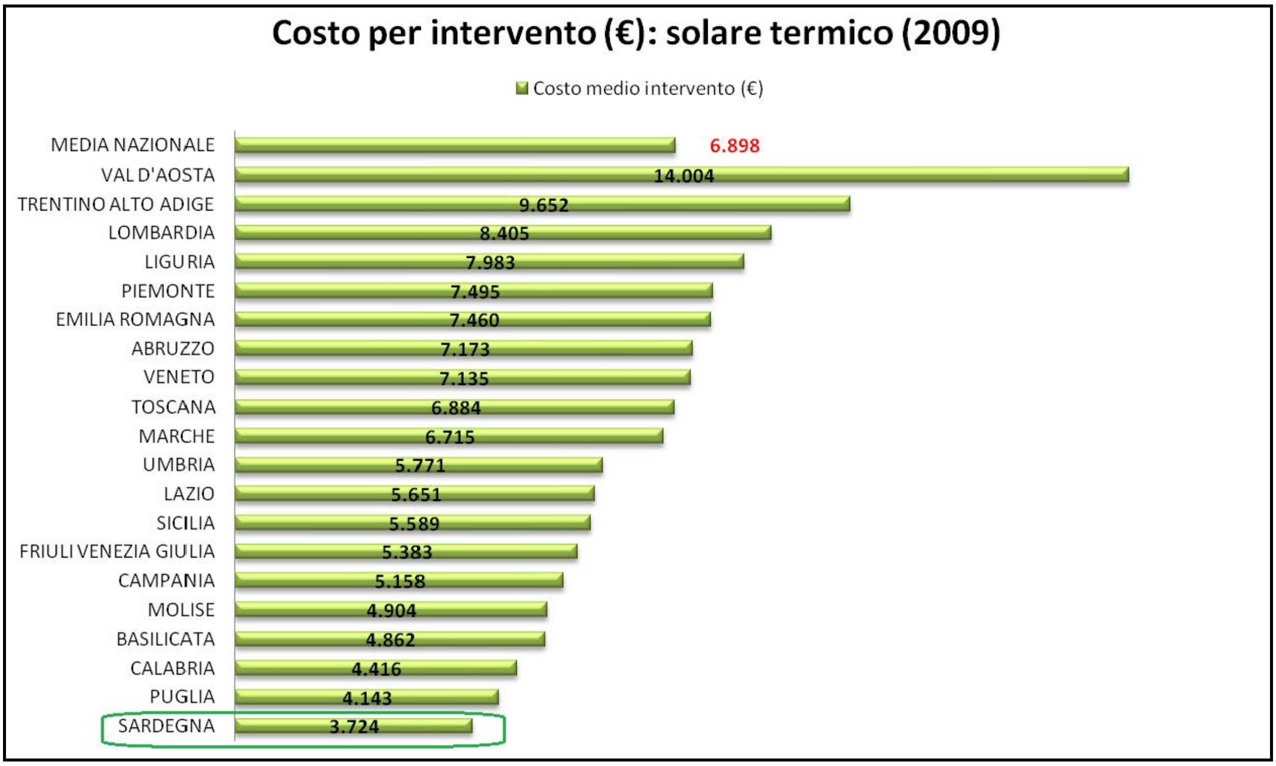


Fig. 6.62-a Enea Report's excerption (ref. year 2009)

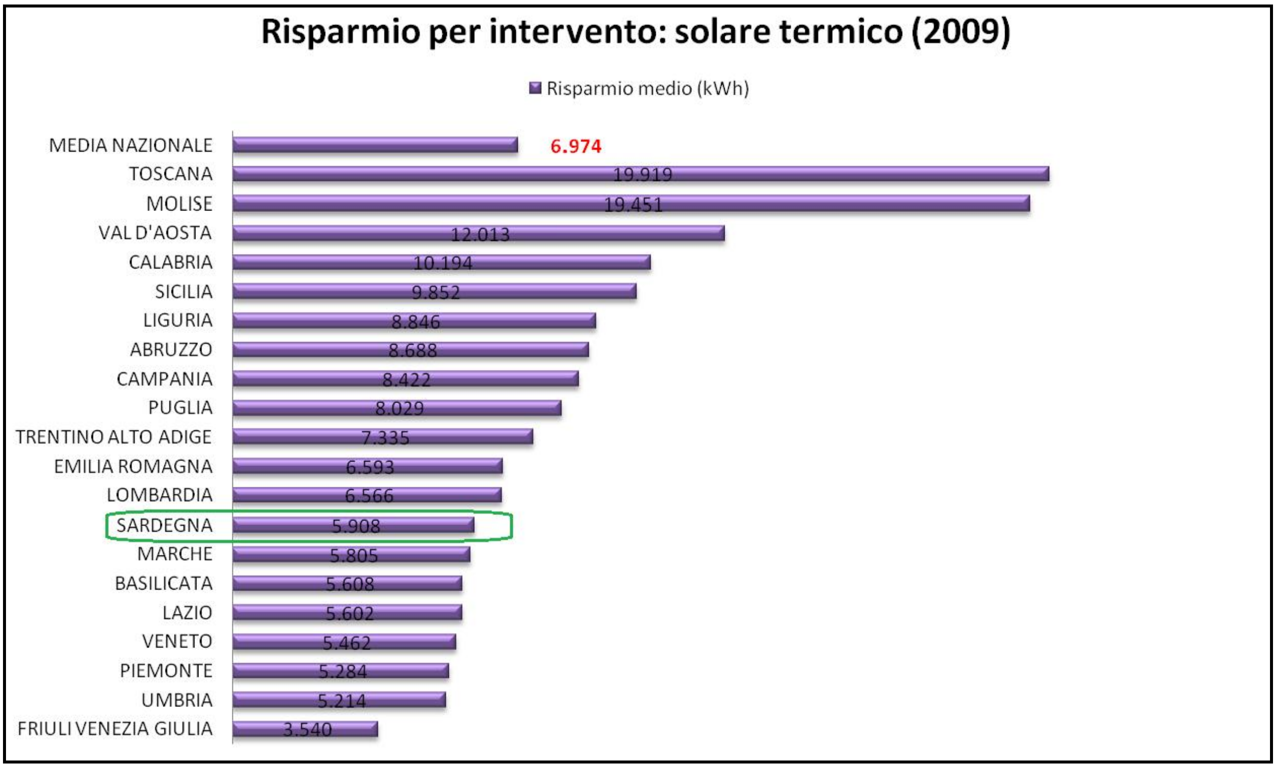


Fig. 6.62-b Enea Report's excerption (ref. year 2009)

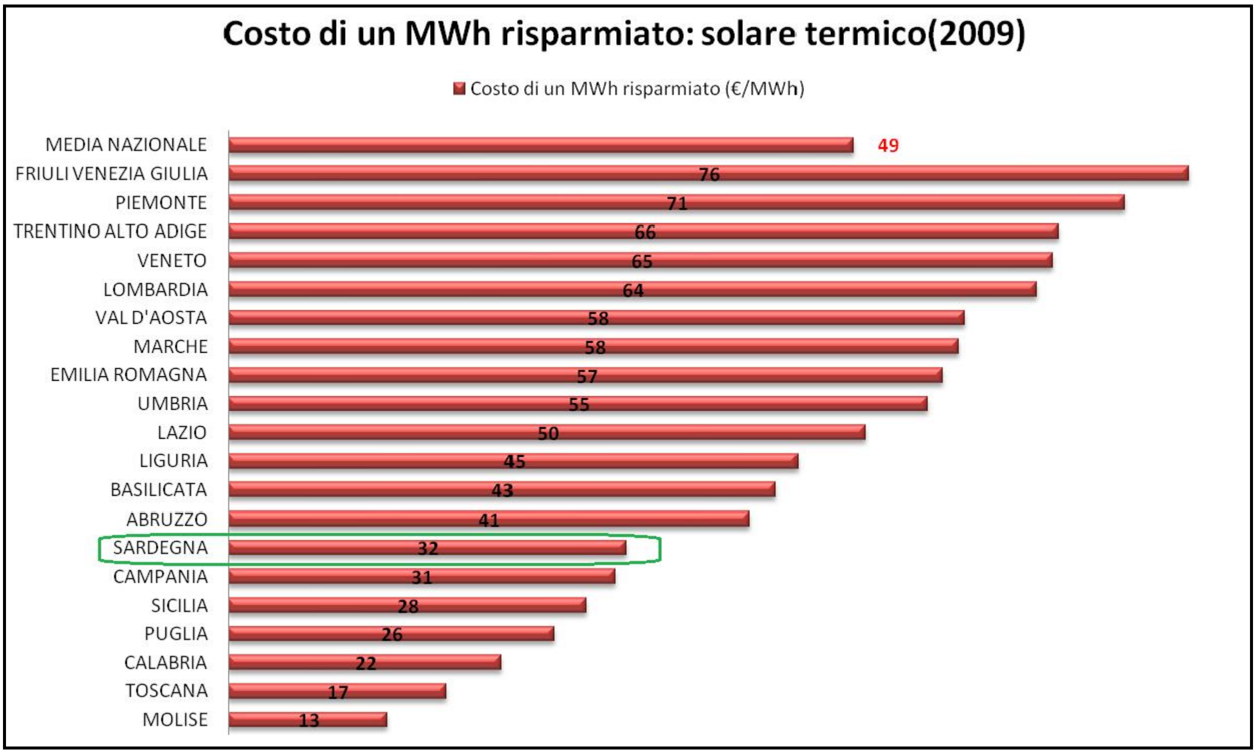


Fig. 6.62-c Enea Report's excerption (ref. year 2009)

RETROFIT'S ACTION TYPE: ENERGY DELIVERING						
BUILDING ELEMENT/APPLIANCE TO BE ASSESSED: SOLAR PANELS INSTALLATION	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)		BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)		ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	5.908		2.022			
RETROFIT COSTS [€]	3.724		4.894			
ASSUMED LIFESPAN [yr]	ENEA REF.	20	ENEA REF.	20		
COSTS SAVED [€/KWh*yr]	0,032		0,121		0,579	0,487
COSTS SAVED [€/MWh*yr]	32		121		57,86	48,68

Tab. 6.43 Global Comparative Framework: Solar Panels installation (exploiting the BEopt *C Zone* results)

RETROFIT'S ACTION TYPE: ENERGY DELIVERING						
BUILDING ELEMENT/APPLIANCE TO BE ASSESSED: SOLAR PANELS INSTALLATION	ENEA STATISTICAL DATA STATIC ASSESSMENT (SARDINIA)		BEOPT DYNAMIC OPTIMIZATION ASSESSMENT (CLIMATIC ZONE C)		ENEA STATISTICAL DATA STATIC ASSESSMENT (as evaluated on average for the ENTIRE ITALY and for ALL the different kinds of building retrofit)	SIMPLEX COMBINED OPTIMIZATION RESULTS (as evaluated on average for the ENTIRE ITALY implementing the ENEA STATISTICAL DATA and for ALL the different kinds of building retrofit)
ENERGY SAVINGS [KWh/yr]	5.908		2.696			
RETROFIT COSTS [€]	3.724		4.894			
ASSUMED LIFESPAN [yr]	ENEA REF.	20	ENEA REF.	20		
COSTS SAVED [€/KWh*yr]	0,032		0,091		0,579	0,487
COSTS SAVED [€/MWh*yr]	32		91		57,86	48,68

Tab. 6.44 Global Comparative Framework: Solar Panels installation (exploiting the BEopt *D Zone* results)

6.18 Italian BEopt assessment vs. Enea results: main observations and concluding remarks

As already mentioned and highlighted, the current research has dealt with two widely different approaches and investigation methods (***Bottom-Up*** vs. ***Top-Down***), along with a markedly different quality of data and information to be implemented.

Furthermore, also the respective working hypotheses and the assumptions until now declared and adopted are partially responsible for all the differences and overall gap detectable within the results globally obtained.
It turns quite reasonable that the **statistical quality** of those main information gathered from ***Enea Reports*** (along with the ***static calculation methodology*** there applied into assessing the post-retrofit energy savings) have played a key-role into leading to such an outcome.

Actually, the more detailed information and input references, as well as the more specific value's ranges processed through the **dynamic assessment implemented by *BEopt***, were also fundamental into achieving so different output data.

Nevertheless, it's possible to judge rather valid and fruitful both the method here applied, along with the respective final results achieved and collected.
It's clear that the choice of the first or the second investigation methodology is strictly dependent, on the one hand on the affordability, the reliability and the quality of the amount of data do deal with, and on the other hand the key-decision-making criterion to be followed is directly connected to the main goals and objectives of the stakeholders, as well as to the specific range of action of all the main actors involved within the entire policy framework.

6.19 Danish BEopt assessment: specific investigation criterion and retrofit results

In order to deal with a so different context and with its respective global boundary conditions, an integrated approach and an all-involving assessment has been adopted.
Actually, beside the already mentioned markedly different dwelling model to be analyzed and its specific building-elements main properties, also a further investigation criterion has characterized the assessment hereinafter reported.
Moreover, such a choice may be referred to the additional tools and optimization tasks provided by the *BEopt* software.
Indeed it also allows to test, since the beginning and by means of a unique more complex and multifactor optimization assessment, different retrofit measures and improving solutions for the entire default building asset.
In particular, as highlighted by the initial, global assessing table previously performed and also according to the energy losses' evaluation already done with reference to the *Danish-Detached House* of default (see **Tab. 6.10**), one of its most weak and leaky building elements consists in the roof.

Roof's insulation:

The existing roof U-value's improvement reveals then fundamental in order to minimize heat losses through the building envelope, also bringing back down the roof's transmittance within the allowed transmittance limits settled by the Danish Law.
The roof's renovation here designed and thence implemented through several software's simulations was characterized by the following main features (to be noticed: all the renovation costs had been evaluated including the ***VAT-MOMS*** contribution, which in Denmark is fixed in the percentage of 25%).

<table>
<tr><th colspan="2">DENMARK: ROOF'S INSULATION</th></tr>
<tr><td colspan="2">BEOPT CUSTOMIZED OPTION 18 Roof ~~R38~~ Fiberglass Batts – 35 cm
(WITH CUSTOM COSTS AND ADAPTED TO THE EXISTING BUILDING'S PROPERTIES)</td></tr>
<tr><td colspan="2">IMPROVEMENT COST EVALUATED IN 67.05 €/m^2 ~ 12.594 €
(ref. SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010)</td></tr>
<tr><td colspan="2">R-VALUE OF ROOF 'S INSULATION - INSULATION PLACED BETWEEN RAFTERS:
GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
9,72 m^2*K/W</td></tr>
<tr><td colspan="2">THICKNESS OF INSULATION TO BE PLACED BETWEEN RAFTERS: GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
35 cm</td></tr>
<tr><td>R-VALUE OF CEILING'S INSULATION (GLASS-WOOL with λ= 0,036 W/m*K)- already existing in the default buiding of reference (and with a thickness of 10 cm):
<u>2,70 m^2*K/W</u></td><td>ROOF NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION for the selected thickness of roof framing :
6,85 m^2*K/W</td></tr>
<tr><td>U-VALUE OF CEILING INSULATION (GLASS-WOOL with 0.036 W/m*K):
<u>0,37 W/ m^2*K</u></td><td>ROOF RESPECTIVE U-VALUE:
0,146 W/m^2*K</td></tr>
<tr><td colspan="2"><u>FINAL ROOF TRANSMITTANCE – U VALUE : 0,146 W/m^2*K < 0,15 W/m^2*K</u></td></tr>
<tr><td colspan="2">BEOPT CUSTOMIZED OPTION 18 Roof ~~R38~~ Fiberglass Batts – 40 cm
(WITH CUSTOM COSTS AND ADAPTED TO THE EXISTING BUILDING'S PROPERTIES)</td></tr>
<tr><td colspan="2">IMPROVEMENT COST EVALUATED IN 75,43 €/m^2 ~ 14.168 €
(ref. SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010)</td></tr>
<tr><td colspan="2">R-VALUE OF ROOF 'S INSULATION - INSULATION PLACED BETWEEN RAFTERS:
GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
11,11 m^2*K/W</td></tr>
<tr><td colspan="2">THICKNESS OF INSULATION TO BE PLACED BETWEEN RAFTERS: GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
40 cm</td></tr>
<tr><td>R-VALUE OF CEILING'S INSULATION (GLASS-WOOL with λ= 0,036 W/m*K)- already existing in the default buiding of reference (and with a thickness of 10 cm): <u>2,70 m^2*K/W</u></td><td>ROOF NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION for the selected thickness of roof framing :
7,40 m^2*K/W</td></tr>
<tr><td>U-VALUE OF CEILING INSULATION (GLASS-WOOL with 0,036 W/m*K):
<u>0,37 W/ m^2*K</u></td><td>ROOF RESPECTIVE U-VALUE:
0,135 W/m^2*K</td></tr>
<tr><td colspan="2"><u>FINAL ROOF TRANSMITTANCE – U VALUE : 0,135 W/m^2*K < 0,15 W/m^2*K</u></td></tr>
<tr><td colspan="2">BEOPT DEFAULT OPTION Roof R38 Fiberglass Batts-30 cm [&+ (9 cm) of rigid insulation] #
(WITH CUSTOM COSTS AND ADAPTED TO THE EXISTING BUILDING'S PROPERTIES)</td></tr>
<tr><td colspan="2">IMPROVEMENT COST EVALUATED IN 58,67 €/m^2 ~ 11.019 €
(ref. SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010)</td></tr>
<tr><td colspan="2">R-VALUE OF ROOF 'S INSULATION - INSULATION PLACED BETWEEN RAFTERS:
GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
6,69 m^2*K/W</td></tr>
<tr><td colspan="2">THICKNESS OF INSULATION TO BE PLACED BETWEEN RAFTERS: GLASS-WOOL (FIBERGLASS BATTS) with λ= 0,036 W/m*K
30 cm</td></tr>
<tr><td colspan="2">R-VALUE OF THE RIGID INSULATION PLACED ON THE EXTERIOR OF THE ROOF: 4,4 m^2*K/W</td></tr>
<tr><td colspan="2">THICKNESS OF THE RIGID INSULATION ADDED TO THE ROOF: 9 cm</td></tr>
<tr><td>R-VALUE OF CEILING'S INSULATION (GLASS-WOOL with λ= 0,036 W/m*K)- already existing in the default buiding of reference (and with a thickness of 10 cm): <u>2,70 m^2*K/W</u></td><td>ROOF NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION for the selected thickness of roof framing :
10,65 m^2*K/W</td></tr>
<tr><td>U-VALUE OF CEILING INSULATION (GLASS-WOOL with 0,036 W/m*K):
<u>0,37 W/ m^2*K</u></td><td>ROOF RESPECTIVE U-VALUE:
0,094 W/m^2*K</td></tr>
<tr><td colspan="2"><u>FINAL ROOF TRANSMITTANCE – U VALUE : 0,094 W/m^2*K < 0,15 W/m^2*K</u></td></tr>
</table>

Tab. 6.45 Danish retrofit case: different roof's improving measures and respective main retrofit features

With reference to the ***RIGID INSULATION*** – default *BEopt* option – (quoting what referred at http://www.finehomebuilding.com):
"Rigid-foam insulation installed above the roof assembly can create an energy-smart roof. With three layers of 11/2 in ***polyisocyanurate*** *insulation* (e.g.) *above the sheathing and approximately 91/4 in of* ***cellulose insulation*** (e.g.) *in the rafter cavities, the roof gets an R-value of approximately 63 h*ft^2*°F/Btu* (actually, the *BEopt* default available option reaches a final Resistance value of 60,5 h*ft^2*°F/Btu ~ 10,65 m^{2}K/W, as here evaluated). *The three layers of foam help to seal air leaks [...]"*

DENMARK: ROOF'S INSULATION (cont.)	
BEOPT DEFAULT OPTION Roof R 37.5 *SIPs (Structural Insulated Panels)* – 20 cm § see FIG.6.63 (WITH CUSTOM COSTS AND ADAPTED TO THE EXISTING BUILDING'S PROPERTIES)	
IMPROVEMENT COST EVALUATED IN 41,91 €/m^2 ~ 7.872 € (ref. ***SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010***)	
R-VALUE OF ROOF 'S INSULATION - INSULATION PLACED BETWEEN RAFTERS: 6,60 m^2*K/W	
THICKNESS OF INSULATION TO BE PLACED BETWEEN RAFTERS: 20 cm	
	ROOF NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION for the selected thickness of roof framing : 6,92 m^2*K/W
	ROOF RESPECTIVE U-VALUE: 0,14 W/m^2*K
FINAL ROOF TRANSMITTANCE – U VALUE : 0,14 W/m^2*K < 0,15 W/m^2*K	
BEOPT DEFAULT OPTION Roof R 47.5 *SIPs (Structural Insulated Panels)* – 24 cm (WITH CUSTOM COSTS AND ADAPTED TO THE EXISTING BUILDING'S PROPERTIES)	
IMPROVEMENT COST EVALUATED IN 48,61 €/m^2 ~ 9.130 € (ref. ***SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010***)	
R-VALUE OF ROOF 'S INSULATION - INSULATION PLACED BETWEEN RAFTERS: 8,37 m^2*K/W	
THICKNESS OF INSULATION TO BE PLACED BETWEEN RAFTERS: 24 cm	
	ROOF NOMINAL R - ASSEMBLY (BEopt AUTOMATIC EVALUATION for the selected thickness of roof framing : 8,68 m^2*K/W
	ROOF RESPECTIVE U-VALUE: 0,115 W/m^2*K
FINAL ROOF TRANSMITTANCE – U VALUE : 0,115 W/m^2*K < 0,15 W/m^2*K	

Tab. 6.45-cont Danish retrofit case: different roof's improving measures and respective main retrofit features

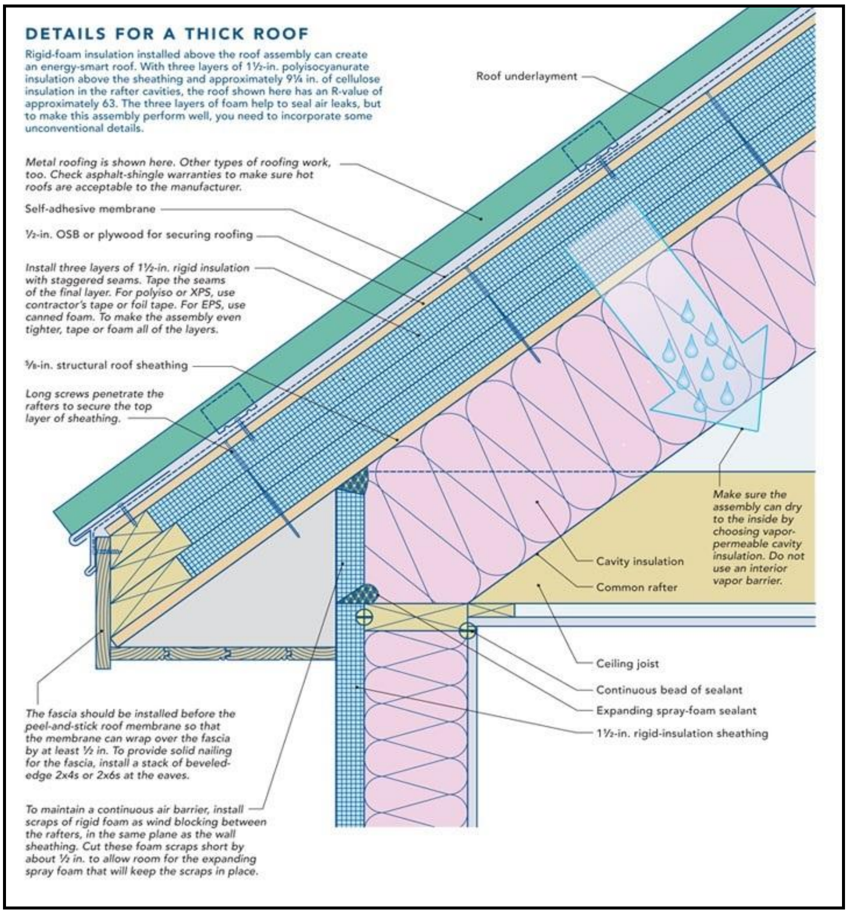


Fig. 6.63 Structural Insulated Panels (*SIPs*) – Default *BEopt* option: details

§ With reference to the ***STRUCTURAL INSULATED PANELS (SIPs)*** – default *BEopt* option (and quoting what referred at http://www.sips.org - ***The Structural Insulated Panel Association***), it's possible to specify that they *"are a high performance building system for residential and light commercial constructions. The panels consist of an insulating foam core sandwiched between two structural facings, typically oriented strand board (OSB). SIPs are manufactured under factory controlled conditions and can be fabricated to fit nearly any building design. The result is a building system that is extremely strong, energy efficient and cost effective [...]"*.

As depicted by the above **Tab. 6.45**, beside the transmittance's assessment a correspondent economic evaluation has also been developed in order to complete the ***BEopt Cost Settings Template*** and its ***User's Library***. Actually, on the one hand the last insulating solutions *ex-novo* introduced were economically estimated, and on the other hand the existing retrofit costs for default insulating options were adapted according to the different boundary conditions now settled (i.e. Denmark).
Regarding this task, it's possible to recall the calculations already worked out by the ***Danish Building Research Institute***, based on an average score of untapped attics and flat roofs.
According to the available information, for the current building element's retrofit it's necessary to budget a marginal retrofit cost settled in **50 DKK (6,70 €)** per m^2 of roof plus **1 DKK (0,13 €)** per mm of insulation.
Thence, also taking into account a costs' increasing ascribable to the VAT contribution ("*MOMS*" = 25% - as already highlighted), the main average retrofit costs above reported (again, see Tab.6.45) have been assessed.

Windows replacement:

Considering the windows and glazing (actually quite weak and outdated) which characterize the default existing building in both Italy and Denmark, it must be considered what following reported:

- The existing windows (*2 Pane-Clear Windows* with non metal frames and air filled) are associated to a high transmittance value of **0,493 Btu/hr*ft^2 °F = 2,8 W/m^2*K** and to a *Solar Heat Gain Factor - SHGC* of **0,564**. It's then clear that is necessary providing for a huge renovation in order to allow their thermal properties fulfilling the National Regulations (U-limit for Denmark: **1,65 W/m^2*K**).

- Besides, as already mentioned when dealing with the Italian context, they are also responsible for a too much high ***Airflow-Infiltration Rate*** (***Leaky - 0,78 ACH*** - Annual Average Changes for Hour as settled for the existing building) and it's then necessary bringing it back to a more suitable rate compliant with the Danish Standards (***0,30 ACH*** or a ***Tight*** Infiltration Rate of ***0,40 ACH*** as here settled).
Actually, when starting the analysis of the default case, a ***Leaky*** infiltration option had been selected also for the Danish building-model. That's because the main source of air leakage (according to a "European standard house structure") is generally ascribable to the window building element - in this case quite crummy - despite an external walls' and/or roof's improvement would also reduce infiltrations and heat losses through the building envelope. Hence, windows' replacement will significantly affect the air tightness of the entire building and for this reason a reduction of infiltration rate had been designed when retrofitting the existing glazing and window frames.

The above goals are only achievable by means of a substantial change of the global, crummy, existing windows' performances: thence, also in this case, it was planned to entirely remove and replace them with new ones, characterized by higher performance levels.

The replacement solutions herein designed and consequently assessed mainly consist in the ones depicted by the following table (see **Tab. 6.46**).
As a matter of fact, likewise what already done when dealing with the Italian study-case, some ***default windows types*** (considered as the most interesting according to the main research's goals) were analyzed, along with some ***new custom windows*** *ex novo* introduced.

DENMARK – WINDOWS RETROFIT OPTIONS	
BEOPT DEFAULT OPTION	
IMPROVEMENT COST EVALUATED IN 400 DKK/m^2 = 53,64 €/m^2 (ref. ***SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010***) **N.B. When assessing the different windows typologies for the Danish context, IS NOT POSSIBLE TO ESTIMATE and settle DIFFERENT RENOVATION COSTS in function of the new glazing properties which characterize the "improved solutions": a unique, average replacement-renovation cost was thence introduced**	
3 PANE LOW EMISSIVITY INSULATED – ARGON FILLED HIGH SHGC	
U-Value: 1,033 W/m^2*K	**SHGC – Solar Heat Gain Coefficient: 0,402**
E_{value} = -14,39 kW/m^2*yr (considering the evaluations previously done with reference to the Net Energy Gain Factor - E=gw*I-Uw*D and the Eref value for Denmark)	
1,033 W/m^2*K <1,65 W/m^2*K	
BEOPT DEFAULT OPTION	
3 PANE LOW EMISSIVITY INSULATED – ARGON FILLED LOW SHGC	
U-Value: 0,943 W/m^2*K	**SHGC – Solar Heat Gain Coefficient: 0,266**
E_{value} = -32,97 kW/m^2*yr (considering the evaluations previously done with reference to the Net Energy Gain Factor - E=gw*I-Uw*D and the Eref value for Denmark)	
0,943 W/m^2*K <1,65 W/m^2*K	
N.B: Even though both the above solutions widely respect the Danish reference limits for windows replacement (since U =1,033 W/m^2*K < U_{LIM}=1,65 W/m^2*K and U=0,943 W/m^2*K< U_{LIM}=1,65 W/m^2*K), it must be noticed that the ***E value*** for the second option **almost reaches** the limit E_{REF} Value (-33 kWh/m^2*yr) stated for Denmark, while the other alternative **fully respects** this limit (since -14,39 kWh/m^2*yr > -33 kWh/m^2*yr). Nevertheless, it's also necessary highlighting that the current ***Net Energy Gain Factor*** assessment only applies to the heating-winter season, while instead the dynamic simulations run by BEopt cover the whole year (moreover, according to the main settings, the current analysis period was settled in 30 years).	
BEOPT DEFAULT OPTION	
3 PANE LOW EMISSIVITY INSULATED - AIR-FILLED HIGH SHGC	
U-Value: 1,17 W/m^2*K	**SHGC – Solar Heat Gain Coefficient: 0,402**
1,17 W/m^2*K <1,65 W/m^2*K	
BEOPT DEFAULT OPTION	
3 PANE LOW EMISSIVITY INSULATED - AIR-FILLED LOW SHGC	
U-Value: 1,09 W/m^2*K	**SHGC – Solar Heat Gain Coefficient: 0,266**
1,09 W/m^2*K <1,65 W/m^2*K	

Tab. 6.46 Danish retrofit case: different windows' improving measures and respective main retrofit features

N.B. When dealing with the windows issue and planning their respective replacements for the **Italian** context, it had been possible (unlikely for the current **Danish** assessment) to estimate and settle different renovation costs according to the different "improved" solutions to be considered. Nonetheless, also in this case the same evaluation criteria before introduced were adopted and were therefore taken into account only the marginal-improved related costs. Actually, they were assessed by calculating the cost difference **between a "new-improved" window's installation (which also provides for a concurrent "energy saving effect") and the replacement of the existing-old window with a new one, but maintaining the same previous thermal properties**.

Further – Possible fringe improvements:

While handling the windows and shading tasks, it's also possible to plan some further interventions in order to avoid, especially during the hot season, an excessive increasing of interior temperatures.
It was thence designed to introduce, in the ***Windows & Shadings Section* → *Overhangs***, some external solar screens by the front and the left sides of the house: actually, these sides are respectively placed in those part of the building South and West faced, and thence corresponding to a higher solar exposure about noon and at the sunset.

*"**Overhangs** are one of the best (and least costly) shade design elements to include in a home. In the **summer**, when the sun is high in the sky, the overhangs should shade the room completely. In the **winter**, when the sun is low, the overhangs should allow the full sun to enter, warming the air, as well as the floor, wall and other features. It's then important that overhangs are properly sized.
Actually, if they are too short and in the summer, the south-facing glass can act as a solar cooker for the living spaces; but if they are too long, the living areas will stay dark and cool not only in the summer, but in the winter as well"* (quoting *http://www.consumerenergycenter.org*).

The **overhangs** defined and selected through the *BEopt* geometrical interface were designed in correspondence of the first storey of the house and have got a **depth of 2 ft (60 cm)**.
By means of a survey directed to exactly determine and adjust overhangs' installation prices according to the European context, a quite high variability has been recognized, both with reference to their building materials and the respective installation solutions, as well as regarding their average prices.
Actually, an average cost approximately varying from a minimum of **70 €/m^2(~8,5 \$/ft^2)** until a maximum of **420 €/m^2 (~51 \$/ft^2)** has been assessed.
Thence, since the software's specifications don't provide for any further information, neither regarding their respective materials, nor with reference to the installation details, it was decided to maintain in the *BEopt Cost Selector Table* the already existing value of **20 \$/ft^2 (~164 €/m^2** of overhang**)**, which actually is fully included into the above range.

However it must be also noticed that those benefits connected to the introduction of overhangs, as well as the influence of all the different glazing Solar Heat Gain Coefficients before settled with reference to windows, are only appreciable after the introduction of new Heating-Conditioning Systems and Appliances, as hereinafter specified.

Exterior walls retrofit:

In order to achieve a higher insulation level for dwelling's external walls - also preventing the respective heat losses - it was planned to remove the existing insulation (consisting in 5 cm of glass-wool) consequently replacing that with a more effective "insulating package".

It was therefore designed to insert a layer of ***EPS*** **– Expanded Polystyrene Insulation** (with a thickness of 20 cm), after the outer white stone wall's removal and its replacement with the same exterior finishing material.
As a matter of fact, the previous *Exterior Walls* recalled by the following table (**Tab. 6.47**) has been replaced by the new solution depicted in the next **Tab. 6.48**.

BUILDING ELEMENTS	EXISTING ELEMENTS' PROPERTIES	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIAL EVALUATED VALUES	
WALLS	"LECA 3 LAYERS WALL"	External walls: " LECA 3 LAYERS WALL " custom			
	3 LAYERS	3 LAYERS			
	ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER				
	LAYER 1: BRICKS	LAYER 1: KLINKER BRICKS	LAYER WIDTH: 11 cm DENSITY: 1.800 kg/m^3 SPECIF.HEAT: 1.000 J/kg*K THERMAL CONDUCT: 1 W/m*K	GLOBAL ***R ASSEMBLY VALUE*** (FOR THE ONLY 3 LAYERS SETTLED): 2,13 m^2*K/W--- CONSEQUENT ***U VALUE***: 0,469 W/m^2*K	
	LAYER 2: INSULATION	LAYER 2: GLASS WOOL INSULATION	LAYER WIDTH: 5 cm DENSITY: 30 kg/m^3 SPECIF.HEAT: 800 J/kg*K) THERMAL CONDUCT: 0,039 W/m*K		GLOBAL ***R ASSEMBLY VALUE*** (resultant from the sum of the 2 differents BEOPT customizing sections): (2,13 + 0,106) m^2*K/W = 2,236 m^2*K/W ---
	LAYER 3: LECA BRICKS	LAYER 3: LECA	LAYER WIDTH: 10 cm DENSITY: 700 kg/m^3 SPECIF.HEAT: 1.000 J/kg*K THERMAL CONDUCT: 0,21 W/m*K		
WALLS – EXTERIOR FINISH	WHITE BRICKS	WHITE BRICKS custom	LAYER WIDTH: 11 cm DENSITY: 1.800 kg/m^3 SPECIF.HEAT: 920 J/kg*K THERMAL CONDUCT: 1 W/m*K ABSORPTIVITY - solar radiation absorptance of the exterior finish - fraction: 0,60 INFRARED EMISSIVITY - fraction: 0,92	RESULTANT ***R VALUE*** (FOR THE ONLY ***EXTERIOR FINISH LAYER*** 0,106 m^2*K/W --------------------------------- CONSEQUENT U VALUE: 9,46 W/m^2*K	CONSEQUENT U VALUE to be considered for the exterior walls: **0,447 W/m^2*K**

Tab. 6.47 Danish retrofit case: existing external walls' main features

BUILDING ELEMENTS	POST-RETROFIT ELEMENTS' PROPERTIES	BEOPT SETTINGS	SPECIFIC INPUT VALUES	BEOPT PARTIAL EVALUATED VALUES	
<u>WALLS</u>	"LECA INSULATED WALLS"	External walls: "LECA 3 LAYERS WALL " custom			
	3 LAYERS	3 LAYERS			
	ARRAY OF LAYERS STARTING WITH OUTSIDE LAYER				GLOBAL <u>*R* ASSEMBLY VALUE</u> (resultant from the sum of the 2 differents BEOPT customizing sections): (7,52 + 0,106) m^2*K/W = 7,626 m^2*K/W --------------------------- --------------------------- CONSEQUENT U VALUE to be considered for the exterior walls: <u>0,13 W/m^2*K</u>
	LAYER 1: <u>BRICKS</u>	LAYER 1: <u>KLINKER BRICKS</u>	LAYER WIDTH: 11 cm DENSITY: 1.800 kg/m^3 SPECIF.HEAT: 1.000 J/kg*K THERMAL CONDUCT: 1 W/m*K		
	LAYER 2: <u>INSULATION</u>	LAYER 2: <u>EPS INSULATION</u>	LAYER WIDTH: 20 cm DENSITY: 15 kg/m^3 SPECIF.HEAT: 1.500 J/kg*K THERMAL CONDUCT: 0,030 W/m*K	GLOBAL <u>*R* ASSEMBLY VALUE</u> (FOR THE ONLY 3 LAYERS SETTLED): 7,52 m^2*K/W--------------------------- CONSEQUENT <u>*U* VALUE</u>: 0,133 W/m^2*K	
	LAYER 3: <u>LECA BRICKS</u>	LAYER 3: <u>LECA</u>	LAYER WIDTH: 10 cm DENSITY: 700 kg/m^3 SPECIF.HEAT: 1.000 J/kg*K THERMAL CONDUCT: 0,21 W/m*K)		
WALLS – EXTERIOR FINISH	WHITE BRICKS	WHITE BRICKS custom	LAYER WIDTH: 11 cm DENSITY: 1.800 kg/m^3 SPECIF.HEAT: 920 J/kg*K THERMAL CONDUCT: 1 W/m*K	RESULTANT <u>*R* VALUE</u> (FOR THE ONLY <u>*EXTERIOR FINISH LAYER*</u>): 0.106 m^2*K/W------------------------------- CONSEQUENT U VALUE: 9,46 W/m^2*K	
			ABSORPTIVITY - solar radiation absorptance of the exterior finish - fraction: 0.60 INFRARED EMISSIVITY - fraction: 0.92		

Tab. 6.48 Danish retrofit case: external walls' improvement's main features

According to the above customizations, the new insulation package introduced into *BEopt* database therefore led to the following "*PRE vs. POST RETROFIT*" main features:

PRE-RETROFIT: GLASS WOOL INSULATION + OUTER WHITE STONE WALLS	RESPECTIVE U-VALUE: 0,447 W/m^2*K
POST-RETROFIT: *EPS* INSULATION 20 cm + OUTER WHITE STONE WALLS	RESPECTIVE U-VALUE: 0,13 W/m^2*K
0,13 W/m^2*K < 0, 20 W/m^2*K	

Tab. 6.49 Danish retrofit case: exterior walls – PRE vs. POST improvement configuration

As already noticed while planning the roof's retrofit, also for the exterior walls' improvement a proper economic assessment is needed in order to complete the ***BEopt Cost Settings Template*** and its ***User's Library*** through the new exterior walls' configuration just now depicted.
Regarding this task, it's possible to recall once again the calculations worked out by the ***Danish Building Research Institute***, also considering the several reports published by this Agency in collaboration with ***Aalborg University***.

Actually, highlighting what also previously mentioned, one of them declares that there are two different evaluation criteria which can be followed in order to calculate the external walls' renovation costs, along with their respective improvements:

1) Every kind of exterior walls renovation (independently of its specific characteristics) provides for the following cost's voices:
   - An upfront cost of 1.500 DKK (201,15 €) per each m^2 of outer wall;
   - An additional charge of 7 DKK (0,94 €) per each mm of insulation added to the outer wall;

- In order to assess the **marginal costs ascribable to the implementation of energy saving measures in conjunction with any other already planned renovation** for exterior walls (also in this case independently of their specific typology and insulating material), the following assumptions are stated:
- The initial costs of **200 DKK (26,82 €)** per each m^2 of outer wall after its insulation;
- An additional charge of **7 DKK (0,94 €)** per each mm of insulation added to the outer wall;

In the light of such remark and since - when dealing with the "Danish Case" - it has been chosen to adopt (as much as possible) the same working hypotheses already assumed for the "Italian Case" analysis, the outer walls insulation's prices were calculated according to the **second criterion**.
The above assumptions therefore led to an average renovation cost evaluated in **268,53 €/m^2 (=32,78 \$/ft^2)** - also considering the prices' increasing due to the VAT ("*MOMS*"=25%) contribution.
The current, partial-retrofit-scenario assessed a total roof's renovation cost evaluated (after due conversions from ***Danish Crowns*** to the main ***European Currency***) in **34.925** €.

Exterior walls retrofit (Denmark) – Alternative solutions:

In order to gather the cost-effectiveness associated to different retrofit solutions and also considering that the post-retrofit U-value depicted by **Tab. 6.49** is rather lower than the maximum admitted, the following alternative options were evaluated and hence compared:

a) a **thinner EPS** insulation layer (15 cm instead of 20 cm);

b) a **thinner EPS** insulation layer (12,5 cm instead of 20 cm);

c) a **thicker EPS** insulation layer (30 cm. instead of 20 cm);

d) a **thicker EPS** insulation layer (35 cm. instead of 20 cm);

e) an **even more thick** EPS insulation layer (40 cm. instead of 20 cm)

PRE-RETROFIT: GLASS WOOL INSULATION + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,447 W/m²*K**	**-------------------**	**0,447 W/m²*K > 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (20 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,13 W/m²*K**	**EVALUATED RETROFIT COSTS: 268,53 €/m²**	**0,13 W/m²*K < 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (15 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,17 W/m²*K**	**EVALUATED RETROFIT COSTS: 209,78 €/m²**	**0,17 W/m²*K < 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (12.5 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,199 W/m²*K**	**EVALUATED RETROFIT COSTS: 180,40 €/m²**	**0,199 W/m²*K ~ 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (30 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,09 W/m²*K**	**EVALUATED RETROFIT COSTS: 385,53 €/m²**	**0,09 W/m²*K < 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (35 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,08W/m²*K**	**EVALUATED RETROFIT COSTS: 444,13 €/m²**	**0,08 W/m²*K < 0,20 W/m²*K**
POST-RETROFIT: EPS INSULATION (40 cm) + OUTER WHITE STONE WALLS	**RESPECTIVE U-VALUE: 0,07 W/m²*K**	**EVALUATED RETROFIT COSTS: 502,86 €/m²**	**0.07 W/m²*K < 0. 20 W/m²*K**

Tab. 6.50 Danish retrofit case: exterior walls improvement - alternative solutions

Slab on grade retrofit:

For the current building element, the same retrofit solution already adopted when dealing with the Italian context were assessed and hence still remain valid the main observations and remarks previously mentioned.
Hence, providing for an *R-20 Exterior Perimeter Insulation* and adopting the same *Winklemann* reference key-factors, the software was settled according to such a retrofit hypothesis, in order to evaluate how this improving action will affect the starting – design case conditions.

N.B.: Since regarding this task (for the Danish boundary conditions) any affordable and specific average price's indication hadn't been detected, the main retrofit default prices provided by the *BEopt* database were considered and therefore applied.
Nevertheless, observing that for the current retrofit option the software referred an average value of 4,26 $/ft² (~ 35 /m²) – and hence quite low compared to the average European prices currently in force – a survey-assessed value of 63 €/m² (~ 7,65 $/ft²) was considered.

On the other hand, according to the main information gathered from the reference document "***SBi 2010:56 Danske bygningers energibehov i 2050***" – section "***Økonomi***" -"***Gulve***" (floors renovations), it's possible to observe that the main average prices suggested for such a task (but without any further specification and no extra cost depending on the mm of insulation adopted) were fixed as follows:

350 DKK/m^2 (~47 €/m^2)~5,7 \$/ft^2

Hence, after having considered and added to the above value also the ***MOMS-VAT*** contribution, the final renovation cost here assessed and *ex-novo* introduced was:

437,5 DKK/m^2 (~58,67 €/m^2)~7,16 \$/ft^2

Energy Delivering actions - Heat Pumps:

As already done when dealing with the Italian assessment, a new heating system has been introduced, replacing the existing standard gas furnace; the typology now selected is characterized by the following average properties: ***14 kW Heating Unit - Conter Hyper DC Inverter – Mitsubishi*** (or similar ones) with a respective installation cost assessed in **5.068 € / unit (~ 6.927 \$/unit).**

N.B. Regarding this task, no specific information has been detected in the main Danish reference document adopted for the current analysis (***SBI-Danish Building Research Institute, "Danske bygningers energibehov i 2050," n° 56, 2010***).
Actually - at pag.13 - it only provides for the average installation prices related to Home Vent Systems with heating recovering (VMC): such installation prices were assessed in **30.000 DKK/unit (~4.000 €/unit ; ~ 5.300 \$/unit).**
It has been therefore decided to adopt the same reference prices currently in force in Italy, consequently customizing the software's *Cost Selector* (and assuming to install **1 unit "*14kW unit custom*"**).

HEAT PUMP
14 kW UNIT CUSTOM
HP Cooling *SEER* (Seasonal Energy Efficiency Ratio): 14,00 kBtu/kWh
1 Stage Compressor
HP Cooling *HSPF* (Heating Seasonal Performance Factor): 8,2 kBtu/kWh

Tab. 6.51 Heat Pump System introduced and assessed: main properties and technical characteristics

Energy Delivering actions – Solar Panels

With reference to the current issue, an average area of **6 m^2 (~ 64 ft^2)** has been once again assumed and therefore introduced into *BEopt* Library Manager.
Besides, the following average installation prices were consequently settled in the *Cost Selector* schedule (*ref. S.Aggerholm, Skærpede krav til nybyggeriet 2010 og fremover–Økonomisk analyse, SBI 2009:04*): **42.614 DKK/unit (~ 5.708 €/unit; ~ 7.830 \$/unit).**

The new configuration assigned to the domestic hot water supplying system, after its integration with such solar panels (and providing for a proper orientation and slope of solar collectors, strictly connected to the Danish Latitude), is characterized by the features below depicted (see **Tab. 6.52**).

SOLAR DHW DOMESTIC HOT WATER
CLOSED LOOP **(including anti-freeze, flatplate collectors and a solar storage tank)**
SDHW Collectors' Area: ~ 6 m^2
SDHW Azimuth : South
SDHW Tilt : 56° (Custom Option)
LIFETIME : 20 YEARS **(Custom Option – actually the default lifetime assumed by BEopt for this appliance is 15 years)**

Tab. 6.52 Solar Thermal Panels *ex-novo* defined and introduced: main properties and technical characteristics

In order to gather how all these latest improvements would reflect their impact on the global dwelling's energy consumption and asset, the program has been launched once again, according to the following main running settings:

- into an **Optimization Mode**;
- consequently adjusting the "*optimization goal – energy saving threshold*" to be respectively reached through the several software's iterations (and also according to the Danish boundary conditions previously detailed);
- evaluating the **improvement solutions** before settled with reference to:
    - Roof
    - Windows (& infiltration rate)
    - External walls
    - Slab on grade basement
    - New Heat Pump system
    - Solar Panels
- moreover, in order to not include in the retrofit costs also the replacement of those building elements that shouldn't be modified during the 30 years of analysis period, some ad hoc adjustments and customizations were artificially introduced within the main system's settings;

  Hence, in particular, both the **lifetime** and the **initial age** of the existing lightings and gas water heater were adjusted and "artificially" settled as follows (in order to not take into account, within the retrofit, any replacement cost connected to these building appliances):

  Lifetime: *99 years*
  Age at the beginning of the analysis period: *0 year*

- the initial age for existing windows was instead fixed in correspondence of their lifetime's expiry in order to allow the program immediately considering their replacement with the new "improved ones";
- analogously, also the existing gas furnace's age has been settled in correspondence of its lifetime's expiry in order to provide for its replacement with the new heat pump system here introduced;
- furthermore, also the initial age of existing roof tiles was fixed in 0 years (i.e. at the beginning of their lifetime) in order to not take into account any replacement related to this building element (which actually hadn't been planned to be modified by the current retrofit).

The consequent optimization results – reached through a total of **269 simulations** deployed in an elapsed running time of **10 hours and 57 minutes** - are below depicted and herein commented.

DANISH RETROFIT OPTIMIZATION SCENARIO Existing Reference Building's Global Energy Consumption (Heating+DHW) = 26.640 kWh/yr				
	MIN COST		MAX SAVING	
ROOF	R38 Fiberglass Batts-30 cm [&+(9 cm) of rigid insulation] – No Radiant Barrier		R38 Fiberglass Batts-30 cm [&+(9 cm) of rigid insulation] + RADIANT BARRIER	
WINDOWS	3 PANE - LOW EMISSIVITY INSULATED – ARGON FILLED- HIGH SHGC		3 PANE - LOW EMISSIVITY INSULATED – ARGON FILLED- HIGH SHGC	
EXTERNAL WALLS	Leca Insulated EPS Walls 12,5 cm thickness		Leca Insulated EPS Walls 40 cm thickness	
SLAB ON GRADE	R-20 Exterior Perimeter insulation		R-20 Exterior Perimeter insulation	
OVERHANGS	YES only left windows		YES only left windows	
HEAT PUMPS	YES		YES	
AIR CONDITIONER	NO		NO	
SOLAR PANELS	YES		YES	
SOURCE ENERGY USE	14.331 kW/yr	~ 46,2% savings	11.459 kW/yr	~ 57% savings
RETROFIT COSTS	48.247 €		101.385 €	
The ***MAX SAVING*** retrofit solution (compared to the ***MIN COST*** configuration) requires a Higher Investment evaluated in **+ 53.138 €** →→ →→			In order to achieve a Higher Level of Energy Savings assessed in →→ →→ **+ 10,8%**	
It's then possible to gather that each "higher energy saving percentage point" requires ("costs") a higher retrofit investment evaluated in ~ 4.920 €				

Tab. 6.53 Optimization assessment: overall framework

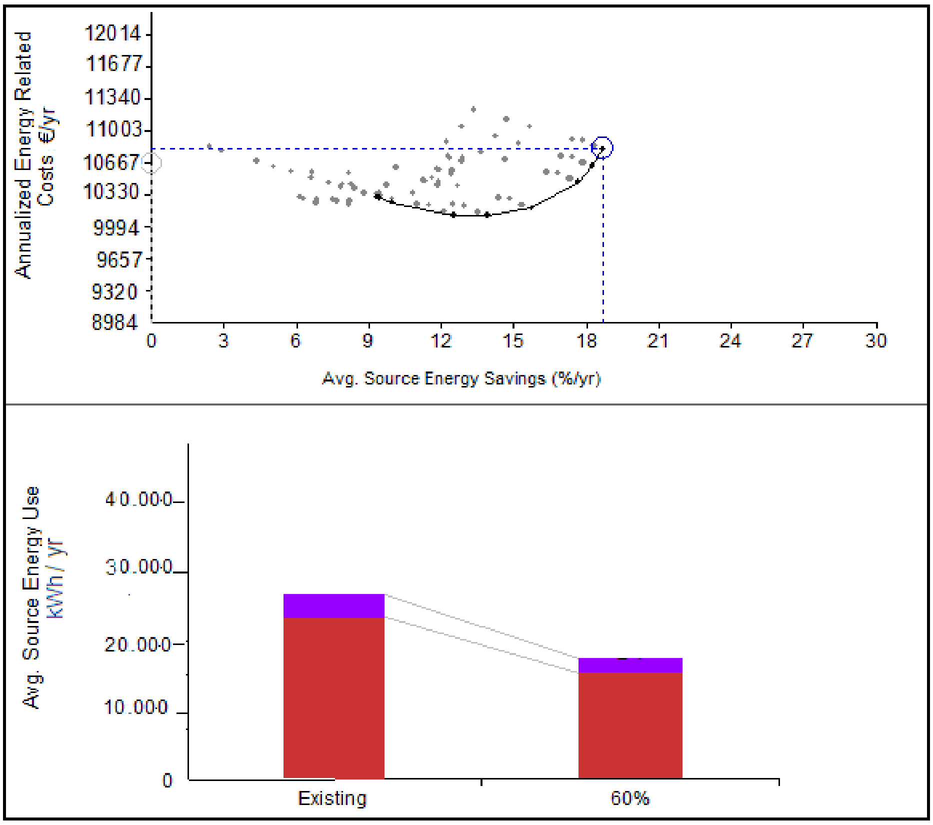


Fig. 6.64 Optimization Assessment – Danish Retrofit

Finally, in the light of the global results until now obtained, it's possible to observe that the different scenarios here assessed reveal themselves quite **sensitive** in particular with reference to the **external walls insulation retrofit solutions** (as below depicted), as well as to the **roof's improvement configurations** previously introduced and tested.

As a matter of fact, such remarks may be reported while observing the main additional information provided by the output graphs below shown in **Fig. 6.65**.
All these data may be indeed gathered by exploiting and implementing all the several fruitful *BEopt* resources and additional task-sections.

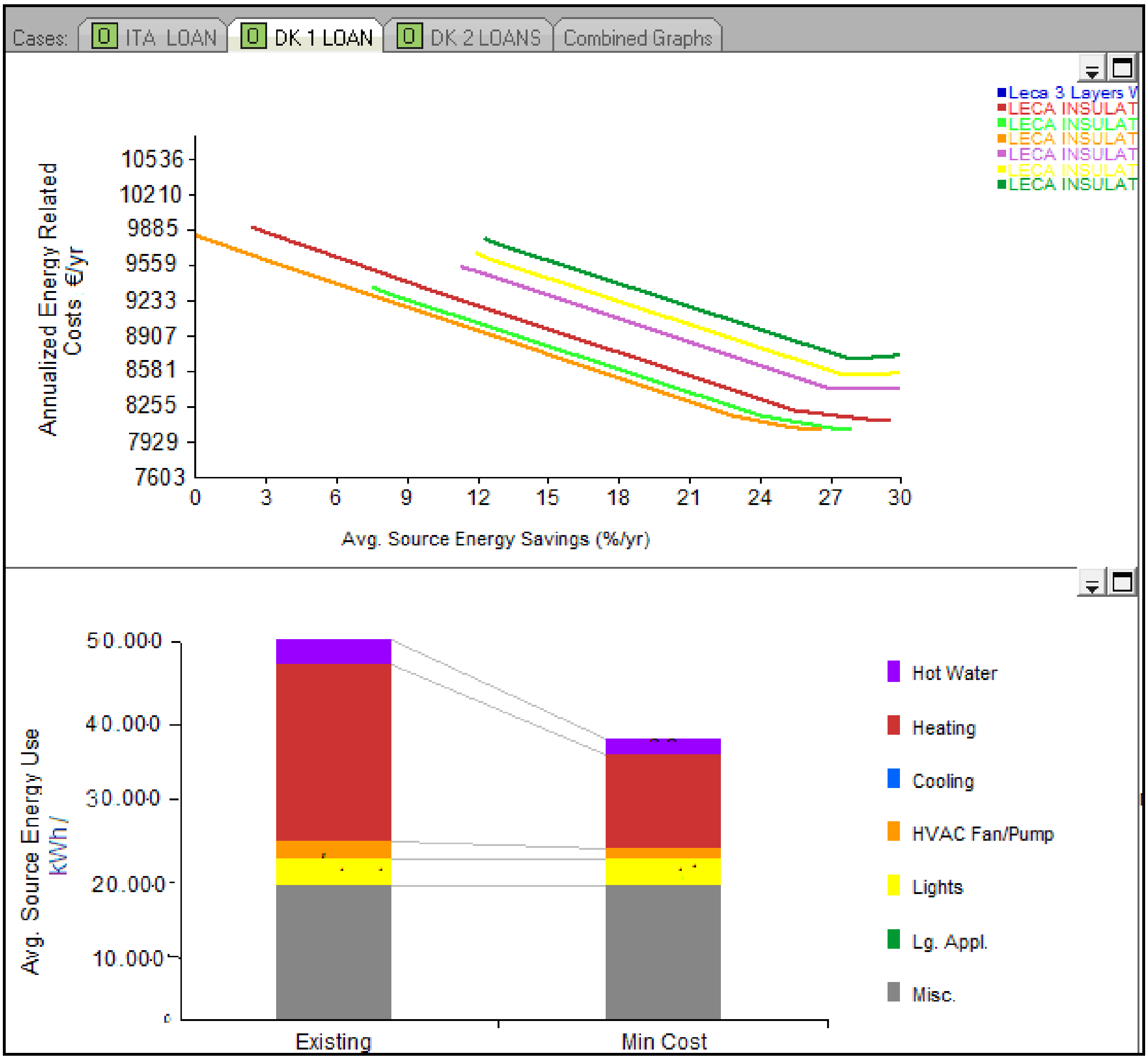


Fig. 6.65 Optimization Assessment – Danish Retrofit
Sensitivity Analysis depending on the different exterior walls retrofit solution assessed (e.g.)

Further observations and enlightenments

As previously mentioned and shown, the *BEopt* optimization program and its assessment tools could be very useful and precise into evaluating different retrofit and assessment scenarios - for the Italian context and for the Danish one as well - along with a wider range of different countries and boundary conditions.
Nonetheless, the main challenge while dealing with *BEopt* actually consists into proper customizing and adapting its database and main working interface from the US metrics to the *International Standard Units*, as well as from the characteristic American building technologies to the most typical European dwellings' features.

Furthermore, a wide range of different building models could also be defined and investigated: actually, even though in principle *BEopt* had been mainly designed for assessing single-detached house building typologies, its flexibility (along with a proper, specific technical knowledge of the single user) would allow to design and define even more scenarios and models to be analyzed (such as flats, multistorey buildings etc..).

Definitely, the main future investigations and key-researches henceforward planned, also involve such latest research's objectives, indeed rather fruitful food for thought and useful inspiring debate.

7 Conclusive remarks and future outlook

After having developed and analyzed into details the main issues which addressed the present research-work, it's possible to clarify and carry out as follows the most significant key statements and conclusive remarks.

Recalling that the main goal of this research was that to propose an optimized methodology and cost effective decision-making process (based on the principal key facts gathered from the adoption of the different energy policies and financial instruments currently in force at European level - particularly in Italy and Denmark), a global overview towards such policies had been initially carried out, also detecting those key elements to be processed and properly balanced through the present work.

Starting from the awareness that it's crucial to find out how to foster and encourage energy efficiency improvements and energy saving measures in private dwellings, also in order to achieve the double advantage of reducing the global energy consumption level within the private sector and increasing the investments (favoring the creation of additional cash flows too), a double assessment criterion has been adopted.

In first instance, by means of a *Top-Down* approach and with the main purpose of defining the best mixing of energy retrofit measures for the different geographical Italian contexts, a methodology based on simple and available data for improving residential buildings' energy efficiency has been applied.

As a matter of fact the current work started off with the analysis of all the several Reports carried out by *ENEA* (the Italian Research Agency for Energy Efficiency) since year 2007, which are based on the data collection drawn up for assessing the effectiveness of the main Italian Government financial policies established to support energy saving interventions into private dwellings.

As previously detailed, such first research-steps were carried out both through manual cost/benefit spreadsheets, as well as with the implementation of a strategic linear programming analysis tool (i.e. the *Simplex Dantzig Algorithm*).

This section analyzed and discussed the consequences of the primary Italian Government policies and purposes of reducing energy demand in the residential sector, in order to facilitate the development of a consistent plan and extension of public incentives and tax deductions for dwellings' energy-saving retrofits.

Thence, it would be instrumental into defining a worthwhile reference point, on the one hand helping decision-makers and relevant stakeholders appreciating how targets have been used till now and how effective they could be and, on the other hand, providing evidence to be used in the upcoming policy's development discussions.

Actually, as the linear programming assessment proved, the earlier outcomes connected with the current *National Energy Strategy* revealed that some adjustments and refinements are needed in order to make it more effective and worthwhile.
Although the praiseworthy initiative and aim that underlies such a political-economic venture, it shows several gaps and faults that should be offset and filled up.

As shown and described into details through the present assessment, by properly exploiting the linear programming potentialities and respective evaluations, a higher level of energy savings with a slightly lower investment budget may be reached, consequently achieving a significant reduction of the average cost for each MWh of energy saved.

Afterwards, such a value was evaluated around 47 €/MWh, against the about 57 €/MWh registered by Enea and was directly connected to a *Gini* coefficient associated to a slightly more concentrated distribution of interventions (i.e. assessed around 0,8 compared to a value nearly 0,6 ascribable to the Enea Reports).

Actually, such a lower value of the *Gini* coefficient analogously assessed for the building retrofits distribution registered by Enea, on the one hand allowed a more varied and mixed configuration along the entire Italian country, but on the other hand has also provided, as a bleak side of such a phenomenon, a sensibly lower final energy savings level.

All the main results discussed in the research therefore confirm what before highlighted regarding the strategic role to be recognized, at a global policy level, to the *simplex optimization algorithm*.

As a matter of fact these outcomes supply a clear proof of how much powerful and strategic such a decisional optimization method could be - if properly handled by the most relevant decision makers - also addressing the future incentives' policies, along with the overall energy-financial plans (nowadays particularly urgent).

Moreover, all the previous analyses, as well as the further scenarios herein performed and analyzed, also provide a worthwhile demonstration about the importance of a proper implementation and exploitation of such linear programming tools.

Indeed, as proved by the results gradually obtained through the current research, the *simplex algorithm*'s application could be particularly useful into steering policies' resolutions, addressing towards the application of a more balanced criterion and restoring the balance of public subsidies in a better way.

At this regard, it's however rather important recalling that there were already depicted, at European International level, various reports and surveys which have taken a closer look at how financial instruments are currently being used in Europe, providing some evidence of their effectiveness too. In particular, they underlined a great variety of financial instruments available throughout the European Union for supporting the improvement of energy performance of buildings, but although their undoubtable relevance, none of them has analyzed into details the respective implications at a "single-nation-level".

As a matter of fact, this particular topic hadn't been thoroughly discussed, neither in scientific literature, nor in specific technical guidelines: thus, the example offered by the ENEA Reports could represent, at a national level, a very important instrument for developing a concrete strategy with the aim of creating some guidelines to optimize and address the challenge of renovating the existing building stock, keeping also pace with the ambitious aims of both the Italian Nation and the European Union.

Actually, all the information on costs and energy savings collected during the latest four years by ENEA and provided by such reports, represent a valuable source that should be systematically used to evaluate the financial policies' current approach and to give some guidance on the future (analogously to the assessment and data implementation here developed).

Furthermore, since achieving energy savings in buildings is a complex process, policy making in this field requires a meaningful understanding of several aspects and characteristics of the building stock: reducing the energy demand involves the deployment of effective policies which, in turn, make it necessary to understand what affects people's decision making processes, the key characteristics of the building stock, the impact of current policies etc.

Thanks to that it would be possible, in the foreseeable future, improving and adjusting the Italian energy policies, also properly addressing the politicians' decisions in order to encourage some kinds of renovation, when they turn out to be more cost-effective, and instead giving up and/or limiting such a financial support, whereas some other interventions reveal their lacks and disadvantages.

And at this regard, all the main results until now gathered - along with all the observation previously done with reference to the several *Simplex* assessment's outputs - provide a further confirmation about how much powerful and fruitful could be the proper implementation and exploitation of such a mathematical algorithm.
Furthermore, if on the one hand (as already mentioned in the recent literature) many other authors have already pointed out that there are many obstacles to the spreading of good practices about this issue (e.g. the cost-effectiveness of home energy retrofits that is rarely taken into account in national policy programs), on the other hand the linear programming optimization techniques hadn't been so common within this kind of assessment.

Hence, the methodology here developed and applied could reveal itself particularly useful in order to fruitfully define a financial policy and an overall energy strategy enough flexible and properly balanced.

Furthermore, such a decision-making process would also be able to easily adapt its main measures in function of any single technology to be fostered, along with its specific geographical field of interest.

With regard to this latest enlightenment and on the main path which addressed the present job (also leading to analyze into details the other particular country here assessed, i.e. Denmark), it's possible to remark as follows what already before mentioned.
Actually, Denmark has got a long tradition of active energy policy ever since the oil crisis of the 70's: in 2012, widespread political support was ensured for a further package of measures – also including building retrofitting – and it has led this country closer to the ultimate goal of eliminating fossil fuel use in the energy and transport sectors by 2050.
Nevertheless, nowadays no incentives or other financial measures and/or tax reliefs are here provided in order to support refurbishment activities and energy saving investments in private dwellings.
And under this point of view the Italian political framework has instead disclosed a more evident and tangible financial support for promoting energy efficient investments in private dwellings and in public buildings too (as previously detailed).

Going ahead within these conclusive remarks, it's possible recalling how, after having analyzed into details those most important aspects and powerful potentialities offered by linear programming tools into dealing with energy saving retrofits and policies for the existing building stock, such a "*macroscopic*", *Top→Down* and statistical approach had been reversed.
As a matter of fact, still in order to analyze the same main problem and its respective many facets, the present work's section has applied a different approach, along with different evaluation's parameters, for defining a fruitful assessment criterion to be applied for a wider class of case studies.
The research has therefore shifted its main approach passing to a *Bottom→Up*, more detailed energy building retrofit analysis, consequently adapting its fundamental working hypotheses and evaluation criteria.
Actually, as thoroughly analyzed, this part of the study has been focused on the most representative examples for a single detached house (respectively in Italy and Denmark), performing a detailed analysis of the main specific retrofit measures which should be preferable adopting in these two so different contexts, with the purpose of achieving acceptable energy consumptions levels.

As it was possible to gather by simply observing the specific building's locations here analyzed, these dwelling's samples widely differ from each other, as well as their respective key boundary conditions.

Nonetheless (as also initially mentioned), a relevant common aspect has been noticed - at the single Nation level - while taking a closer look at the overall building stocks' distribution (in Italy as well as in Denmark).
As already observed and highlighted, the current research has dealt with two widely different approaches and investigation methods (*Bottom-Up* vs. *Top-Down*), along with a markedly different quality of data and information to be implemented.

Furthermore, also the respective working hypotheses and the assumptions until now declared and adopted are partially responsible for all the differences and overall gap detectable within the final results globally obtained.
It turns quite reasonable that the statistical quality of the main information gathered from Enea Reports (as well as the static calculation methodology there applied into assessing the post-retrofit energy savings) have played a key-role into leading to such an outcome.
Actually the more detailed information typologies, along with the more specific values ranges processed through the dynamic assessment implemented by *BEopt*, were on the other hand fundamental into achieving so different output data.

But it's also possible to judge rather valid and fruitful both the method here applied, along with the respective final results globally achieved and collected.

Nevertheless it's clear that the choice between the first and the second investigation methodology is strictly dependent, on the one hand on the affordability, the reliability and the quality of the amount of data to deal with, and on the other hand the key-decision-making criterion to be followed is directly connected to the main goals and objectives of the stakeholders, as well as to the specific range of action of all the main actors involved within the entire policy framework.

In order to analyze two so different backgrounds (Italy vs. Denmark) and their respective global boundary conditions, an integrated approach and an all-involving assessment has been adopted only when dealing with the Danish context.
Actually, beside the before mentioned markedly distinct dwelling models and their specific building-elements main properties, also a further different investigation criterion has characterized the assessment here reported: such a choice directly came from the additional tools and optimization tasks provided by *BEopt* software.
Indeed it also allows to test, since the beginning and by means of a unique, more complex and multifactor optimization assessment, different retrofit measures and improving solutions for the entire default building asset.
As gathered by the present investigation, such a *BEopt optimization mood assessment* has led, for the Danish background and in correspondence of the "*Min Cost*" retrofit asset (but still involving all the main building elements improvement, along with the main energy delivering systems integration), to a global level of energy savings evaluated in a percentage around 46,2%, with an investment cost calculated in 48.247 €. Such results were estimated against an initial level of energy demand which could be further reduced of a percentage assessed in approximately 57% with an investment cost of 101.385 € (associated to the "*Max energy savings"* point).

Afterwards, as already intended and set out to do, the future studies, starting from the data and the results until now achieved, would continue and go on through the investigation of new retrofit scenarios and dwellings' models.
Actually, it was planned to go further into analyzing both the Italian and the Danish boundary conditions in order to properly and thoroughly exploiting the main capabilities and resources provided by the main tools until now implemented.

And if on the one hand the linear programming and main *Simplex* potentialities are going to be still balanced according to the main Italian policies and retrofitting scenarios, on the other hand the other principal optimization tool applied within the present research - namely *BEopt* – is going to be entirely customized and adapted in function of the main key-European boundary conditions.

Actually, another fundamental task and issue to deal with would be the more specific and purely financial approach connected to the evaluation of all the other economic parameters and additional information which may be assessed and investigated more in details - such as the respective Net Present Value evaluation, the several Loan scenarios which is possible to define etc..

As before mentioned and shown, such an optimization program and its assessment tools could be very useful and precise into evaluating different retrofit and evaluation scenarios – for the Italian context and for the Danish one as well – and along a wider range of different countries and boundary conditions.

It should be however recalled that the main challenge while dealing with *BEopt* consists into proper customizing and adapting its database and main working interface from the *US* metrics to the *International Standard Units*, as well as from the characteristic American building technologies to the most typical European dwelling's features.
Furthermore, a wide range of different building models could also be defined and investigated: actually, even though in principle *BEopt* had been mainly designed for assessing single-detached house building typologies, its flexibility (along with a proper, specific technical knowledge of the single user) would allow to design and define even more scenarios and models to be analyzed (such as flats, multistorey buildings etc..).

Definitely, the main future investigations and key-researches henceforward planned, also involve such latest research's objectives, indeed rather fruitful food for thought and useful inspiring debate.

Furthermore, coming back to the Top-Down analysis carried out in the first part of this study - and also in the light of the ongoing political financial strategies and future policy makers' statements - the other main key-research-goal of finding out and encouraging (at a macroeconomic level) only the most cost-effective kinds of building retrofits is going to be further developed and fostered.

As already highlighted, it's fundamental recalling once again that one of the most important aspects to be highlighted with reference to the Italian "*Strategia Energetica Nazionale – National Energy Strategy*" is referable, besides to the lengthening and reshaping of the tax deductions measures for building energy retrofits, also to their distinction and differentiation based on the real and concrete benefits post-renovations-related.
Moreover, they are going to play a fundamental role into future banks' plans of innovative, financial and contractual models focused on such a feature.
But on the other side, it's also important to observe that, as well as it happens in almost every context and as already underlined, a fair balance should be reached between the ideal and most profitable actions to be planned and the real economic background of the people to deal with.
Whilst a different, best-fitting binding target is needed in order to address the future policy makers' statements, the risk that it would limit a certain flexibility of response should be recognized.

As a matter of fact, a binding target should be linked to a harmonized measurement method; but this should be both robust and flexible so that stakeholders have enough confidence that it will enable the demonstration of all the consequent, achievable progresses.

Such targets are very important into galvanizing action and understanding progress, but they also have to tread a fine balance between achievability and ambition.
They must be founded upon need and evidence of the energy saving potential, moderated by real-word expectations (in addition to fruitful economic and technical considerations) of what can realistically be achieved, as well as upon the progresses that can be credibly and transparently shown.

Undoubtedly, there will be necessary more innovative ideas and initiatives. Deep renovations are expensive, even if they are cost-effective. They require considerable up-front capital that is normally beyond the support of any single financial instrument.

Moreover, new strategies to secure sufficient financing for deep renovations of the whole building stock are needed, which ideally bring together private and public investment streams.

The future targets need to balance achievability and ambition: in fact, if they are too low, they reveal themselves meaningless, but on the other side, if they are too much high-flying and ambitious, the main risk is that the key-stakeholders will not engage in the entire innovation process.

Thence, policy makers and all the relevant stakeholders in the building sector should elaborate which policy framework would enable the necessary investments: and this would, not only create new investment opportunities for the private sector, but would also reduce the global burden on public budgets.

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ANNEX:
LINDO SCRIPTS

SPECIFICATIONS AND ACRONYMS:
The labels associated to the different variables and constraints contained in the several scripts have got the following meanings:
OONW is, in general, related to the opaque horizontal surfaces insulation for the North West of Italy;
OONE is, in general, related to the opaque horizontal surfaces insulation for the North East of Italy;
OOCE is, in general, related to the opaque horizontal surfaces insulation for the Centre of Italy;
OOME is, in general, related to the opaque horizontal surfaces insulation for the South of Italy;
OOIS is, in general, related to the opaque horizontal surfaces insulation for the Islands of Italy;
OVNW is associated with the opaque vertical surfaces insulation for the North West of Italy;
OVNE is associated with the opaque vertical surfaces insulation for the North East of Italy;
OVCE is associated with the opaque vertical surfaces insulation for the Centre of Italy;
OVME is associated with the opaque vertical surfaces insulation for the South of Italy;
OVIS is associated with the opaque vertical surfaces insulation for the Islands of Italy;
INNW is associated with the replacement of windows and windows frames in the North West of Italy;
INNE is associated with the replacement of windows and windows frames in the North East of Italy;
INCE is associated with the replacement of windows and windows frames in the Centre of Italy;
INME is associated with the replacement of windows and windows frames in the South of Italy;
INIS is associated with the replacement of windows and windows frames in the Islands of Italy;
STNW is related to solar panels installation in the North West of Italy;
STNE is related to solar panels installation in the North East of Italy;
STCE is related to solar panels installation in the Centre of Italy;
STME is related to solar panels installation in the South of Italy;
STIS is related to solar panels installation in the Islands of Italy;
CINW is related to heating plants replacement in the North West of Italy;
CINE is related to heating plants replacement in the North East of Italy;
CICE is related to heating plants replacement in the Centre of Italy;
CIME is related to heating plants replacement in the South of Italy;
CIIS is related to heating plants replacement in the Islands of Italy;

YEAR 2007 – SCRIPT 1[07]
Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]
Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each intervention [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW +
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE +
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE +
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME +
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 840241834

! Number of dwellings in the whole Italian Country
OONW < 7444761
OVNW < 7444761
INNW < 7444761
STNW < 7444761
CINW< 7444761
OONE < 5075838
OVNE < 5075838
INNE < 5075838
STNE < 5075838

CINE< 5075838
OOCE < 5137694
OVCE < 5137694
INCE < 5137694
STCE < 5137694
CICE< 5137694
OOME < 6260594
OVME < 6260594
INME < 6260594
STME < 6260594
CIME< 6260594
OOIS < 3349993
OVIS < 3349993
INIS < 3349993
STIS < 3349993
CIIS< 3349993
End
GIN 25

YEAR 2007 – SCRIPT 2[07]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]
Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each intervention [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW +
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE +
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE +
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME +
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 840241834

! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
End
GIN 25

YEAR 2007 – SCRIPT 3^{07} (block)

- North-West Macroarea:

```
Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW
s.t.
! Sum of the average costs for each intervention [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW < 332056659
!  Number of dwellings involved in the North West of Italy
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
End
GIN 5
```

- North-East Macroarea:

```
Max 812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE
s.t.
! Sum of the average costs for each intervention [€]
 28466.74 OONE +  20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE < 300050291
! Number of dwellings involved in the North East of Italy
 OONE < 30130
 OVNE < 30130
 INNE < 30130
 STNE < 30130
 CINE< 30130
End
GIN 5
```

- Central Macroarea:

```
Max 544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE
s.t.
! Sum of the average costs for each intervention [€]
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE < 129502275
! Number of dwellings involved in the Center of Italy
 OOCE < 15005
 OVCE < 15005
 INCE < 15005
 STCE < 15005
 CICE< 15005
End
GIN 5
```

- South Macroarea:

```
Max 260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME
s.t.
! Sum of the average costs for each intervention [€]
 18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME < 53437509
! Number of dwellings involved in the South of Italy
OOME < 6216
 OVME < 6216
 INME < 6216
 STME < 6216
 CIME< 6216
End
GIN 5
```

- Islands Macroarea:

```
Max 200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of  the average costs for each intervention [€]
 10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 25195100
```

! Number of dwellings involved in the Islands of Italy
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
End
GIN 5

YEAR 2007 – SCRIPT 4[07]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]
Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW < 332056659
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE < 300050291
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE < 129502275
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME < 53437509
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 25195100
! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
35721.69 OONW + 28466.74 OONE + 23881.13 OOCE + 18304.63 OOME + 10435.85 OOIS < 37596991
21573.11 OVNW + 20577.44 OVNE + 15002.42 OVCE + 13578.09 OVME + 13985.85 OVIS < 42698300
10517.35 INNW + 10377.48 INNE + 9422.62 INCE + 11086.18 INME + 10339.83 INIS < 344742563
9968.49 STNW + 7101.84 STNE + 6171.21 STCE + 6492.09 STME + 4187.20 STIS < 133619889
12848.64 CINW + 10218.78 CINE + 8083.54 CICE + 5134.22 CIME + 5508.54 CIIS < 281584091
! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
End
GIN 25

YEAR 2007 – SCRIPT 5[07]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW < 332056659
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE < 300050291
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE < 129502275
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME < 53437509
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 25195100
! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
35721.69 OONW + 28466.74 OONE + 23881.13 OOCE + 18304.63 OOME + 10435.85 OOIS < 37596991
21573.11 OVNW + 20577.44 OVNE + 15002.42 OVCE + 13578.09 OVME + 13985.85 OVIS < 42698300
10517.35 INNW + 10377.48 INNE + 9422.62 INCE + 11086.18 INME + 10339.83 INIS < 344742563
9968.49 STNW + 7101.84 STNE + 6171.21 STCE + 6492.09 STME + 4187.20 STIS < 133619889
12848.64 CINW + 10218.78 CINE + 8083.54 CICE + 5134.22 CIME + 5508.54 CIIS < 281584091
! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
! Number of interventions imposed in the several Italian Macroareas
OONW > 156
OVNW > 150
INNW > 128
STNW > 137
CINW > 159
OONE > 159
OVNE > 153
INNE > 128
STNE > 142
CINE > 154
OOCE > 154
OVCE > 148
INCE > 118
STCE > 147
CICE > 153
OOME > 137

OVME > 136
INME > 93
STME > 158
CIME > 146
OOIS > 150
OVIS > 114
INIS > 88
STIS > 158
CIIS > 136
End
GIN 25

YEAR 2007 – SCRIPT 5^{07} COUNTER-CHECK

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]
Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW < 332056659
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE < 300050291
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE < 129502275
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME < 53437509
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 25195100
! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
35721.69 OONW + 28466.74 OONE + 23881.13 OOCE + 18304.63 OOME + 10435.85 OOIS < 37596991
21573.11 OVNW + 20577.44 OVNE + 15002.42 OVCE + 13578.09 OVME + 13985.85 OVIS < 42698300
10517.35 INNW + 10377.48 INNE + 9422.62 INCE + 11086.18 INME + 10339.83 INIS < 344742563
9968.49 STNW + 7101.84 STNE + 6171.21 STCE + 6492.09 STME + 4187.20 STIS < 133619889
12848.64 CINW + 10218.78 CINE + 8083.54 CICE + 5134.22 CIME + 5508.54 CIIS < 281584091
! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264

! Number of interventions imposed in the several Italian Macroareas
OONW > 156
OVNW > 150
INNW > 128
STNW > 137
CINW > 159
OONE > 159

OVNE > 153
INNE > 128
STNE > 142
CINE > 154
OOCE > 154
OVCE > 148
INCE > 118
STCE > 147
CICE > 153
OOME > 137
OVME > 136
INME = 93
STME > 158
CIME > 146
OOIS > 150
OVIS > 114
INIS > 88
STIS > 158
CIIS > 136
End
GIN 25

YEAR 2007 – SCRIPT 5^{07} COUNTER-CHECK-BIS

Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 855.45 OONW + 399.85 OVNW + 113.07 INNW + 128.95 STNW + 359.19 CINW +
812.61 OONE + 465.67 OVNE + 113.50 INNE + 103.25 STNE + 224.34 CINE +
544.29 OOCE + 255.28 OVCE + 83.29 INCE + 103.98 STCE + 173.40 CICE +
260.92 OOME + 193.35 OVME + 71.66 INME + 174.54 STME + 100.64 CIME +
200 OOIS + 112.26 OVIS + 60 INIS + 113.38 STIS + 75 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
35721.69 OONW + 21573.11 OVNW + 10517.35 INNW + 9968.49 STNW + 12848.64 CINW < 332056659
28466.74 OONE + 20577.44 OVNE + 10377.48 INNE + 7101.84 STNE + 10218.78 CINE < 300050291
23881.13 OOCE + 15002.42 OVCE + 9422.62 INCE + 6171.21 STCE + 8083.54 CICE < 129502275
18304.63 OOME + 13578.09 OVME + 11086.18 INME + 6492.09 STME + 5134.22 CIME < 53437509
10435.85 OOIS + 13985.85 OVIS + 10339.83 INIS + 4187.20 STIS + 5508.54 CIIS < 25195100

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
35721.69 OONW + 28466.74 OONE + 23881.13 OOCE + 18304.63 OOME + 10435.85 OOIS < 37596991
21573.11 OVNW + 20577.44 OVNE + 15002.42 OVCE + 13578.09 OVME + 13985.85 OVIS < 42698300
10517.35 INNW + 10377.48 INNE + 9422.62 INCE + 11086.18 INME + 10339.83 INIS < 344742563
9968.49 STNW + 7101.84 STNE + 6171.21 STCE + 6492.09 STME + 4187.20 STIS < 133619889
12848.64 CINW + 10218.78 CINE + 8083.54 CICE + 5134.22 CIME + 5508.54 CIIS < 281584091
! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 719
STME < 6216
CIME< 6216
OOIS < 4264

OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
! Number of interventions imposed in the several Italian Macroareas
OONW > 156
OVNW > 150
INNW > 128
STNW > 137
CINW > 159
OONE > 159
OVNE > 153
INNE > 128
STNE > 142
CINE > 154
OOCE > 154
OVCE > 148
INCE > 118
STCE > 147
CICE > 153
OOME > 137
OVME > 136
INME > 93
STME > 158
CIME > 146
OOIS > 150
OVIS > 114
INIS > 88
STIS > 158
CIIS > 136
End
GIN 25

YEAR 2007 – SCRIPT 6[07]

Entire Italian country:

Objective function to minimize: Sum of the average costs associated to the different kinds of building retrofit [€]
Min
35679.72 OONW + 21559.29 OVNW + 10515.18 INNW + 9973.96 STNW + 12848.71 CINW +
28443.66 OONE + 20578.79 OVNE + 10377.49 INNE + 7108.82 STNE + 10218.43 CINE +
23914.99 OOCE + 15060.75 OVCE + 9422.66 INCE + 6171.16 STCE + 8082.29 CICE +
18305.87 OOME + 13639.68 OVME + 11086.45 INME + 6491.90 STME + 5125.18 CIME +
10443.52 OOIS + 13987.14 OVIS + 10341.55 INIS + 4186.96 STIS + 5508.62 CIIS
s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
854.49 OONW + 400 OVNW + 113.03 INNW + 128.83 STNW + 359.19 CINW > 8441540
812.48 OONE + 465.78 OVNE + 113.50 INNE + 103.35 STNE + 224.35 CINE > 4081005
545.13 OOCE + 256.00 OVCE + 83.29 INCE + 103.98 STCE + 173.53 CICE > 1815255
260.58 OOME + 193.38 OVME + 71.68 INME + 174.53 STME + 99.83 CIME > 1213015
200 OOIS + 112.28 OVIS + 60 INIS + 113.37 STIS + 75 CIIS > 589480

! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
854.49 OONW + 812.48 OONE + 545.13 OOCE + 260.58 OOME + 200 OOIS > 952300
400 OVNW + 465.78 OVNE + 256.00 OVCE + 193.38 OVME + 112.28 OVIS > 901850
113.03 INNW + 113.50 INNE + 83.29 INCE + 71.68 INME + 60 INIS > 3617820
128.83 STNW + 103.35 STNE + 103.98 STCE + 174.53 STME + 113.37 STIS > 2036405
359.19 CINW + 224.35 CINE + 173.53 CICE + 99.83 CIME + 75 CIIS > 7837125

! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130

INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216
OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
End
GIN 25

<u>YEAR 2007 – SCRIPT 7</u>[07]

<u>Entire Italian country:</u>

Objective function to minimize: Sum of the average costs associated to the different kinds of building retrofit [€]
Min
35679.72 OONW + 21559.29 OVNW + 10515.18 INNW + 9973.96 STNW + 12848.71 CINW +
28443.66 OONE + 20578.79 OVNE + 10377.49 INNE + 7108.82 STNE + 10218.43 CINE +
23914.99 OOCE + 15060.75 OVCE + 9422.66 INCE + 6171.16 STCE + 8082.29 CICE +
18305.87 OOME + 13639.68 OVME + 11086.45 INME + 6491.90 STME + 5125.18 CIME +
10443.52 OOIS + 13987.14 OVIS + 10341.55 INIS + 4186.96 STIS + 5508.62 CIIS
s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
854.49 OONW + 400 OVNW + 113.03 INNW + 128.83 STNW + 359.19 CINW > 8441540
812.48 OONE + 465.78 OVNE + 113.50 INNE + 103.35 STNE + 224.35 CINE > 4081005
545.13 OOCE + 256.00 OVCE + 83.29 INCE + 103.98 STCE + 173.53 CICE > 1815255
260.58 OOME + 193.38 OVME + 71.68 INME + 174.53 STME + 99.83 CIME > 1213015
200 OOIS + 112.28 OVIS + 60 INIS + 113.37 STIS + 75 CIIS > 589480
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
854.49 OONW + 812.48 OONE + 545.13 OOCE + 260.58 OOME + 200 OOIS > 952300
400 OVNW + 465.78 OVNE + 256.00 OVCE + 193.38 OVME + 112.28 OVIS > 901850
113.03 INNW + 113.50 INNE + 83.29 INCE + 71.68 INME + 60 INIS > 3617820
128.83 STNW + 103.35 STNE + 103.98 STCE + 174.53 STME + 113.37 STIS > 2036405
359.19 CINW + 224.35 CINE + 173.53 CICE + 99.83 CIME + 75 CIIS > 7837125
! Number of dwellings involved in the whole Italian Country
OONW < 27916
OVNW < 27916
INNW < 27916
STNW < 27916
CINW< 27916
OONE < 30130
OVNE < 30130
INNE < 30130
STNE < 30130
CINE< 30130
OOCE < 15005
OVCE < 15005
INCE < 15005
STCE < 15005
CICE< 15005
OOME < 6216
OVME < 6216
INME < 6216
STME < 6216
CIME< 6216

OOIS < 4264
OVIS < 4264
INIS < 4264
STIS < 4264
CIIS< 4264
! Number of interventions imposed in the several Italian Macroareas
OONW > 156
OVNW > 150
INNW > 128
STNW > 137
CINW > 159
OONE > 159
OVNE > 153
INNE > 128
STNE > 142
CINE > 154
OOCE > 154
OVCE > 148
INCE > 118
STCE > 147
CICE > 153
OOME > 137
OVME > 136
INME > 93
STME > 158
CIME > 146
OOIS > 150
OVIS > 114
INIS > 88
STIS > 158
CIIS > 136
End
GIN 25

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YEAR 2008 – SCRIPT 1[08]

Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 1322.97 OONW + 518.20 OVNW + 84.46 INNW + 195.27 STNW + 431.99 CINW +
990.17 OONE + 497.58 OVNE + 88.92 INNE + 147.89 STNE + 251.17 CINE +
735.15 OOCE + 338.73 OVCE + 56.20 INCE + 210.26 STCE + 225.59 CICE +
375.41 OOME + 256.96 OVME + 55.38 INME + 378.21 STME + 153.87 CIME +
275.25 OOIS + 189.25 OVIS + 40.68 INIS + 281.46 STIS + 110.03 CIIS
s.t.

! Sum of the average costs for each intervention [€]
39159.15 OONW + 20277.30 OVNW + 9298.15 INNW + 8792.76 STNW + 15178.14 CINW +
31176.37 OONE + 18643.78 OVNE + 9126.08 INNE + 7426.15 STNE + 11628.85 CINE +
32424.66 OOCE + 18590.47 OVCE + 8449.24 INCE + 5916.00 STCE + 9510.86 CICE +
26601.26 OOME + 15665.67 OVME + 12806.32 INME + 4932.54 STME + 6561.00 CIME +
28085.75 OOIS + 17266.00 OVIS + 9454.92 INIS + 3991.97 STIS + 6020.20 CIIS < 2225404392

! Number of dwellings in the whole Italian Country
OONW < 7444761
OVNW < 7444761
INNW < 7444761
STNW < 7444761
CINW< 7444761
OONE < 5075838
OVNE < 5075838
INNE < 5075838
STNE < 5075838
CINE< 5075838

OOCE < 5137694
OVCE < 5137694
INCE < 5137694
STCE < 5137694
CICE< 5137694
OOME < 6260594
OVME < 6260594
INME < 6260594
STME < 6260594
CIME< 6260594
OOIS < 3349993
OVIS < 3349993
INIS < 3349993
STIS < 3349993
CIIS< 3349993
End
GIN 25

YEAR 2008 – SCRIPT 2[08]

Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]
Max 1322.97 OONW + 518.20 OVNW + 84.46 INNW + 195.27 STNW + 431.99 CINW +
990.17 OONE + 497.58 OVNE + 88.92 INNE + 147.89 STNE + 251.17 CINE +
735.15 OOCE + 338.73 OVCE + 56.20 INCE + 210.26 STCE + 225.59 CICE +
375.41 OOME + 256.96 OVME + 55.38 INME + 378.21 STME + 153.87 CIME +
275.25 OOIS + 189.25 OVIS + 40.68 INIS + 281.46 STIS + 110.03 CIIS
s.t.
! Sum of the average costs for each intervention [€]
39159.15 OONW + 20277.30 OVNW + 9298.15 INNW + 8792.76 STNW + 15178.14 CINW +
31176.37 OONE + 18643.78 OVNE + 9126.08 INNE + 7426.15 STNE + 11628.85 CINE +
32424.66 OOCE + 18590.47 OVCE + 8449.24 INCE + 5916.00 STCE + 9510.86 CICE +
26601.26 OOME + 15665.67 OVME + 12806.32 INME + 4932.54 STME + 6561.00 CIME +
28085.75 OOIS + 17266.00 OVIS + 9454.92 INIS + 3991.97 STIS + 6020.20 CIIS < 2225404392

! Number of dwellings involved in the whole Italian Country
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411
End
GIN 25

YEAR 2008 – SCRIPT 3^{08} (block)

- North-West Macroarea:

Max 1322.97 OONW + 518.20 OVNW + 84.46 INNW + 195.27 STNW + 431.99 CINW
s.t.
! Sum of the average costs for each intervention [€]
39159.15 OONW + 20277.30 OVNW + 9298.15 INNW + 8792.76 STNW + 15178.14 CINW < 901500521
! Number of dwellings involved in the North West of Italy
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
End
GIN 5

- North-East Macroarea:

Max 990.17 OONE + 497.58 OVNE + 88.92 INNE + 147.89 STNE + 251.17 CINE
s.t.
! Sum of the average costs for each intervention [€]
31176.37 OONE + 18643.78 OVNE + 9126.08 INNE + 7426.15 STNE + 11628.85 CINE < 748497392
! Number of dwellings involved in the North East of Italy
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
End
GIN 5

- Central Macroarea:

Max 735.15 OOCE + 338.73 OVCE + 56.20 INCE + 210.26 STCE + 225.59 CICE s.t.
! Sum of the average costs for each intervention [€]
32424.66 OOCE + 18590.47 OVCE + 8449.24 INCE + 5916.00 STCE + 9510.86 CICE < 336053831
! Number of dwellings involved in the Center of Italy
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
End
GIN 5

- South Macroarea:

Max 375.41 OOME + 256.96 OVME + 55.38 INME + 378.21 STME + 153.87 CIME
s.t.
! Sum of the average costs for each intervention [€]
26601.26 OOME + 15665.67 OVME + 12806.32 INME + 4932.54 STME + 6561.00 CIME < 176535722
! Number of dwellings involved in the South of Italy
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
End
GIN 5

- Islands Macroarea:

Max 275.25 OOIS + 189.25 OVIS + 40.68 INIS + 281.46 STIS + 110.03 CIIS
s.t.
! Sum of the average costs for each intervention [€]
28085.75 OOIS + 17266.00 OVIS + 9454.92 INIS + 3991.97 STIS + 6020.20 CIIS < 62816926
! Number of dwellings involved in the Islands of Italy
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411
End
GIN 5

YEAR 2008 – SCRIPT 4[08]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 1322.97 OONW + 518.20 OVNW + 84.46 INNW + 195.27 STNW + 431.99 CINW +
990.17 OONE + 497.58 OVNE + 88.92 INNE + 147.89 STNE + 251.17 CINE +
735.15 OOCE + 338.73 OVCE + 56.20 INCE + 210.26 STCE + 225.59 CICE +
375.41 OOME + 256.96 OVME + 55.38 INME + 378.21 STME + 153.87 CIME +
275.25 OOIS + 189.25 OVIS + 40.68 INIS + 281.46 STIS + 110.03 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
39159.15 OONW + 20277.30 OVNW + 9298.15 INNW + 8792.76 STNW + 15178.14 CINW < 901500521
31176.37 OONE + 18643.78 OVNE + 9126.08 INNE + 7426.15 STNE + 11628.85 CINE < 748497392
32424.66 OOCE + 18590.47 OVCE + 8449.24 INCE + 5916.00 STCE + 9510.86 CICE < 336053831
26601.26 OOME + 15665.67 OVME + 12806.32 INME + 4932.54 STME + 6561.00 CIME < 176535722
28085.75 OOIS + 17266.00 OVIS + 9454.92 INIS + 3991.97 STIS + 6020.20 CIIS < 62816926

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
39159.15 OONW + 31176.37 OONE + 32424.66 OOCE + 26601.26 OOME + 28085.75 OOIS < 212771284
20277.30 OVNW + 18643.78 OVNE + 18590.47 OVCE + 15665.67 OVME + 17266.00 OVIS < 66191452
9298.15 INNW + 9126.08 INNE + 8449.24 INCE + 12806.32 INME + 9454.92 INIS < 958254097
8792.76 STNW + 7426.15 STNE + 5916.00 STCE + 4932.54 STME + 3991.97 STIS < 249774013
15178.14 CINW + 11628.85 CINE + 9510.86 CICE + 6561.00 CIME + 6020.20 CIIS < 738413546

! Number of dwellings involved in the whole Italian Country
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411
End
GIN 25

YEAR 2008 – SCRIPT 5[08]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 1322.97 OONW + 518.20 OVNW + 84.46 INNW + 195.27 STNW + 431.99 CINW +
990.17 OONE + 497.58 OVNE + 88.92 INNE + 147.89 STNE + 251.17 CINE +
735.15 OOCE + 338.73 OVCE + 56.20 INCE + 210.26 STCE + 225.59 CICE +
375.41 OOME + 256.96 OVME + 55.38 INME + 378.21 STME + 153.87 CIME +
275.25 OOIS + 189.25 OVIS + 40.68 INIS + 281.46 STIS + 110.03 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
39159.15 OONW + 20277.30 OVNW + 9298.15 INNW + 8792.76 STNW + 15178.14 CINW < 901500521
31176.37 OONE + 18643.78 OVNE + 9126.08 INNE + 7426.15 STNE + 11628.85 CINE < 748497392
32424.66 OOCE + 18590.47 OVCE + 8449.24 INCE + 5916.00 STCE + 9510.86 CICE < 336053831

26601.26 OOME + 15665.67 OVME + 12806.32 INME + 4932.54 STME + 6561.00 CIME < 176535722
28085.75 OOIS + 17266.00 OVIS + 9454.92 INIS + 3991.97 STIS + 6020.20 CIIS < 62816926

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
39159.15 OONW + 31176.37 OONE + 32424.66 OOCE + 26601.26 OOME + 28085.75 OOIS < 212771284
20277.30 OVNW + 18643.78 OVNE + 18590.47 OVCE + 15665.67 OVME + 17266.00 OVIS < 66191452
9298.15 INNW + 9126.08 INNE + 8449.24 INCE + 12806.32 INME + 9454.92 INIS < 958254097
8792.76 STNW + 7426.15 STNE + 5916.00 STCE + 4932.54 STME + 3991.97 STIS < 249774013
15178.14 CINW + 11628.85 CINE + 9510.86 CICE + 6561.00 CIME + 6020.20 CIIS < 738413546
! Number of dwellings involved in the whole Italian Country
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411

! Number of interventions imposed in the several Italian Macroareas
OONW > 158
OVNW > 155
INNW > 130
STNW > 153
CINW > 158
OONE > 158
OVNE > 156
INNE > 135
STNE > 152
CINE > 153
OOCE > 152
OVCE > 150
INCE > 116
STCE > 158
CICE > 155
OOME > 144
OVME > 147
INME > 85
STME > 164
CIME > 155
OOIS > 135
OVIS > 135
INIS > 89
STIS > 164
CIIS > 150
End
GIN 25

YEAR 2008 – SCRIPT 6^{08}
Entire Italian country:

Objective function to minimize: Sum of the average costs associated to the different kinds of building retrofit [€]
Min
39161.08 OONW + 20290.68 OVNW + 9302.03 INNW + 8792.37 STNW + 15178.12 CINW +
31164.84 OONE + 18645.11 OVNE + 9126.08 INNE + 7439.43 STNE + 11647.38 CINE +
32400.38 OOCE + 18577.15 OVCE + 8449.24 INCE + 5916.02 STCE + 9510.88 CICE +
26626.53 OOME + 15616.43 OVME + 12805.46 INME + 4932.61 STME + 6559.06 CIME +
28091.84 OOIS + 17260.18 OVIS + 9454.59 INIS + 3991.96 STIS + 6019.50 CIIS
s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1322.97 OONW + 518.57 OVNW + 84.54 INNW + 195.27 STNW + 431.99 CINW > 26421929
989.42 OONE + 497.63 OVNE + 88.92 INNE + 148.13 STNE + 251.76 CINE > 9148858
735.87 OOCE + 338.60 OVCE + 56.20 INCE + 210.26 STCE + 225.61 CICE > 6021838
375.58 OOME + 256.86 OVME + 55.39 INME + 378.21 STME + 153.77 CIME > 6881086
275.27 OOIS + 188.83 OVIS + 40.68 INIS + 281.45 STIS + 109.94 CIIS > 2806484

! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1322.97 OONW + 989.42 OONE + 735.87 OOCE + 375.58 OOME + 275.27 OOIS > 6885126
518.57 OVNW + 497.63 OVNE + 338.60 OVCE + 256.86 OVME + 188.83 OVIS > 1678885
84.54 INNW + 88.92 INNE + 56.20 INCE + 55.39 INME + 40.68 INIS > 8148893
195.27 STNW + 148.13 STNE + 210.26 STCE + 378.21 STME + 281.45 STIS > 13584715
431.99 CINW + 251.76 CINE + 225.61 CICE + 153.77 CIME + 109.94 CIIS > 20982577

! Number of dwellings involved in the whole Italian Country
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411
End
GIN 25

YEAR 2008– SCRIPT 7^{08}
Entire Italian country:
Min
39161.08 OONW + 20290.68 OVNW + 9302.03 INNW + 8792.37 STNW + 15178.12 CINW +
31164.84 OONE + 18645.11 OVNE + 9126.08 INNE + 7439.43 STNE + 11647.38 CINE +
32400.38 OOCE + 18577.15 OVCE + 8449.24 INCE + 5916.02 STCE + 9510.88 CICE +
26626.53 OOME + 15616.43 OVME + 12805.46 INME + 4932.61 STME + 6559.06 CIME +
28091.84 OOIS + 17260.18 OVIS + 9454.59 INIS + 3991.96 STIS + 6019.50 CIIS

s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1322.97 OONW + 518.57 OVNW + 84.54 INNW + 195.27 STNW + 431.99 CINW > 26421929
989.42 OONE + 497.63 OVNE + 88.92 INNE + 148.13 STNE + 251.76 CINE > 9148858
735.87 OOCE + 338.60 OVCE + 56.20 INCE + 210.26 STCE + 225.61 CICE > 6021838
375.58 OOME + 256.86 OVME + 55.39 INME + 378.21 STME + 153.77 CIME > 6881086
275.27 OOIS + 188.83 OVIS + 40.68 INIS + 281.45 STIS + 109.94 CIIS > 2806484

! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1322.97 OONW + 989.42 OONE + 735.87 OOCE + 375.58 OOME + 275.27 OOIS > 6885126
518.57 OVNW + 497.63 OVNE + 338.60 OVCE + 256.86 OVME + 188.83 OVIS > 1678885
84.54 INNW + 88.92 INNE + 56.20 INCE + 55.39 INME + 40.68 INIS > 8148893
195.27 STNW + 148.13 STNE + 210.26 STCE + 378.21 STME + 281.45 STIS > 13584715
431.99 CINW + 251.76 CINE + 225.61 CICE + 153.77 CIME + 109.94 CIIS > 20982577

! Number of dwellings involved in the whole Italian Country
OONW < 74729
OVNW < 74729
INNW < 74729
STNW < 74729
CINW< 74729
OONE < 71216
OVNE < 71216
INNE < 71216
STNE < 71216
CINE< 71216
OOCE < 37200
OVCE < 37200
INCE < 37200
STCE < 37200
CICE< 37200
OOME < 16903
OVME < 16903
INME < 16903
STME < 16903
CIME< 16903
OOIS < 9411
OVIS < 9411
INIS < 9411
STIS < 9411
CIIS< 9411
! Number of interventions imposed in the several Italian Macroareas
OONW > 158
OVNW > 155
INNW > 130
STNW > 153
CINW > 158
OONE > 158
OVNE > 156
INNE > 135
STNE > 152
CINE > 153
OOCE > 152
OVCE > 150
INCE > 116
STCE > 158
CICE > 155
OOME > 144
OVME > 147
INME > 85
STME > 164
CIME > 155
OOIS > 135
OVIS > 135

INIS > 89
STIS > 164
CIIS > 150
End
GIN 25

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YEAR 2009 – SCRIPT 1 [09]

Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]

Max
1008.35 OONW + 442.67 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW +
713.12 OONE + 423.64 OVNE + 69.11 INNE + 138.89 STNE + 233.25 CINE +
633.36 OOCE + 302.93 OVCE + 61.34 INCE + 284.10 STCE + 236.34 CICE +
320.88 OOME + 247.76 OVME + 57.38 INME + 216.46 STME + 119.12 CIME +
215.68 OOIS + 129.18 OVIS + 45.24 INIS + 176.06 STIS + 115.17 CIIS
s.t.
! Sum of the average costs for each intervention [€]

29140.29 OONW + 18314.09 OVNW + 9638.13 INNW + 8113.10 STNW + 15760.68 CINW +
25039.13 OONE + 15776.40 OVNE + 9322.07 INNE + 7152.66 STNE + 11776.73 CINE +

23696.48 OOCE + 17592.28 OVCE + 8673.56 INCE + 6323.16 STCE + 10301.19 CICE +

19531.83 OOME + 13151.31 OVME + 10516.71 INME + 4909.06 STME + 7861.85 CIME +
17305.93 OOIS + 13698.54 OVIS + 9721.95 INIS + 4260.45 STIS + 7580.60 CIIS < 2563271161

! Number of dwellings in the whole Italian Country
OONW < 7444761
OVNW < 7444761
INNW < 7444761
STNW < 7444761
CINW< 7444761
OONE < 5075838
OVNE < 5075838
INNE < 5075838
STNE < 5075838
CINE< 5075838
OOCE < 5137694
OVCE < 5137694
INCE < 5137694
STCE < 5137694
CICE< 5137694
OOME < 6260594
OVME < 6260594
INME < 6260594
STME < 6260594
CIME< 6260594
OOIS < 3349993
OVIS < 3349993
INIS < 3349993
STIS < 3349993
CIIS< 3349993
End
GIN 25

YEAR 2009 – SCRIPT 2 [09]

Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]

Max
1008.35 OONW + 442.67 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW +

713.12 OONE + 423.64 OVNE + 69.11 INNE + 138.89 STNE + 233.25 CINE +
633.36 OOCE + 302.93 OVCE + 61.34 INCE + 284.10 STCE + 236.34 CICE +
320.88 OOME + 247.76 OVME + 57.38 INME + 216.46 STME + 119.12 CIME +
215.68 OOIS + 129.18 OVIS + 45.24 INIS + 176.06 STIS + 115.17 CIIS
s.t.
! Sum of the average costs for each intervention [€]
29140.29 OONW + 18314.09 OVNW + 9638.13 INNW + 8113.10 STNW + 15760.68 CINW +
25039.13 OONE + 15776.40 OVNE + 9322.07 INNE + 7152.66 STNE + 11776.73 CINE +

23696.48 OOCE + 17592.28 OVCE + 8673.56 INCE + 6323.16 STCE + 10301.19 CICE +

19531.83 OOME + 13151.31 OVME + 10516.71 INME + 4909.06 STME + 7861.85 CIME +
17305.93 OOIS + 13698.54 OVIS + 9721.95 INIS + 4260.45 STIS + 7580.60 CIIS < 2563271161

! Number of dwellings involved in all the several italian macroareas
OONW < 89702
OVNW < 89702
INNW < 89702
STNW < 89702
CINW< 89702
OONE < 78071
OVNE < 78071
INNE < 78071
STNE < 78071
CINE< 78071
OOCE < 39533
OVCE < 39533
INCE < 39533
STCE < 39533
CICE< 39533
OOME < 19486
OVME < 19486
INME < 19486
STME < 19486
CIME< 19486
OOIS < 9930
OVIS < 9930
INIS < 9930
STIS < 9930
CIIS< 9930
End
GIN 25

YEAR 2009 – SCRIPT 3^{09} (block)

- North-West Macroarea:
Max 1008.35 OONW + 442.67 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW
s.t.
! Sum of the average costs for each intervention [€]
29140.29 OONW + 18314.09 OVNW + 9638.13 INNW + 8113.10 STNW + 15760.68 CINW < 1107018392
! Number of dwellings involved in the North West of Italy
OONW < 89702
OVNW < 89702
INNW < 89702
STNW < 89702
CINW< 89702
End
GIN 5
- North-East Macroarea:
Max 713.12 OONE + 423.64 OVNE + 69.11 INNE + 138.89 STNE + 233.25 CINE
s.t.
! Sum of the average costs for each intervention [€]
25039.13 OONE + 15776.40 OVNE + 9322.07 INNE + 7152.66 STNE + 11776.73 CINE < 820792380

! Number of dwellings involved in the North East of Italy
OONE < 78071

OVNE < 78071
INNE < 78071
STNE < 78071
CINE< 78071
End
GIN 5

- Central Macroarea:

Max 633.36 OOCE + 302.93 OVCE + 61.34 INCE + 284.10 STCE + 236.34 CICE
s.t.
! Sum of the average costs for each intervention [€]
23696.48 OOCE + 17592.28 OVCE + 8673.56 INCE + 6323.16 STCE + 10301.19 CICE < 377233821
! Number of dwellings involved in the Center of Italy
OOCE < 39533
OVCE < 39533
INCE < 39533
STCE < 39533
CICE< 39533
End
GIN 5

- South Macroarea:

Max 320.88 OOME + 247.76 OVME + 57.38 INME + 216.46 STME + 119.12 CIME
s.t.
! Sum of the average costs for each intervention [€]
19531.83 OOME + 13151.31 OVME + 10516.71 INME + 4909.06 STME + 7861.85 CIME < 182069755
! Number of dwellings involved in the South of Italy
OOME < 19486
OVME < 19486
INME < 19486
STME < 19486
CIME< 19486
End
GIN 5

Islands Macroarea:

Max 215.68 OOIS + 129.18 OVIS + 45.24 INIS + 176.06 STIS + 115.17 CIIS
s.t.
! Sum of the average costs for each intervention [€]
17305.93 OOIS + 13698.54 OVIS + 9721.95 INIS + 4260.45 STIS + 7580.60 CIIS < 76156813

! Number of dwellings involved in the Islands of Italy
OOIS < 9930
OVIS < 9930
INIS < 9930
STIS < 9930
CIIS< 9930
End
GIN 5

YEAR 2009 – SCRIPT 4[09]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 1008.35 OONW + 442.67 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW +
713.12 OONE + 423.64 OVNE + 69.11 INNE + 138.89 STNE + 233.25 CINE +
633.36 OOCE + 302.93 OVCE + 61.34 INCE + 284.10 STCE + 236.34 CICE +
320.88 OOME + 247.76 OVME + 57.38 INME + 216.46 STME + 119.12 CIME +
215.68 OOIS + 129.18 OVIS + 45.24 INIS + 176.06 STIS + 115.17 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
29140.29 OONW + 18314.09 OVNW + 9638.13 INNW + 8113.10 STNW + 15760.68 CINW < 1107018392
25039.13 OONE + 15776.40 OVNE + 9322.07 INNE + 7152.66 STNE + 11776.73 CINE < 820792380
23696.48 OOCE + 17592.28 OVCE + 8673.56 INCE + 6323.16 STCE + 10301.19 CICE < 377233821
19531.83 OOME + 13151.31 OVME + 10516.71 INME + 4909.06 STME + 7861.85 CIME < 182069775
17305.93 OOIS + 13698.54 OVIS + 9721.95 INIS + 4260.45 STIS + 7580.60 CIIS < 76156813

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
29140.29 OONW +25039.13 OONE + 23696.48 OOCE + 19531.83 OOME +17305.93 OOIS < 258482877
18314.09 OVNW + 15776.40 OVNE + 17592.28 OVCE + 13151.31 OVME + 13698.54 OVIS < 89740550
9638.13 INNW + 9322.07 INNE + 8673.56 INCE + 10516.71 INME + 9721.95 INIS < 1087748314
8113.10 STNW + 7152.66 STNE + 6323.16 STCE + 4909.06 STME + 4260.45 STIS < 247910531
15760.68 CINW + 11776.73 CINE + 10301.19 CICE + 7861.85 CIME + 7580.60 CIIS < 879388889
! Number of dwellings involved in all the several italian macroareas
OONW < 89702
OVNW < 89702
INNW < 89702
STNW < 89702
CINW< 89702
OONE < 78071
OVNE < 78071
INNE < 78071
STNE < 78071
CINE< 78071
OOCE < 39533
OVCE < 39533
INCE < 39533
STCE < 39533
CICE< 39533
OOME < 19486
OVME < 19486
INME < 19486
STME < 19486
CIME< 19486
OOIS < 9930
OVIS < 9930
INIS < 9930
STIS < 9930
CIIS< 9930
End
GIN 25

YEAR 2009 – SCRIPT 5^{09}

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

Max 1008.35 OONW + 442.67 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW +
713.12 OONE + 423.64 OVNE + 69.11 INNE + 138.89 STNE + 233.25 CINE +
633.36 OOCE + 302.93 OVCE + 61.34 INCE + 284.10 STCE + 236.34 CICE +
320.88 OOME + 247.76 OVME + 57.38 INME + 216.46 STME + 119.12 CIME +
215.68 OOIS + 129.18 OVIS + 45.24 INIS + 176.06 STIS + 115.17 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
29140.29 OONW + 18314.09 OVNW + 9638.13 INNW + 8113.10 STNW + 15760.68 CINW < 1107018392
25039.13 OONE + 15776.40 OVNE + 9322.07 INNE + 7152.66 STNE + 11776.73 CINE < 820792380
23696.48 OOCE + 17592.28 OVCE + 8673.56 INCE + 6323.16 STCE + 10301.19 CICE < 377233821
19531.83 OOME + 13151.31 OVME + 10516.71 INME + 4909.06 STME + 7861.85 CIME < 182069775
17305.93 OOIS + 13698.54 OVIS + 9721.95 INIS + 4260.45 STIS + 7580.60 CIIS < 76156813

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]
29140.29 OONW +25039.13 OONE + 23696.48 OOCE + 19531.83 OOME +17305.93 OOIS < 258482877
18314.09 OVNW + 15776.40 OVNE + 17592.28 OVCE + 13151.31 OVME + 13698.54 OVIS < 89740550
9638.13 INNW + 9322.07 INNE + 8673.56 INCE + 10516.71 INME + 9721.95 INIS < 1087748314
8113.10 STNW + 7152.66 STNE + 6323.16 STCE + 4909.06 STME + 4260.45 STIS < 247910531
15760.68 CINW + 11776.73 CINE + 10301.19 CICE + 7861.85 CIME + 7580.60 CIIS < 879388889

! Number of dwellings involved in all the several italian macroareas
OONW < 89702
OVNW < 89702
INNW < 89702
STNW < 89702
CINW< 89702
OONE < 78071

OVNE < 78071
INNE < 78071
STNE < 78071
CINE< 78071
OOCE < 39533
OVCE < 39533
INCE < 39533
STCE < 39533
CICE< 39533
OOME < 19486
OVME < 19486
INME < 19486
STME < 19486
CIME< 19486
OOIS < 9930
OVIS < 9930
INIS < 9930
STIS < 9930
CIIS< 9930

! Number intervention imposed in the several Italian Macroareas
OONW > 157
OVNW > 153
INNW > 123
STNW > 148
CINW> 153
OONE > 156
OVNE > 154
INNE > 127
STNE > 148
CINE> 148
OOCE > 152
OVCE > 146
INCE > 113
STCE > 185
CICE> 157
OOME > 145
OVME > 146
INME > 95
STME > 160
CIME> 142
OOIS > 137
OVIS > 127
INIS > 85
STIS > 159
CIIS> 142
End
GIN 25

YEAR 2009 – SCRIPT 6[09]

Entire Italian country:
Objective function to minimize: Sum of the average costs associated to the different kinds of building retrofit [€]

Min
29140.18 OONW + 18328.01 OVNW + 9638.12 INNW +8107.82 STNW + 15760.69 CINW +
25050.16 OONE + 15776.41 OVNE + 9322.07 INNE + 7165.12 STNE + 11779.16 CINE +
23711.55 OOCE + 17589.66 OVCE + 8673.63 INCE + 6323.17 STCE + 10301.17 CICE +
19506.48 OOME + 13128.88 OVME + 10516.67 INME + 4909.02 STME + 7863.44 CIME +
17309.24 OOIS + 13701.97 OVIS + 9721.91 INIS + 4260.54 STIS + 7580.59 CIIS
s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1008.32 OONW + 443.32 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW > 25016764
713.25 OONE + 423.64 OVNE + 89.11 INNE + 139.14 STNE + 233.39 CINE > 9401551
633.77 OOCE + 303.15 OVCE + 61.27 INCE + 284.10 STCE + 236.33 CICE > 11007807
320.72 OOME + 248.32 OVME + 57.38 INME + 216.45 STME + 119.23 CIME > 4757108

215.84 OOIS + 129.04 OVIS + 45.24 INIS + 176.07 STIS + 115.18 CIIS > 1940910
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1008.32 OONW + 713.25 OONE + 633.77 OOCE + 320.72 OOME + 215.84 OOIS > 8787874
443.32 OVNW + 423.64 OVNE + 303.15 OVCE + 248.32 OVME + 129.04 OVIS > 2331894
85.90 INNW + 89.11 INNE + 61.27 INCE + 57.38 INME + 45.24 INIS > 9762516
157.71 STNW + 139.14 STNE + 284.10 STCE + 216.45 STME + 176.07 STIS > 10848810
368.28 CINW + 233.39 CINE + 236.33 CICE + 119.23 CIME + 115.18 CIIS > 20393046
! Number of dwellings involved in all the several italian macroareas
OONW < 89702
OVNW < 89702
INNW < 89702
STNW < 89702
CINW< 89702
OONE < 78071
OVNE < 78071
INNE < 78071
STNE < 78071
CINE< 78071
OOCE < 39533
OVCE < 39533
INCE < 39533
STCE < 39533
CICE< 39533
OOME < 19486
OVME < 19486
INME < 19486
STME < 19486
CIME< 19486
OOIS < 9930
OVIS < 9930
INIS < 9930
STIS < 9930
CIIS< 9930
End
GIN 25

YEAR 2009 – SCRIPT 7[09]
Entire Italian country:
Objective function to minimize: Sum of the average costs associated to the different kinds of building retrofit [€]

Min
29140.18 OONW + 18328.01 OVNW + 9638.12 INNW +8107.82 STNW + 15760.69 CINW +
25050.16 OONE + 15776.41 OVNE + 9322.07 INNE + 7165.12 STNE + 11779.16 CINE +
23711.55 OOCE + 17589.66 OVCE + 8673.63 INCE + 6323.17 STCE + 10301.17 CICE +
19506.48 OOME + 13128.88 OVME + 10516.67 INME + 4909.02 STME + 7863.44 CIME +
17309.24 OOIS + 13701.97 OVIS + 9721.91 INIS + 4260.54 STIS + 7580.59 CIIS
s.t.
! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1008.32 OONW + 443.32 OVNW + 85.90 INNW + 157.71 STNW + 368.28 CINW > 25016764
713.25 OONE + 423.64 OVNE + 89.11 INNE + 139.14 STNE + 233.39 CINE > 9401551
633.77 OOCE + 303.15 OVCE + 61.27 INCE + 284.10 STCE + 236.33 CICE > 11007807
320.72 OOME + 248.32 OVME + 57.38 INME + 216.45 STME + 119.23 CIME > 4757108
215.84 OOIS + 129.04 OVIS + 45.24 INIS + 176.07 STIS + 115.18 CIIS > 1940910

! Sum of the energy savings [MWh] achievable through the different kinds of intervention suggested by the previous maximization
1008.32 OONW + 713.25 OONE + 633.77 OOCE + 320.72 OOME + 215.84 OOIS > 8787874
443.32 OVNW + 423.64 OVNE + 303.15 OVCE + 248.32 OVME + 129.04 OVIS > 2331894
85.90 INNW + 89.11 INNE + 61.27 INCE + 57.38 INME + 45.24 INIS > 9762516
157.71 STNW + 139.14 STNE + 284.10 STCE + 216.45 STME + 176.07 STIS > 10848810
368.28 CINW + 233.39 CINE + 236.33 CICE + 119.23 CIME + 115.18 CIIS > 20393046

```
! Number of dwellings involved in all the several italian macroareas
 OONW < 89702
 OVNW < 89702
 INNW < 89702
 STNW < 89702
 CINW< 89702
 OONE < 78071
 OVNE < 78071
 INNE < 78071
 STNE < 78071
 CINE< 78071
 OOCE < 39533
 OVCE < 39533
 INCE < 39533
 STCE < 39533
 CICE< 39533
 OOME < 19486
 OVME < 19486
 INME < 19486
 STME < 19486
 CIME< 19486
 OOIS < 9930
 OVIS < 9930
 INIS < 9930
 STIS < 9930
 CIIS< 9930
!  Number intervention imposed in the several Italian Macroareas
OONW > 157
 OVNW > 153
 INNW > 123
 STNW > 148
 CINW> 153
 OONE > 156
 OVNE > 154
 INNE > 127
 STNE > 148
 CINE> 148
 OOCE > 152
 OVCE > 146
 INCE > 113
 STCE > 185
 CICE> 157
OOME > 145
 OVME > 146
 INME > 95
 STME > 160
 CIME> 142
 OOIS > 137
 OVIS > 127
 INIS > 85
 STIS > 159
 CIIS> 142
 End
GIN 25
```

≈≈≈≈≈≈ ≈≈≈≈≈≈ ≈≈≈≈≈≈ ≈≈≈≈≈≈ ≈≈≈≈≈≈

YEAR 2010– SCRIPT 1[10]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]

```
Max
  1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW +
  1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE +
  807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE +
```

621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME +
554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS

s.t.
! Sum of the average costs for each intervention [€]
50103.35 OONW + 44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW +
47513.62 OONE + 47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE +
45555.49 OOCE + 49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE +
45013.15 OOME + 36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME +
47208.66 OOIS + 49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 4607733288

! Number of dwellings in the whole Italian Country
OONW < 7444761
OVNW < 7444761
INNW < 7444761
STNW < 7444761
CINW< 7444761
OONE < 5075838
OVNE < 5075838
INNE < 5075838
STNE < 5075838
CINE< 5075838
OOCE < 5137694
OVCE < 5137694
INCE < 5137694
STCE < 5137694
CICE< 5137694
OOME < 6260594
OVME < 6260594
INME < 6260594
STME < 6260594
CIME< 6260594
OOIS < 3349993
OVIS < 3349993
INIS < 3349993
STIS < 3349993
CIIS< 3349993
End
GIN 25

YEAR 2010 – SCRIPT 2[10]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]
Max
1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW +
1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE +
807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE +
621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME +
554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS
s.t.
! Sum of the average costs for each intervention [€]
50103.35 OONW + 44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW +
47513.62 OONE + 47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE +
45555.49 OOCE + 49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE +
45013.15 OOME + 36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME +
47208.66 OOIS + 49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 4607733288

! Number of dwellings involved in all the several italian macroareas
OONW < 161017
OVNW < 161017
INNW < 161017
STNW < 161017
CINW< 161017
OONE < 131040
OVNE < 131040
INNE < 131040

STNE < 131040
CINE< 131040
OOCE < 65307
OVCE < 65307
INCE < 65307
STCE < 65307
CICE< 65307
OOME < 33238
OVME < 33238
INME < 33238
STME < 33238
CIME< 33238
OOIS < 15025
OVIS < 15025
INIS < 15025
STIS < 15025
CIIS< 15025
End
GIN 25

YEAR 2010 – SCRIPT 3[10] (block)

- North-West Macroarea:

Max 1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW
s.t.
! Sum of the average costs for each intervention [€]
50103.35 OONW + 44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW < 1942066768

! Number of dwellings involved in the North West of Italy
OONW < 161017
OVNW < 161017
INNW < 161017
STNW < 161017
CINW< 161017
End
GIN 5

- North-East Macroarea:

Max 1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE
s.t.
! Sum of the average costs for each intervention [€]
47513.62 OONE + 47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE < 1528396867

! Number of dwellings involved in the North East of Italy
OONE < 131040
OVNE < 131040
INNE < 131040
STNE < 131040
CINE< 131040
End
GIN 5

- Central Macroarea:

Max 807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE
s.t.
! Sum of the average costs for each intervention [€]
45555.49 OOCE + 49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE < 668907232
! Number of dwellings involved in the Center of Italy
OOCE < 65307
OVCE < 65307
INCE < 65307
STCE < 65307
CICE< 65307
End
GIN 5

- South Macroarea:

Max 621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME

s.t.
! Sum of the average costs for each intervention [€]
45013.15 OOME + 36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME < 337292144
! Number of dwellings involved in the South of Italy
OOME < 33238
OVME < 33238
INME < 33238
STME < 33238
CIME< 33238
End
GIN 5

Islands Macroarea:
Max 554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS
s.t.
! Sum of the average costs for each intervention [€]
47208.66 OOIS + 49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 131070277
! Number of dwellings involved in the Islands of Italy
OOIS < 15025
OVIS < 15025
INIS < 15025
STIS < 15025
CIIS< 15025
End
GIN 5

YEAR 2010 – SCRIPT 4[10]
Entire Italian country:
Objective function to maximize: Sum of the average values of energy saving [MWh]
Max
1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW +
1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE +
807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE +
621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME +
554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
50103.35 OONW + 44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW < 1942066768
47513.62 OONE + 47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE < 1528396867
45555.49 OOCE + 49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE < 668907232
45013.15 OOME + 36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME < 337292144
47208.66 OOIS + 49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 131070277

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]

50103.35 OONW + 47513.62 OONE + 45555.49 OOCE + 45013.15 OOME + 47208.66 OOIS < 299697181
44672.11 OVNW + 47156.29 OVNE + 49010.45 OVCE + 36835.78 OVME + 49260.12 OVIS < 210117828
9805.31 INNW + 9492.60 INNE + 8746.28 INCE + 10934.36 INME + 9567.83 INIS < 2133771137
8137.73 STNW + 7647.65 STNE + 7326.51 STCE + 5277.29 STME + 4544.29 STIS < 352773881
14766.15 CINW + 12808.76 CINE + 11519.67 CICE + 7919.02 CIME + 7777.19 CIIS < 1611373261

! Number of dwellings involved in all the several italian macroareas
OONW < 161017
OVNW < 161017
INNW < 161017
STNW < 161017
CINW< 161017
OONE < 131040
OVNE < 131040
INNE < 131040
STNE < 131040
CINE< 131040
OOCE < 65307
OVCE < 65307
INCE < 65307
STCE < 65307
CICE< 65307

OOME < 33238
OVME < 33238
INME < 33238
STME < 33238
CIME< 33238
OOIS < 15025
OVIS < 15025
INIS < 15025
STIS < 15025
CIIS< 15025
End
GIN 25

YEAR 2010 – SCRIPT 4[10-bis]

Entire Italian country:

Objective function to maximize: Sum of the average values of energy saving [MWh]
Max
1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW +
1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE +
807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE +
621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME +
554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
50103.35 OONW + 44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW < 1942066768
47513.62 OONE + 47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE < 1528396867
45555.49 OOCE + 49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE < 668907232
45013.15 OOME + 36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME < 337292144
47208.66 OOIS + 49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 131070277

! Sum of the average costs for the same kind of intervention in the different Italian macroareas [€]

50103.35 OONW + 47513.62 OONE + 45555.49 OOCE + 45013.15 OOME + 47208.66 OOIS < 299697181
44672.11 OVNW + 47156.29 OVNE + 49010.45 OVCE + 36835.78 OVME + 49260.12 OVIS < 210117828
9805.31 INNW + 9492.60 INNE + 8746.28 INCE + 10934.36 INME + 9567.83 INIS < 2133771137
8137.73 STNW + 7647.65 STNE + 7326.51 STCE + 5277.29 STME + 4544.29 STIS < 352773881
14766.15 CINW + 12808.76 CINE + 11519.67 CICE + 7919.02 CIME + 7777.19 CIIS < 1611373261

! Number of dwellings involved in all the several italian macroareas
OONW < 161017
OVNW < 161017
INNW < 161017
STNW < 161017
CINW< 161017
OONE < 131040
OVNE < 131040
INNE < 131040
STNE < 131040
CINE< 131040
OOCE < 65307
OVCE < 65307
INCE < 65307
STCE < 65307
CICE< 65307
OOME < 33238
OVME < 33238
INME < 33238
STME < 33238
CIME< 33238
OOIS < 15025
OVIS < 15025
INIS < 15025
CIIS< 15025
End
GIN 25

YEAR 2010 – SCRIPT 4[10-ter]

Entire Italian country:

```
Objective function to maximize: Sum of the average values of energy saving [MWh]
Max
  1528.44 OONW + 982.58 OVNW + 96.44 INNW + 120.53 STNW + 265.48 CINW +
  1141.28 OONE + 879.00 OVNE + 97.23 INNE + 126.58 STNE + 174.39 CINE +
  807.49 OOCE + 649.27 OVCE + 65.37 INCE + 135.85 STCE + 134.81 CICE +
  621.70 OOME + 418.83 OVME + 66.95 INME + 186.98 STME + 85.49 CIME +
  554.86 OOIS + 490.15 OVIS + 48.37 INIS + 199.62 STIS + 152.51 CIIS
s.t.
! Sum of the average costs for each kind of intervention in a certain macroarea [€]
50103.35 OONW +  44672.11 OVNW + 9805.31 INNW + 8137.73 STNW + 14766.15 CINW < 921546657
47513.62 OONE +  47156.29 OVNE + 9492.60 INNE + 7647.65 STNE + 12808.76 CINE < 921546657
45555.49 OOCE +  49010.45 OVCE + 8746.28 INCE + 7326.51 STCE + 11519.67 CICE < 921546657
45013.15 OOME +  36835.78 OVME + 10934.36 INME + 5277.29 STME + 7919.02 CIME < 921546657
47208.66 OOIS +  49260.12 OVIS + 9567.83 INIS + 4544.29 STIS + 7777.19 CIIS < 921546657
! Sum of  the average costs for the same kind of intervention in the different Italian macroareas [€]
50103.35 OONW + 47513.62 OONE +  45555.49 OOCE +  45013.15 OOME +  47208.66 OOIS < 921546657
44672.11 OVNW +  47156.29 OVNE +  49010.45 OVCE +  36835.78 OVME +  49260.12 OVIS < 921546657
9805.31 INNW + 9492.60 INNE + 8746.28 INCE + 10934.36 INME + 9567.83 INIS < 921546657
8137.73 STNW + 7647.65 STNE + 7326.51 STCE + 5277.29 STME + 4544.29 STIS < 921546657
14766.15 CINW + 12808.76 CINE + 11519.67 CICE + 7919.02 CIME + 7777.19 CIIS < 921546657
! Number of dwellings involved in all the several italian macroareas
OONW < 161017
 OVNW < 161017
 INNW < 161017
 STNW < 161017
 CINW< 161017
 OONE < 131040
 OVNE < 131040
 INNE < 131040
 STNE < 131040
 CINE< 131040
OOCE < 65307
 OVCE < 65307
 INCE < 65307
 STCE < 65307
 CICE< 65307
OOME < 33238
 OVME < 33238
 INME < 33238
 STME < 33238
 CIME< 33238
 OOIS < 15025
 OVIS < 15025
 INIS < 15025
 STIS < 15025
 CIIS< 15025
 End
GIN 25
```