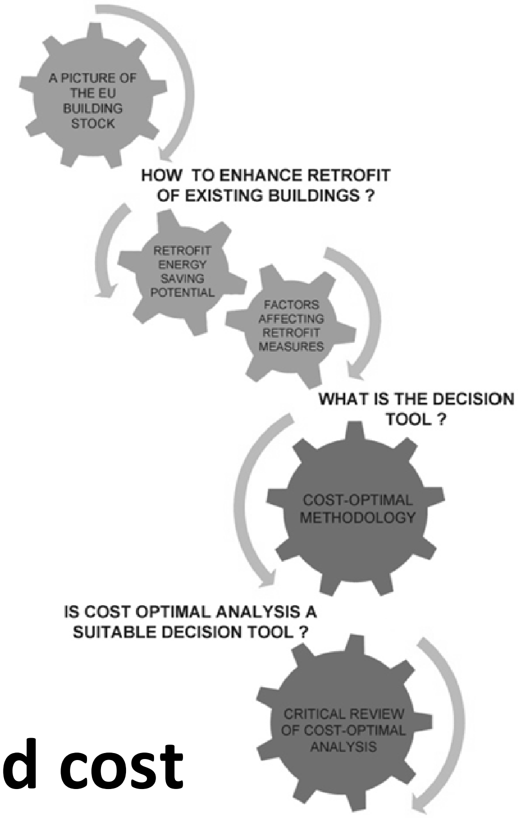

Assessment of energy and cost effectiveness in retrofitting existing buildings

Cristina Becchio

Doctoral Dissertation | Politecnico di Torino

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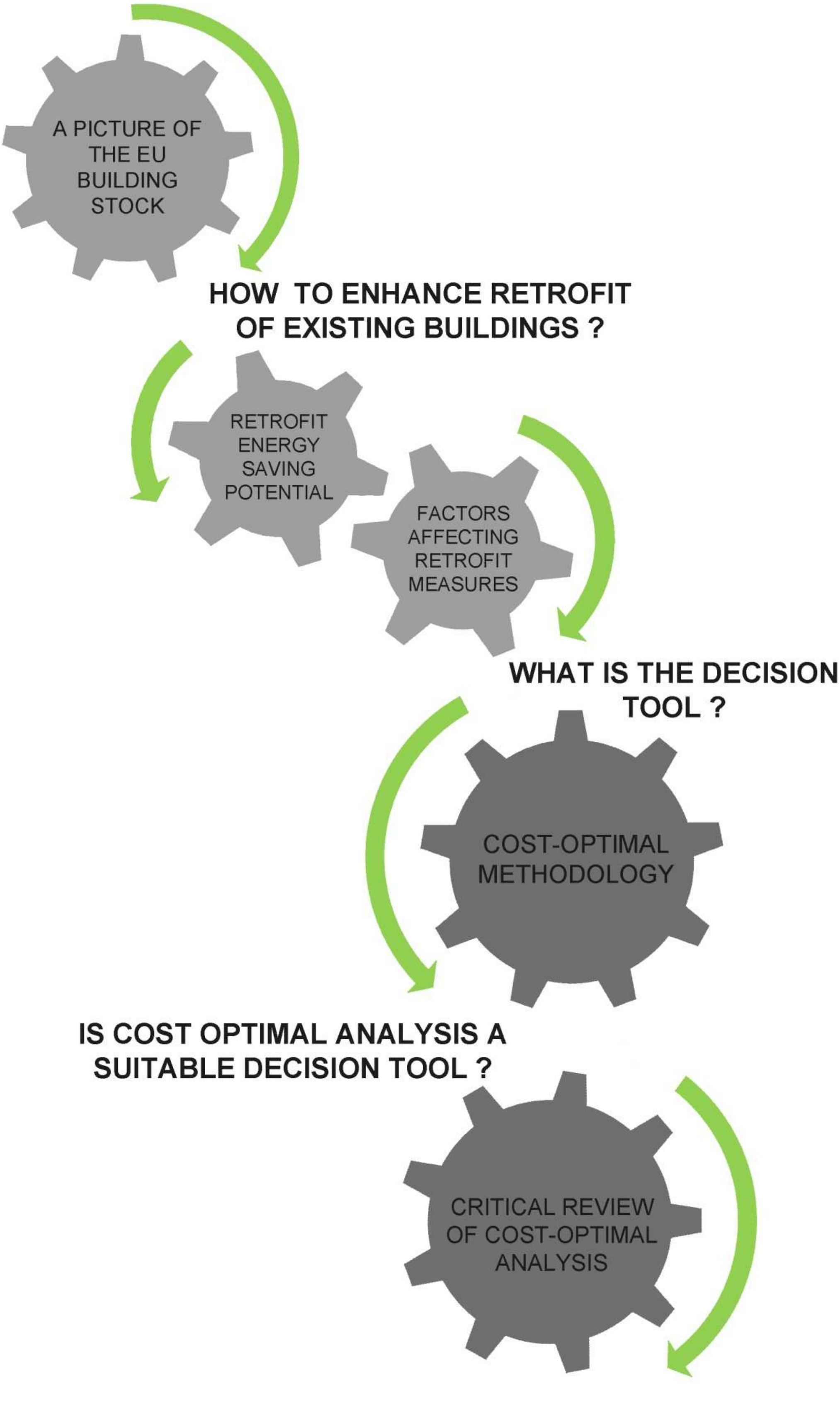
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1 Abstract

The construction of buildings and their operation contribute to a large proportion of total energy end-use worldwide; indeed, buildings account for 40% of the total energy consumption and for 36% of CO_2 emissions in the European Union. The sector is expanding, which is bound to increase its energy consumption. In order to reduce the growing energy expenditure, the European Directive imposes the adoption of measures to improve the energy efficiency in buildings. The recast of the Directive on the Energy Performance of Buildings defined all new buildings will be nearly zero-energy buildings by the end of 2020. However, the transformation of the EU's building stock will not be completed until well after 2020 and this target can only constitute an intermediate step. Indeed, the recent Commission Roadmap for moving towards a competitive, low-carbon economy showed that emissions in the building sector could be reduced by around 90% by 2050.

While new buildings should be designed as intelligent low or zero-energy buildings, refurbishment of existing building stock has many challenges and opportunities because, in the building sector, most energy is consumed by existing buildings. Since the replacement rate of existing buildings by the new-build is only around 1–3% per annum, a rapid enhancement of taking up retrofit measures on a large scale is essential for a timely reduction in global energy use and promotion of environmental sustainability. Consequently, defining minimum energy performance requirements for new and, in particular, for existing buildings represent a key element in European building codes. For this reason, EPBD recast has set out Member States must ensure that minimum energy performance requirements are set with a view to achieve cost-optimal levels for buildings, building units and buildings elements. A cost-optimal level is defined as the energy performance level which leads to the lowest cost during the estimated economic lifecycle. It must be calculated in accordance with a comparative methodology framework that is based on the global cost method. To apply this methodology Member States are expected to define a series of Reference Buildings as baseline and representative models of the national building stock. Additionally, they must define energy efficiency measures to be applied to Reference Building; these ones can be a single measure or constitute a package of measures. Reference Buildings can be exploited as a basis for analysing national building stock and the potential impacts of energy efficiency measures in order to select effective strategies for upgrading existing buildings. Finally, once estimated the Reference Building energy consumptions and the impact of the different energy efficiency measures, the costs of the different packages are estimated in order to establish which of them has the lowest global cost and, consequently, represents the cost-optimal level. Global cost method considers the initial investment, the sum of the annual costs for every year and the final value, all with reference to the starting year of the calculation period. A measure or package of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result, taken over the expected life of the measure. The cost-optimal result represents that retrofit action or combination of actions that minimized the global cost. From the variety of specific results, a cost curve can be derived; the lowest part of this curve represents the economic optimum for the specific set of the analyzed energy efficiency measures.

This PhD study deals with complex scenario above described. Its main objective is to examine cost-optimal analysis in order to establish if this methodology can be an appropriate tool to guide and support decisions related with buildings energy performances. In detail, a critical review of the methodology has been developed and some sensitivity analyses have been exploited in order to testing the robustness of the cost-optimal analysis results. Considering the influence that similar outcomes could have on the European energy policies and on the roadmap towards 2050, it is fundamental to evaluate, even before the same outcomes, how these are reliable. Cost-optimality as a theoretical concept is well and clearly established. However, its application is far from easy and straightforward. Indeed, cost-optimal analysis is a complex methodology characterized by an inherent degree of uncertainty in the final outputs; choices of methodology, procedural decision and complexity of much of the input data significantly affect outcomes. In addition, the research highlights that often although a cost-optimal calculation is being developed and some energy efficiency retrofit measures are individualized, there are no effective instruments, in term of energy policies and financial tools, to drive the market to increase the rate of deep renovations.

2 Riassunto

A livello europeo, gli edifici sono responsabili del 40% del consumo totale di energia e del 36% delle emissioni di anidride carbonica. Inoltre, il settore si sta espandendo con conseguente aumento di tali consumi. Al fine di ridurre questi ultimi, la Direttiva Europea ha imposto agli Stati Membri l'adozione di misure atte a migliorare l'efficienza energetica degli edifici. In particolare, ha stabilito che, entro il 2020, tutti gli edifici di nuova costruzione siano dei *nearly zero-energy buildings*. Tuttavia tale obbiettivo rappresenta solo lo step intermedio di un programma ben più esteso: infatti, la recente *Roadmap* per il 2050 volta al conseguimento di una *low-carbon economy* entro il 2050 ha decretato che entro tale data le emissioni di gas serra relative al settore edilizio debbano essere ridotte del 90%.

Mentre gli edifici di nuova costruzione possono essere facilmente progettati e realizzati come *low* o *zero-energy buildings* e poiché il tasso annuale di sostituzione di edifici esistenti con edifici di nuova costruzione è compreso tra l'1 e il 3%, la vera opportunità di risparmio energetico è rappresentata dal retrofit del patrimonio edilizio esistente. E' essenziale un rapido aumento dell'applicazione di misure di efficientamento energetico su larga scala. Di conseguenza, definire i requisiti minimi di prestazione energetica per i nuovi edifici e, in particolar modo, per quelli esistenti costituisce un elemento chiave della nuova legislazione energetica europea. Per questa ragione, l'EPBD *recast* ha stabilito che gli Stati Membri debbano fissare i requisiti minimi di prestazione energetica in modo da soddisfare il cosiddetto *cost-optimal level*. Quest'ultimo rappresenta il livello di prestazione energetica che comporta il costo globale più basso durante il ciclo di vita economico dell'edificio stesso. Esso deve essere calcolato in conformità ad un quadro metodologico comparativo denominato *cost-optimal analysys*. Per applicare questa metodologia gli Stati Membri sono tenuti a definire una serie di *Reference Buildings*, ovvero di archetipi rappresentativi del patrimonio edilizio nazionale. Inoltre, essi devono definire gli interventi di efficientamento energetico da applicare al *Reference Building*; questi possono essere costituiti da una singola misura di retrofit o da un pacchetto di misure. In tal modo i *Reference Buildings* possono essere sfruttati come base per l'analisi del patrimonio edilizio nazionale, permettendo la stima del potenziale risparmio legato all'applicazione delle diverse misure di retrofit energetico, al fine di selezionare quelle maggiormente efficaci per la riqualificazione dell'esistente. Infine, una volta stimati i consumi energetici del *Reference Building* e l'impatto delle diverse misure di efficientamento energetico sullo stesso, la metodologia prevede la stima dei costi dei diversi interventi, al fine di stabilire quale di essi abbia il minor costo globale e, di conseguenza, costituisca il *cost-optimal level*. Una misura di retrofit o un pacchetto di misure è definito *cost-effective* quando il suo costo globale è inferiore al valore dei risparmi che derivano dalla sua messa in opera. All'interno delle misure *cost-effective*, costituisce il *cost-optimal* quella caratterizzata dal costo globale più basso. Riportando i valori di costo globale delle singole misure di efficientamento in funzione del relativo risparmio di energia primaria su un grafico, è possibile tracciare la cosiddetta *cost-curve* che rappresenta l'inviluppo delle misure con i costi globali inferiori; il minimo della curva coincide con il *cost-optimal level*.

Tale tesi di dottorato si colloca all'interno del complesso scenario appena descritto. Il suo obbiettivo principale è quello di analizzare la *cost-optimal analysis* al fine di stabilire se essa possa essere un valido strumento decisionale atto a supportare le scelte riguardanti le prestazioni energetiche degli edifici. Nel dettaglio, è stata sviluppata un'analisi critica della metodologia e sono state svolte alcune analisi di sensitività dei risultati di due *cost-optimal analyses* al fine di testarne la solidità. Considerando, infatti, l'influenza che tali risultati potrebbero avere sulle politiche energetiche europee risulta fondamentale valutare, prima ancora che i risultati stessi, la loro affidabilità. Infatti, il concetto teorico di *cost-optimal* è chiaro, tuttavia la sua applicazione è tutt'altro che semplice e lineare. La *cost-optimal analysis* è una metodologia complessa caratterizzata da un alto grado di incertezza: la scelta del soggetto al quale rivolgere l'analisi, alcune decisioni procedurali (come la scelta del *Reference Building*) e la complessità nello stabilire alcuni dati di input influenzano significativamente i risultati della stessa. Infine, tale ricerca sottolinea come spesso individuato il cost-optimal level per un determinato *Reference Building* e le relative misure di efficientamento energetico, mancano nel panorama europeo strumenti efficaci a livello politico e finanziario per poter mettere in opera tali misure di retrofit su larga scala.

3 List of papers

The Ph. D. research has led to the following publications.

Paper I: Becchio C., Corgnati S.P., Ballarini I., Corrado V. *Energy saving potential by retrofitting residential buildings in Europe*, in « The Rehva European HVAC Journal », ISSN 1307-3729, December 2012

Paper II: Becchio C., Guglielmino D., Fabrizio E., Filippi M. *Metodologie di calcolo del fabbisogno di energia annuale per la climatizzazione: Risultati a confronto*. Proceeding of Congresso Nazionale sull'Edilizia Sostenibile, ISBN: 9788890449703, Torino, 7-8 Ottobre 2009

Paper III: Becchio C., Guglielmino D., Fabrizio E., Filippi M. *Whole cost analysis of building envelope technologies according to the European Standard EN 15459*. Proceeding of CLIMAMED 2011, ATECYR: Asociaciòn Técnica Española de Climatizacìon y Refrigeraciòn (ESP), ISBN: 9788495010414, Madrid, 2-3 June 2011

Paper IV: Becchio C., Fabrizio E., Monetti V. *Livelli di prestazione energetica ottimali per edifici a energia quasi zero: il caso di un edificio multifamiliare*. Proceeding of 67° Congresso Nazionale ATI, ISBN: 9788890767609, Trieste, 11-14 Settembre 2012

Paper V: Becchio C., Fabrizio E., Filippi M., Monetti V. *Cost-optimal levels of energy requirements for nearly-ZEB: application to an Italian reference building for existing office*. Proceeding of CLIMA 2013, 11th REHVA World Congress and the 8th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings, paper accepted in its final version on January 2013, Prague 16-19 June 2013

4 Foreword

The European Union (EU) provides its Member States (MSs) with a long-term framework for dealing with the issue of sustainability and the cross-border effects of phenomena that cannot be dealt with at the national level alone. The European Commission recently proposed the Europe 2020 flagship initiative for reaching resources efficiency in Europe and within this framework it is now putting forward a series of long-term policy plans in areas such as transport, energy and climate change. The Commission realized a Roadmap that identifies key elements that should guide the EU's climate actions helping the EU become a competitive low carbon economy by 2050 [1]. In particular, in order to keep climate change below 2°C, the objective is reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990. The approach is based on the view that innovative solutions are required to mobilize investments in energy, transport, industry and information and communication technologies, and that more focus is needed on energy efficiency policies. The Europe 2020 Strategy for smart, sustainable and inclusive growth includes five headline targets that set out where the EU should be in 2020. One of them relates to climate and energy: MSs have committed themselves to reducing greenhouse gas emissions by 20% compared to 1990 levels, increasing the share of renewable sources in the EU's energy mix to 20%, and achieving the 20% energy efficiency target by 2020 [2-10]. The EU is currently on track to meet two of those targets, but will not meet its energy efficiency target unless further efforts are made.

It is widely recognized that the building sector is one of the key consumer of energy. Buildings account for 40% of the total energy consumption and are responsible of 36% of total carbon dioxide emissions in the European Union [11]. The sector is expanding, which is bound to increase its energy consumption. This trend raises some environmental issues such as the exhaustion of energy resources, global warming, the depletion of the ozone layer and climatic changes. The Commission’s Roadmap showed that greenhouse gas emissions in this sector could be reduced by around 90% by 2050 compared to 1990. The most immediate and cost-effective way of achieving this target is through a combination of cutting energy demand in buildings through increased energy efficiency and a wider deployment of renewable technologies. Reducing energy consumption has another particular importance in improving security of supply and reducing import dependency. The EU 27 dependency on energy imports increased from less than 40% of gross energy consumption in the 1980s to 54.8% by 2008, with the highest dependency rates for crude oil (84.2%) and for natural gas (62.3%) [12].

Consequently, European legislation set out a cross-sectional framework of ambitious targets for achieving high energy performances in buildings. Key parts of this European regulatory framework are the Energy Performance of Buildings Directive 2002/91/EC (EPBD) [13] and its recast [14]. In particular, the recast of the EPBD defined all new buildings will be nearly zero-energy buildings by the end of 2020; this represents a real step-change relative to the current way of designing and building, both from an architectural perspective and from the side of technical systems, including HVAC and lighting. The extra cost of this can be recovered through fuel savings. The transposition of these Directives into national legislation influences the achievement of energy saving targets [15].

While new buildings should be designed as intelligent low or zero-energy buildings, a greater challenge, however, is the refurbishment of the existing building stock, and in particular how to finance the necessary investments and which energy efficiency measures are the most cost-effective [16;17]. Giving clear guidance and developing suitable policies for deep renovation of the building stock can therefore be seen as an important step of the EU to hit its long term energy and climate targets. At European and national levels some studies on the possible scenarios for the renovation of the EU buildings stock have been fostered in order to help policy maker to determine the appropriate way forward. Therefore, defining minimum energy performance requirements for new and, in particular, for existing buildings represent a key element in European building codes. The Energy Performance of Buildings Directive of 2002 introduced requirements to set such standards in all MSs but did not at that time give guidance on the desired ambition level [18]. It simply expected MSs to behave in a responsible way and to establish ambitious minimum requirements. A few years later, it was quite clear that, although every MSs had moved in the right direction, the minimum requirements set by many of them were not really ambitious enough yet. It was the recast of the EPBD in 2010 that included a provision that national ambitious minimum energy performance requirements should be set with the view to achieving cost optimum levels by applying a harmonized calculation methodology [19]. The Commission requests MSs to use and apply this methodology to calculate the required cost-optimal levels for their specific countries and compare them with the national requirements they have set in their regulations. If the results of the calculations and comparison show that the current minimum energy performance requirements are significantly less efficient than the cost-optimal ones, MSs are required to justify this difference in writing to the Commission. To the extent that the gap is not justifiable, a plan for reducing it has to be drawn up. The comparative methodology framework is not meant to harmonize the minimum energy performance requirements per se, but to ensure that the level of ambition of every EU MSs in their given context is similar. Performance requirements are set by the MSs depending on local factors such as climate, resource availability and economic development. This ensures an equitable approach towards MSs with different levels of progress and experience.

As explained above, EPBD recast has set out that MSs ensure that energy performance requirements are set with a view to achieve cost-optimal levels for buildings, building units and buildings elements. A cost-optimal level is defined as the energy performance level which leads to the lowest cost during the estimated economic lifecycle. It must be calculated in accordance with a comparative methodology framework that is based on the global cost method. The methodology is addressed to national authorities and the cost-optimal level is not calculated for each case, but for developing generally applicable regulations at national level. To apply this methodology MSs are expected to define a series of Reference Buildings (RBs) as baseline and representative models of the national building stock. In the Guidelines of the EPBD recast [21] it is clearly stated that the establishment of RBs is the first step of the calculation procedure. In fact, the developed RBs can be exploited as a basis for analyzing national building stock and the potential impacts of energy efficiency measures (EEMs) in order to select effective strategies for upgrading existing buildings. Additionally, MSs must define EEMs to be applied to RBs; EEM can be a single measure or constitute a package of measures. Finally, once estimated the RBs energy consumptions and the impact of the different EEMs, the costs of the different packages are estimated in order to establish which of them has the lowest global cost and, consequently, represents the cost-optimal level. The global cost method, calculated according with the European Standard 15459:2008 [22], considers, for each EEM, the initial investment, the sum of the annual costs for every year and the final value, all with reference to the starting year of the calculation period. A measure or package of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result, taken over the expected life of the measure. The cost-optimal result represents that retrofit action or combination of actions that minimized the global cost. From the variety of specific results for the assessed packages, a cost curve can be derived. The lowest part of the curve represents the economic optimum for a combination of packages. Its primary energy consumption gives the cost-optimal level of minimum energy performance requirements.

This Ph.D. study fits into the complex scenario above described. In particular, it try to understand if the cost-optimal analysis proposed by the EPBD recast can be an appropriate and complete decision tool to identify the more suitable retrofit measures that have to be applied to the European existing building stock in order to hit 2020 and 2050 targets.

5 Research objective and methods

The main objective of the Ph.D. study is to examine the cost-optimal analysis in order to establish if this methodology can be an appropriate tool to guide and support decisions related with building energy performances and in particular to identify which energy efficiency measures are the most cost-effective for renovating the EU building stock.

In detail, a critical review and some sensitivity analyses have been exploited in order to test the completeness and the robustness of cost-optimal analysis results. Considering the influence that similar results could have on the European energy policies and on the Roadmap towards 2050, it is fundamental to evaluate, even before the same results, how these are reliable. Indeed, cost-optimal analysis is a complex methodology characterized by an inherent degree of uncertainty in the final results. Choices of perspective to use and procedural decisions have significant impact on the outcomes. Furthermore, a mathematical model as this one of global cost is defined by a great number of input variables for which there are multiplicity selection criteria. Often, further tools are required to specify input data that must be included in the cost-optimal analysis. This is the case, for example, of energy consumptions that require complex dynamic simulation software like EnergyPlus to be assessed. It is this multiplicity of selection criteria in terms of perspectives, procedures and input data that determine the uncertainty of the cost-optimal level. Even EPBD Guidelines establish that sensitivity analyses are necessary to complete cost-optimal methodology; they declare that sensitivity analysis is standard practice in ex-ante assessments when outcomes depend on assumptions on key parameters of which the future development can have a significant impact on the final results. The Regulation therefore requires some sensitivity analyses to be undertaken by the Member States and that those perform at least a sensitivity analysis on different price scenarios for all energy carriers of relevance in national context, plus at least two scenarios each for the discount rates to be used for the macroeconomic and financial cost optimum calculations. Nevertheless they do not consider the whole variance of the input data to be used in energy simulation and that have a great influence on the final result.

In order to achieve the main objective of the Ph. D. research the following actions were launched. Each of them had a specific intermediate goal.

- A picture of the European buildings stock was taken (Chapter 6). This depiction highlighted that with its high potential to reduce energy consumptions and emissions of greenhouse gas and other pollutants, existing buildings retrofit, and not new buildings construction, could have a crucial role in a sustainable future and in hitting the 2050 targets.

- An analysis of different studies that were fostered at European and national levels is developed. In this way, a first approximate valuation of energy saving potential by retrofitting existing buildings in Europe was made analyzing the results of a BPIE study on the possible scenarios for the renovation of EU buildings stock and the first outcomes derives at national level from the TABULA project (Chapter 7, Paper I). This kind of studies highlights the significant energy and, consequently, CO_2

emissions saving potential that is connected to the retrofit of existing buildings because of their very poor energy performances. Nevertheless, these fast analyses provide some basic guidelines but don't specify anything about which energy efficiency measures are the most cost-effective.

- The factors affecting the taking up of retrofit measures were identified (Chapter 8). This study drew attention to the complexity of the current European scenario where there are a lot of obstacles that hinder the launch of renovation measures in a large scale. Consequently, in order to breaking down these barriers there is the need to have a tool to supporting decisions about what kind of renovation measures are the most cost-effective and energy-effective.

- The cost-optimal analysis methodology, which is developed by European Commission as a tool to support decisions about which energy efficiency measures lead to minimum energy performance requirement achieving cost optimal levels, was described (Chapter 9, Paper II e III). This description stressed the complexity of the methodology related also with the high number of input data required.

- The results of two cost-optimal analyses were examined and critically revised, also testing their robustness with the application of sensitivity analyses (Chapter 10, Papers IV and V). The two analyses regard a reference building for an existing multi-family house and an existing office respectively, both customized for the Italian context.

- Some conclusions are marked a front of the results of critical review and of the sensitivity analyses (Chapter 11). Some questions derive from these analyses and, in particular, if a so complex tool is the most suited to provide answers so influential on future energy policies and on stakeholder decisions.

6 A picture of the European building stock

Buildings represent the sector with the largest cost-effective opportunity for energy and emissions savings, due to the fact that in this sector the technological solutions needed for a low-carbon economy are already available today. While new buildings can be constructed with high performance levels, they are the existing buildings, representing the vast majority of the European building stock, which are predominantly characterized by very poor energy performances and consequently in need of renovation work. Moreover the replacement rate of existing buildings by the new-build is only around 1–3% per year [23-28]. The renovation of existing buildings stock offers significant potential for both cost-effective CO_2 emissions mitigation and substantial energy consumption reduction. The minimum energy savings in buildings can generate a reduction of 60-80 Mtoe/year in final energy consumption by 2020 [29]. Therefore energy efficiency can be seen as Europe's biggest energy resource. At the same time, measures to increase energy efficiency in buildings support several other important societal and individual goals, such as increased employment and an enhance to economic activity, improved quality of life, reduction of fuel poverty and better security of supply with its lower dependence on imported fossil fuels. This makes energy policies in building sector a highly multi-purpose tool to achieve numerous important targets. With its potential to reduce energy consumptions and emissions of greenhouse gas and other pollutants, existing buildings retrofit can have a crucial role in hitting 2050 targets. Nevertheless, it remains unclear which concrete actions and legislative measures are necessary at the EU level to reach these long-term targets. Indeed, achieving the energy and emissions savings in buildings with the application of retrofit actions is a complex process.

In order to become aware of that it is existing buildings renovation more than new buildings construction the Europe's biggest resource in terms of energy and emissions savings, a picture of the European building stock is provided below.

Buildings typology and main features

The residential stock is the biggest segment with a floor space of 75% of the EU buildings; non-residential buildings account for 25% of the total stock in Europe and consist of a more complex and heterogeneous sector compared to the residential one (Figure 1). The retail and wholesale buildings comprise the largest portion of the non-residential stock, while office buildings are the second biggest category with a floor space corresponding to one quarter of the total non-residential floor space.

A substantial share of the EU stock is older than 50 years with many buildings in use today that are hundreds of years old. The age of a building is a very important feature because it is strongly linked to the level of energy consumption. Construction techniques and building regulations such as building codes imposed at the design phase have a great influence on the energy performance of a building built in a specific period.

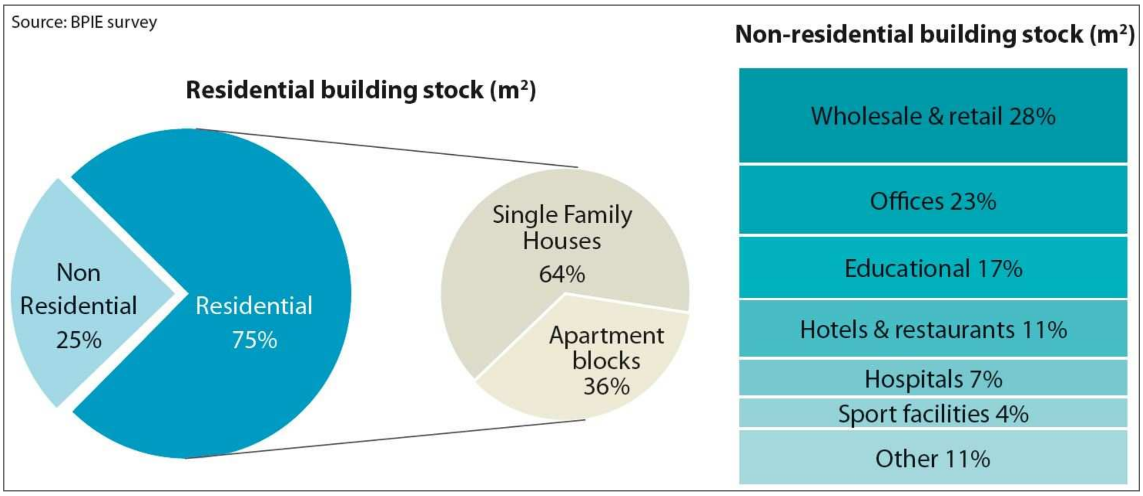

Figure 1. Composition of European existing building stock [30]

A Building Performance Institute Europe (BPIE) study [30] grouped European countries into three wide regions (South, North & West, Central & East) according to climatic conditions, building typology factors and market similarities. Then, residential buildings were divided in three different representative age bands for each region:

- old: typically representing buildings up to 1960;
- modern: typically representing buildings from 1961 to 1990;
- recent: typically representing buildings from 1991 to 2010.

As depicted in Figure 2, almost 40% of European residential buildings was constructed before the 1960s when energy building regulations were very limited. Furthermore, a large boom in construction in 1961-1990 is also evident; in that period the housing stock, with a few exceptions, grew up more than doubles in the current period.

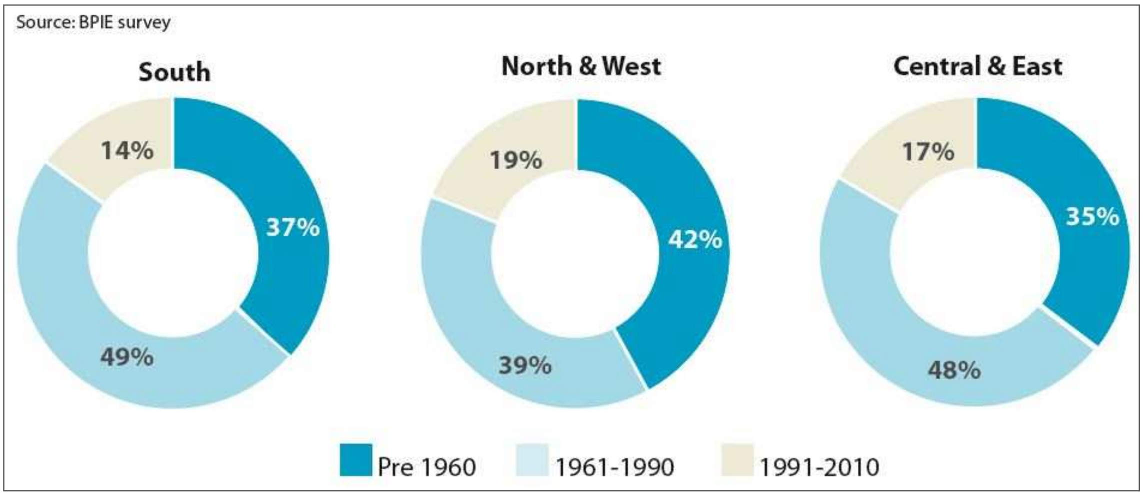

Figure 2. Age categorization of housing building stock in Europe regions [30]

There is a great lack of data about age for non-residential buildings.

Buildings ownership has relevance on the rate at which renovations are undertaken and the depth of the energy savings measures that may be included in renovation projects. Probably, the public sector should be taking the lead in deep renovations and its large portfolio of buildings provides many opportunities for economies of scale. Private owners may be reluctant to act early and may require incentives and regulations to stimulate reasonable rates and depths of renovation. The largest share of residential buildings is held in private ownership, while 20% is allocated to pure public ownership [30].

Furthermore, another key factor which undoubtedly influences the application of renovation measures to improve energy performance in the residential building stock is the question of rental. At least 50% of residential buildings are occupied by the owner in all European countries.

The availability of data about the ownership of non-residential buildings is more limited. From the available data analysis it is clear that the ownership profile in the non-residential sector is more heterogeneous than that in the residential one; private ownership can span from as low as 10% to nearly 90% depending on the country. The extension of public ownership of non-residential buildings suggests that this would be a good target for public policy to begin large-scale renovation to deliver significant reductions in energy use. Obviously, this has a different impact in the various countries.

Finally, buildings location is another element that conditions the starting of renovation measures to improve energy performance and their depth. In the urban environment, economies of scale will come into play with large-scale renovation plans able to act on streets, districts and localities. This is not possible in rural environments. At the EU level, 49% of population lives in densely populated areas (at least 500 inhabitants/km^2), 26% in intermediate (100-499 inhabitants/km^2) and the rest in thinly populated areas (less than 100 inhabitants/km^2) [30].

Energy performances

Analyzing the historical final energy consumptions in buildings in EU27, Norway and Switzerland since the 1990s, two main trends are observed: a 50% increase in electricity and gas use and a decrease in use of oil and solid fuels by 27% and 75% respectively. Generally, the energy use in buildings is a rising trend with an increase from around 400 Mtoe to 450 Mtoe over the last 20 years [12]. This is likely to continue if insufficient action is taken to improve buildings energy performance. Energy consumptions are directly related with CO_2 emissions; nowadays buildings are responsible for around 36% in Europe [31]. In addition, CO_2 emissions are linked to the particular energy mix used in buildings in a given country.

Constituting the biggest segment of the EU stock, residential buildings are responsible for the majority of the buildings energy consumption. In 2009, European households were responsible for 68% of the total final energy use in buildings. Energy is mainly consumed by heating, cooling, hot water, cooking and appliances, where the dominant energy end-use is space heating, that accounts for around 70% of European total final energy use. The end-uses final consumption is shown in Figure 3 divided between all fuels and electricity. The correlation between heating degreedays and fuels consumption underline the link between climatic conditions and use for heating. The significant increase in use of appliances in households is evident through the steady increase in electricity consumption over the last 20 years (38%).

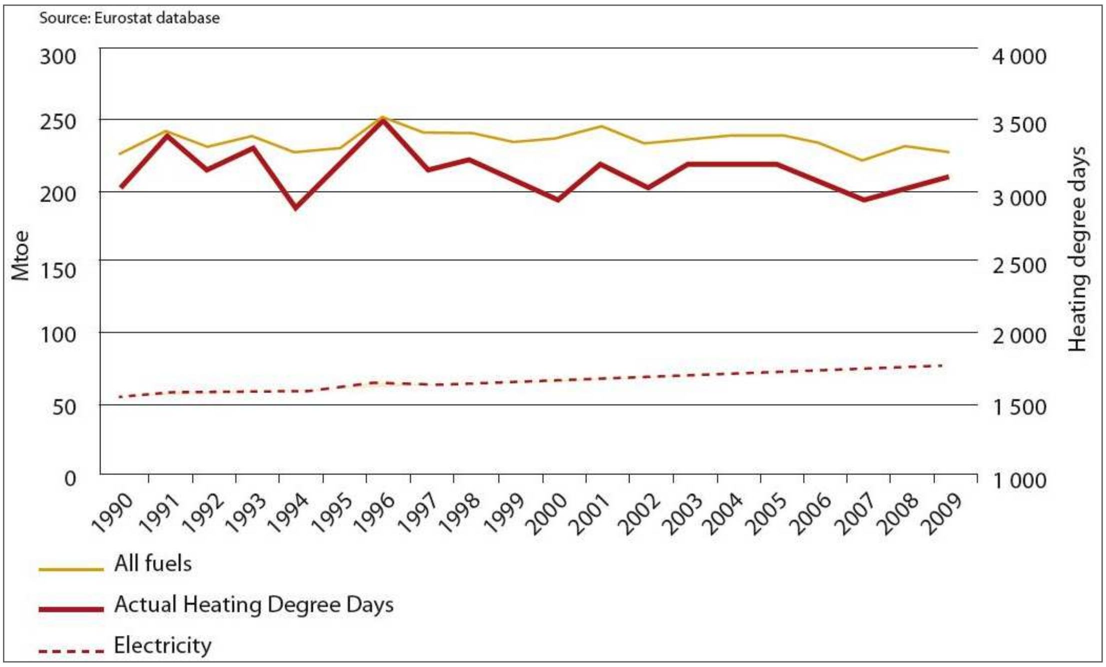

Figure 3. Historical final energy use in the residential sector in EU27, Norway and Switzerland [12]

As shown in

Figure 4, in which is reported the final energy mix in residential buildings per region in 2009, gas is the most common fuel in all regions which stands at 41%, 39% and 26% in North & West, South and Central & East regions respectively. District heating is most common in Central & Eastern Europe and least in Southern countries, while renewable energy sources (solar heat, biomass, geothermal, wastes) have a share of 21%, 12% and 9% in the total final consumption of Central & Eastern, South and North & West regions respectively [12].

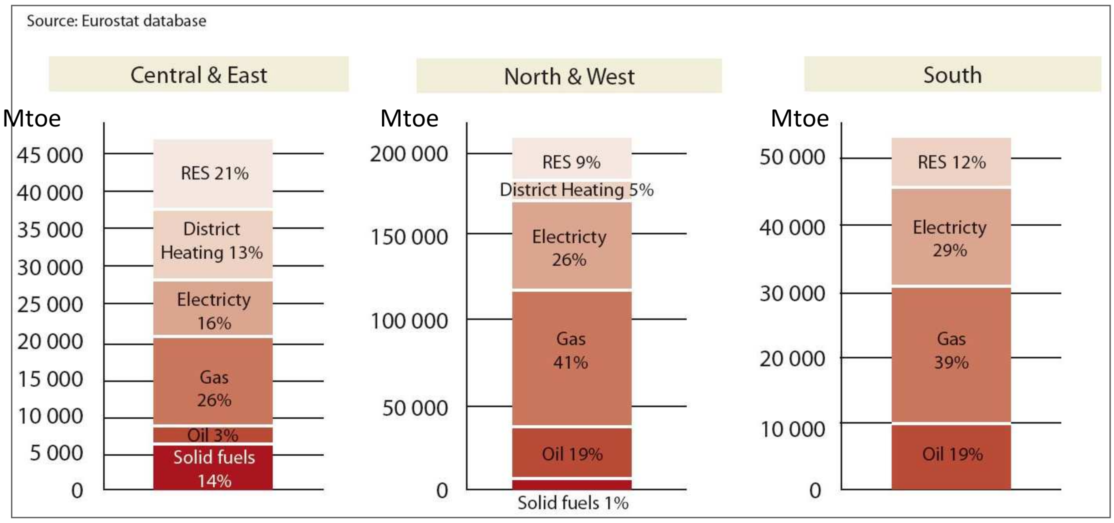

Figure 4. Final energy mix in residential buildings by region [12]

The performance of households depends on a number of factors such as thermal performance of building envelope, efficiency of installed heating system, climatic conditions and occupant behavioral features. Despite different improvements in envelope technologies and heating systems, there is still a large saving potential associated with residential buildings that didn't be exploited. These technologies are easily implemented in new buildings, but the challenge is to exploit them at European existing buildings stock. In fact, as mentioned above within the existing European stock, a large share is built before 1960s where there were only few or no requirements for energy efficiency and only a small part of these have undergone major energy retrofits, meaning that, these have low insulation levels and their systems are old and inefficient. The oldest part of the building stock contributes greatly to the high energy consumption in the building sector. Older buildings tend to consume more due to their low performance levels. Therefore, even if making comparisons between different countries are difficult due to the multiple factors affecting heating consumptions, it is clear that the largest energy saving potential is associated with the older building stock.

Envelope thermal insulation is essential for separating building interior from the exterior environment and minimizing thermal transfer during winter and summer periods. The lack of an appropriate insulation level in older buildings is clear in all European countries due to the lack of insulation standards in those construction years. This is clear, for example, in some Southern countries such as Portugal and Italy where heating needs are relatively high despite of milder winters. This is an indication of insufficient envelope thermal insulation in those countries building stocks due to the lack of energy efficiency standards in the past construction years.

In addition to the lack of sufficient thermal insulation, gaps at connection points between different elements of a building envelope (e.g. window frame and surrounding wall) can lead to considerable energy expenditure. A building with high air tightness levels typically may suffers from high energy consumptions while a building with very low air tightness levels can be characterized by unhealthy conditions for its occupants, especially if there is inadequate ventilation. Establishing the appropriate level of air tightness in buildings is, therefore, a key aspect from the viewpoints of energy consumptions and comfortable occupant conditions. Usually older buildings are characterized by high air tightness due to inadequate past construction techniques and consequently by high energy consumptions.

Evaluating energy use in the non-residential buildings is complex because end-uses such as lighting, ventilation, heating, cooling, refrigeration and appliances vary greatly from one building category to another one. Variations of the data are registered not only from one building type to another one but also from country to country.

As depicted in Figure 5, generally in Europe over the last 20 years electricity consumption in non-residential buildings has increased (74%) [12]. This is due to the technological advances over the last years with an increasing utilization of equipment, air conditioning systems etc., which means that electricity demand within this sector is on an increasing trend.

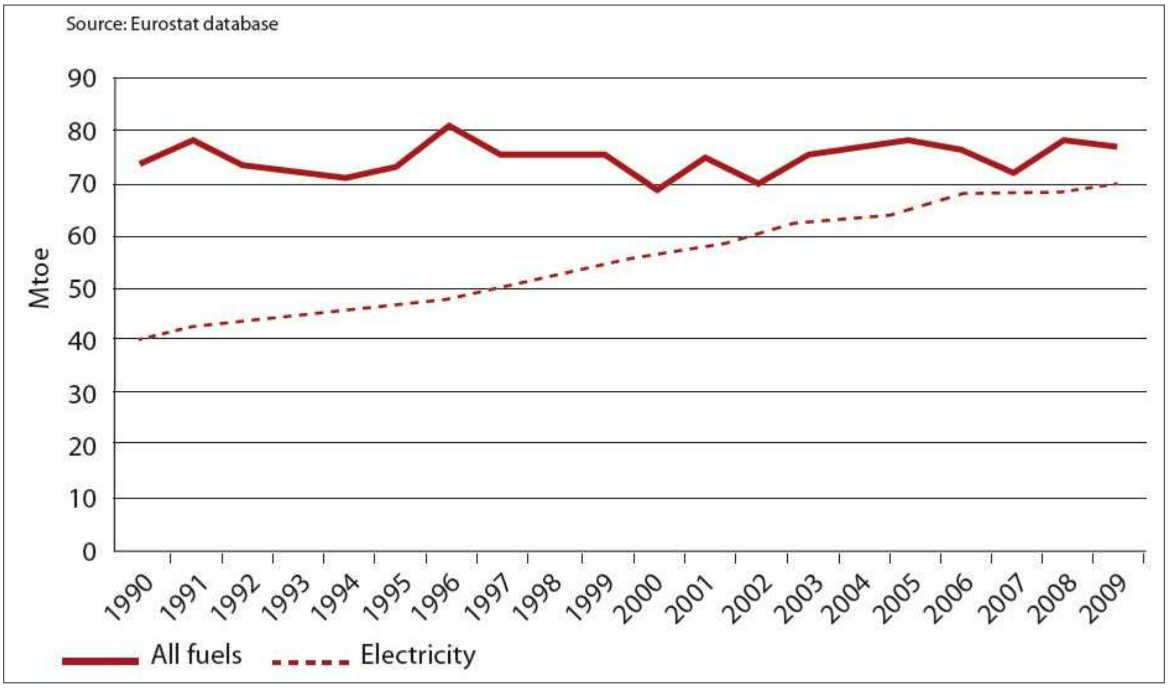

Figure 5. Historical final energy use in the non-residential sector in the EU27, Norway and Switzerland [12]

Construction techniques of non-residential buildings are similar to those of residential ones built during the same period.

In the non-residential sector similar renovation measures to those for the residential one should be considered. Moreover, the installation of smart energy management systems in non-residential buildings becomes more important due to their high share of electricity use. For example, the deployment of efficient lighting control systems has substantial potential in the non-residential sector because the electricity consumption for office lighting is among the highest end-use in this sector.

7 Energy saving potential by retrofitting European existing buildings

As demonstrating by the analysis of European building stock of the previous chapter, it is existing buildings renovation more than new buildings construction that represents the Europe's biggest resource in terms of energy and emissions savings. However the question for policymakers remains how to proceed.

In order to help policy makers to determine the appropriate way forward, different studies at European and national level have been fostered [32-41]. The analyses conducted at European level constitute the guide for the editing of the Roadmap for 2050. Following the results of BPIE study on the possible scenarios for the renovation of the EU building stock by 2050 and the first outcomes derives at national level from the TABULA project are described.

BPIE's renovation model: scenarios

At European level two recent independent EU-wide assessments show the potential for energy savings and CO_2 emission reductions in the built environment sector. The Fraunhofer Institute and partners show that, by implementing energy savings measures, fuel-use in the EU built environment can be reduced by 22% (2020) and by 46% (2030) compared to 2005 [42]. Ecofys et al. shows that GHG emissions can even be reduced by 44% (2020) and 60% (2030) compared to 2005, when full energy savings are applied in conjunction with renewable energies [43].

One of the most completed studies at European level has been developed by BPIE and describes a number of possible scenarios for the renovation of the EU building stock by 2050 [30]. The scenarios illustrate the impact on energy use and CO_2 emissions at different rates (percentage of buildings renovated each year) and depths of renovation (extent of measures applied and size of resulting energy and emissions reduction) from 2010 up to 2050. The model has assessed energy saved, CO_2 saved, total investment required, energy cost savings, employment impact and a range of cost-effectiveness indicators, such as internal rate of return and net saving to consumers. These assessments allow policymakers the opportunity to focus on what they consider the highest priorities. The model considers features such as the age of building and quality of its energy performance. When considering the share of buildings that can undergo low energy renovation, a practical limit is applied in the residential and non-residential building sectors in the 2010 to 2050 timeframe. This practical limit is affected by a number of considerations such as demolitions, heritage buildings, recent renovations and new buildings (that therefore are not liable for retrofitting). The model applies different discount rates, learning curves and future energy prices (based on Eurostat forecasts [12]) in order to derive how costs will evolve from 2010 until 2050. Finally, two decarbonisation pathways are considered, a slow pathway based on what has been happened since 1990 and a fast pathway based on what is needed to achieve the levels of carbon reduction assumed in the EU 2050 Roadmap.

In detail, the BPIE model has been used to create different scenarios that combine depths renovation pathway (shallow, intermediate, deep and two-stage) and various rates of renovation (slow, medium and fast). All but one scenario assume that a building will be renovated once between 2010 and 2050. The so-called two-stage scenario allows for a second renovation during the analyzed period. The presumed scenarios have been compared to a baseline scenario, which assesses what would happen if there were no changes from the approach taken from 2010.

In regard to depth of renovation, energy performance of a building can be improved by the application of a single energy efficiency measure (EEM), such as a new boiler plant or the thermal insulation of the roof space. In the BPIE study this type of measures is indicated with the term “minor” renovation. Typically, the application of three of these minor EEMs is associated to a 30% of an energy saving and they are characterized by low investment costs. At the other end of the scale, renovation can involve the wholesale replacement or upgrade of all elements which have an influence on energy use, as well as the installation of renewable energy technologies in order to reduce energy consumption and carbon emission levels to close to zero, or, in the case of an energy positive building, to less than zero. The hypothesis of BPIE study is that the reduction of the energy needs towards very low energy levels will lead to the avoidance of a traditional heating system. This is considered to be a break point where the ratio of the benefits, in terms of energy cost savings, to investment costs reaches a maximum. This depth of renovation is called “nearly Zero Energy Building” (nZEB). In between these two renovations levels there are some intermediate ones. These can be subdivided into “moderate”, involving three - five EEMs, and “deep”. A deep renovation typically adopts a holistic approach, viewing the renovation as a package of measures working together, but its definition represents a problem because there is currently no commonly agreed definition of the term. Deep renovation is defined differently from country to country; often it is referred to percentage reductions in energy use, but they can also refer to reaching an A category under the Energy Performance Certificate schemes or achieving a certain level of energy consumption per square meter per year. This makes difficult comparing different deep renovations in the MSs.

Even if it is not possible to say with certainty what the current depth of renovation is being undertaken within Europe, the available evidence shows a picture where the majority of activity is in the minor category. Deep renovations, where they do occur, are frequently pilots or demonstration projects to assess the viability of achieving energy savings of 60% or more and to provide a learning opportunity. Therefore nowadays, it is plausible to suppose that minor renovation correspond to 85% of total renovations, moderate to 10%, deep to 5% and nZEB is negligible (these percentage are those of baseline scenario). In front of these data, BPIE has presumed four renovation paths characterized by different speeds of renovation. In all paths 5% is the minimum level for minor renovations to reflect situations where the only improvement in energy performance is due to replacement of equipments at the end of their life.

In the shallow one (Figure 6), the minor renovations continue to represent most activity over the next two decades, and still account for 25% of activity by the middle of the century; moderate renovations grow steadily over the period, reaching 50% of total activity in 2050, while deep renovations grow more modestly, achieving only 25% of total activity in 2050; nZEB activity continues to be negligible.

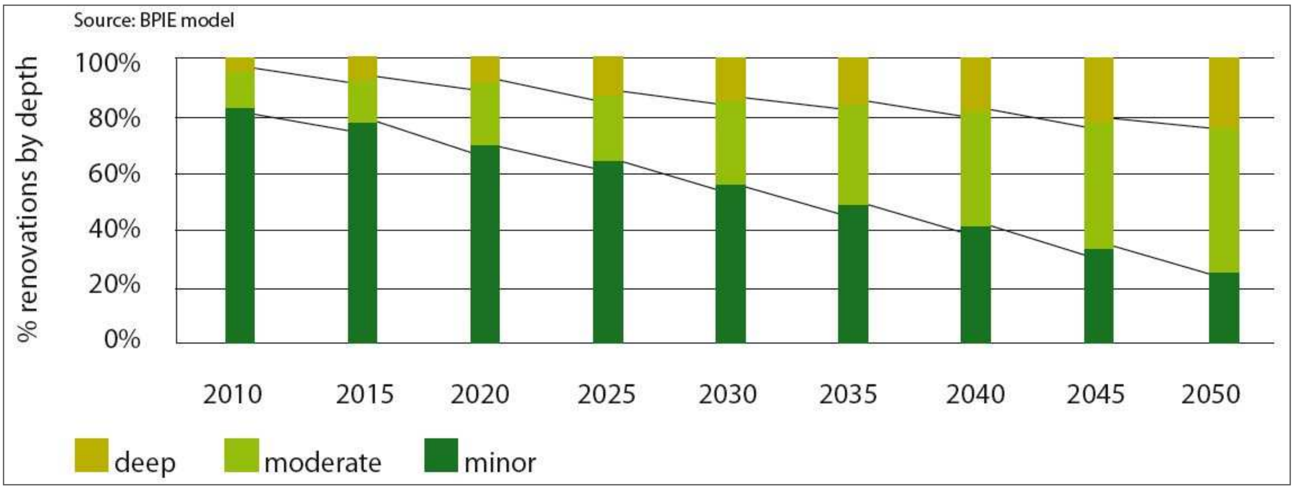

Figure 6. The shallow renovation path [30]

In the intermediate path (Figure 7), minor renovations continue to be most common for the next decade, but fall away such that, by 2030, they reach just 5% of the total, continuing at that level thereafter; deep renovations grow to 65% of activity by 2050, while nZEB renovations are introduced, reaching 5% of renovations by 2050; the balance is made up of moderate renovations.

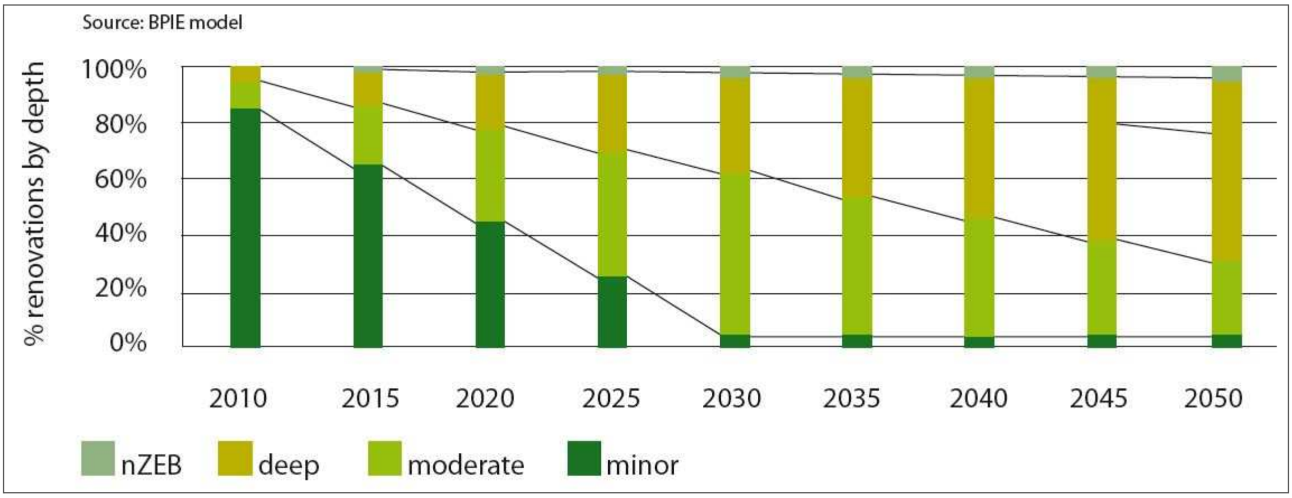

Figure 7. The intermediate renovation path [30]

In the deep path (Figure 8), by the end of this decade, deep renovations become the dominant activity and remain so until 2050; nZEB renovations accelerate from 2020 onwards, such that they account for 30% of the total by 2050, by which time both minor and moderate each account for just 5% of the total.

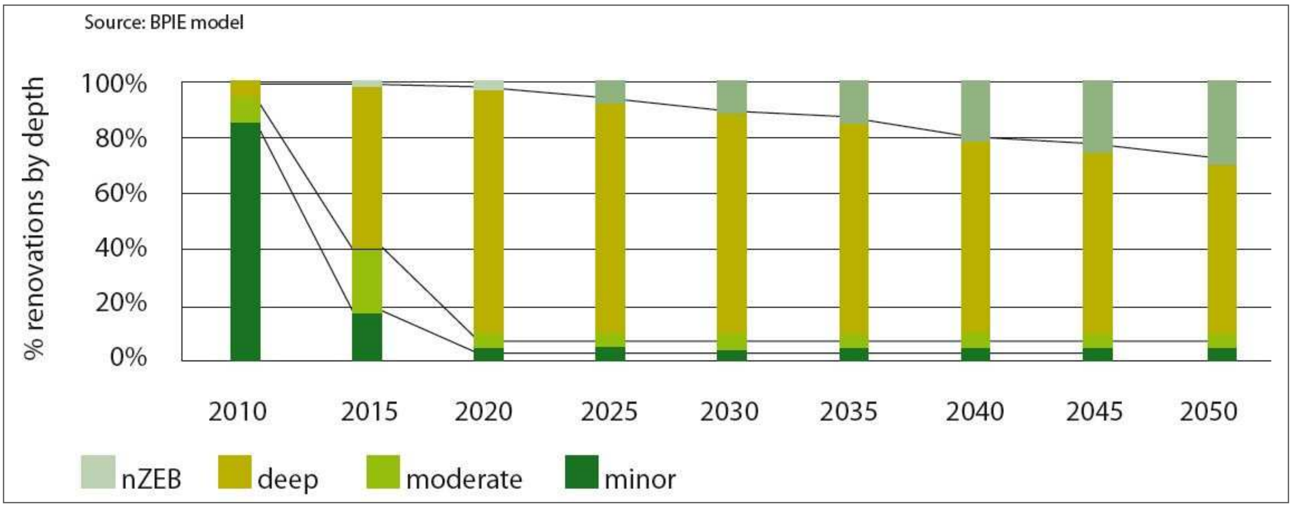

Figure 8. The deep renovation path [30]

In the two-stage renovation path (Figure 9), properties that undergo minor or moderate renovation between 2011 and 2030 are then upgraded 20 years later, to deep and nZEB standards respectively.

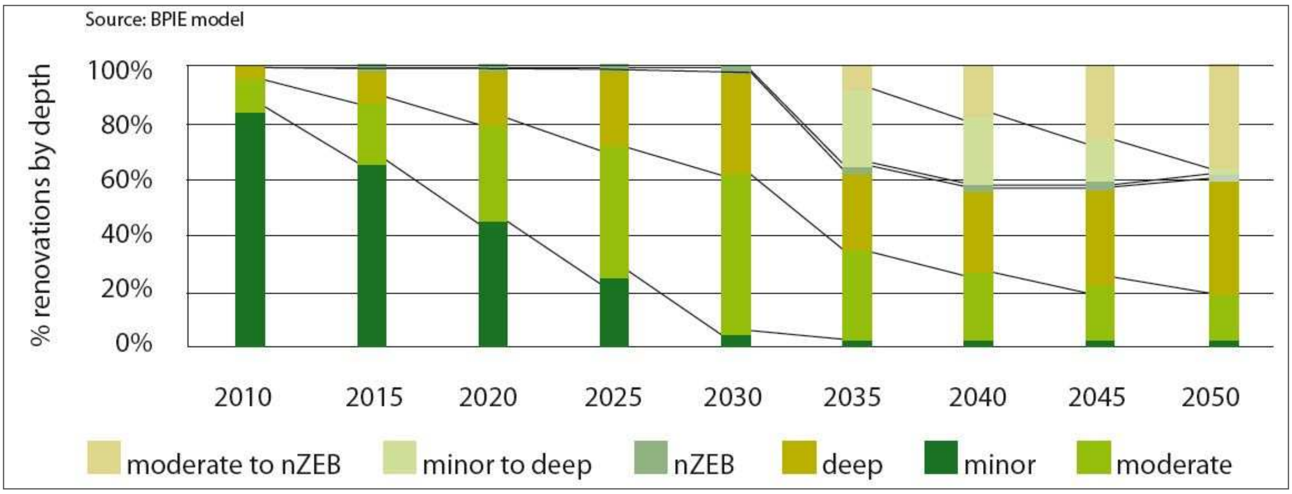

Figure 9. The two-stage renovation path [30]

In regard to rate of renovation, the target is that of achieving the 100% renovation until 2050 (considering the practical limit mentioned above). Consequently an average annual renovation rate of 2.5% needs to be attended. Therefore with current rate of about 1%, levels of retrofit activity need to more than double to achieve the required annual rate. The main variables concerning renovation rates and considered by the model are the speed at which renovation activity ramps up, and the potential peak renovation rate. As depicted in Figure 10, taking into account these assumptions and considering at the same time the practical limits of the renovation rate, the BPIE model proposes three main growth patterns: slow, medium and fast. These three growth patterns are benchmarked against a baseline which assumes that the current renovation rate remains unchanged over time.

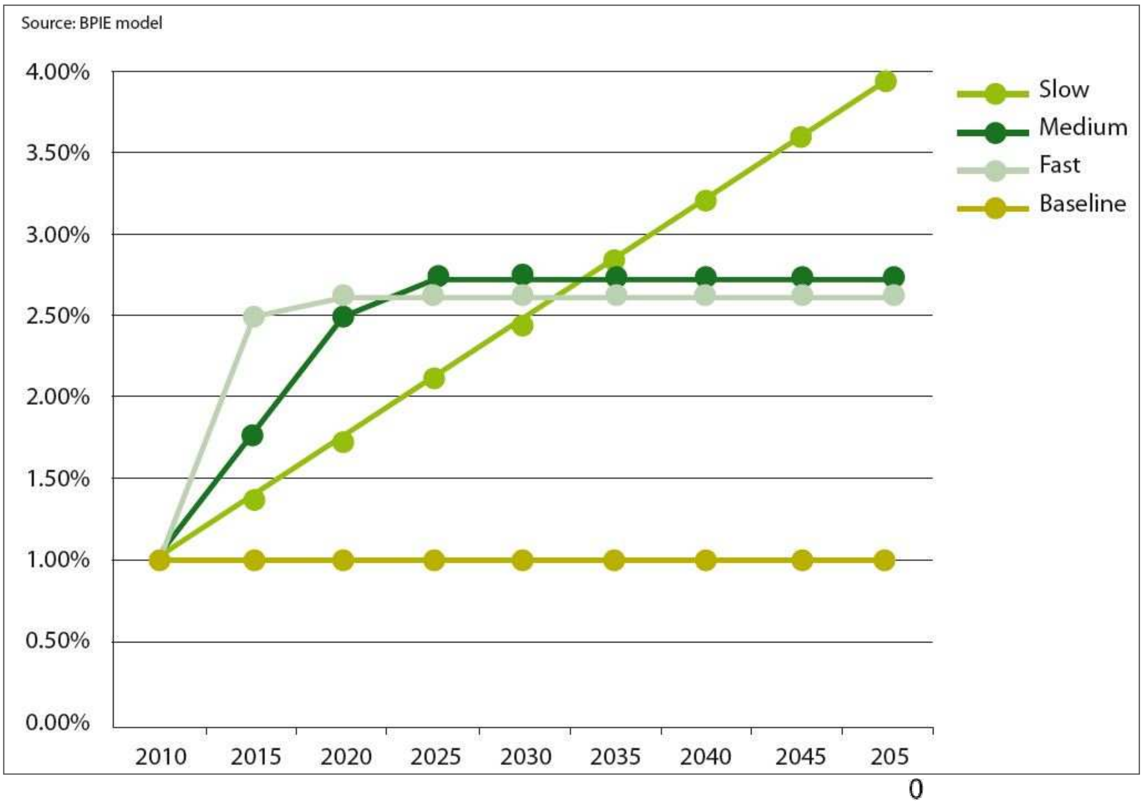

Figure 10. Profiles of renovation rates considered in BPIE model [30]

The speed of renovation is a very important parameter because of its influence on the so called "learning curve" that represents the reductions of renovation costs for different levels of renovation over the time. Cost renovation reduction factors are applied in BPIE study, reflecting the impact of increasing renovation activity over the period to 2050. Higher factors are applied to the deeper renovation profiles, given that there is a steeper learning curve as the volume of activity increases, and the cost of buildings integrated renewable technologies in particular come down with increasing market maturity. The impact is illustrated in Figure 11 with cost reductions ranging from 1% p.a. for minor renovations to 4% p.a. for nZEB renovations.

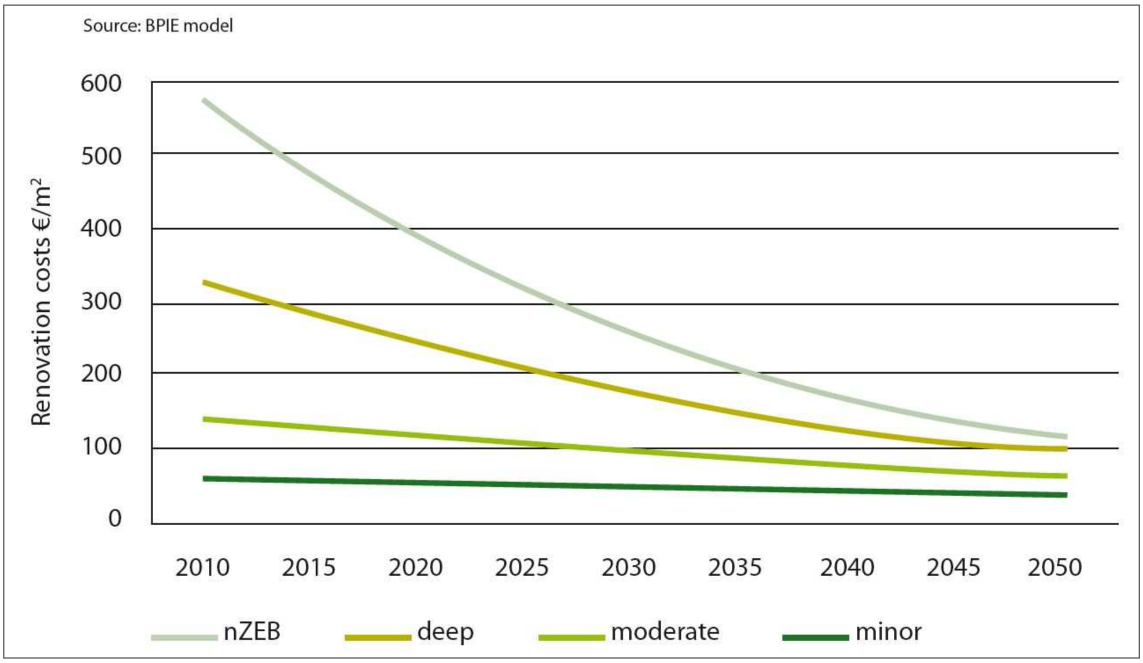

Figure 11. Cost reductions for different levels of renovation over time [30]

The different scenarios have been derived from combinations of the speed of renovation and the depth pathways as well as the two decarbonisation rates mentioned above (Table 1). For the baseline scenario, it is assumed that the prevailing renovation rates, which are predominantly minor, continue until 2050. Unlike the other scenarios, this does not result in a full renovation of the building stock. In fact, at the prevailing renovation rate of just 1% p.a., only 40% of the stock is renovated by 2050. There are two scenarios that take the shallow renovation path. They compare the impact of a rapid acceleration in the rate of renovation ("fast and shallow") with a slow but steady ramping up ("slow and shallow"). These scenarios are analyzed in order to illustrate the consequences of focusing mainly on shallow renovation measures which may be perceived as the cheaper and more pragmatic solution. The medium scenario combines the intermediate renovation path with the medium rate of growth. The deep scenario combines the deep renovation path with the medium rate of renovation growth. The last scenario deviates from the assumption in the previous scenarios that buildings will be renovated once between 2010 and 2050. In this scenario, from 2031 forward the second stage of renovation works starts, occurring in addition to the first time renovations.

	Slow and Shallow	Fast and Shallow	Medium	Deep	Two-stage
Rate of renovation	slow	fast	medium	medium	medium until 2030 fast after 2030
Depht renovation path	shallow	shallow	intermediate	deep	two-stage

Table 1. The different scenarios of BPIE study

BPIE's renovation model: results

Analyzing the results of the five scenarios reported in Table 2, it is clear that only two of the scenarios achieve the ambitious European CO_2 reduction targets as described by the European Commission in its Roadmap 2050 paper [1]. Indeed, the deep and the two-stage scenario, achieve a CO_2 reduction of around 90%, but only under the assumption that the power supply sector undergoes a fast decarbonisation as well. Nevertheless, in both scenarios the majority of CO_2 savings are achieved through energy savings measures on the demand side.

			Scenario					
			Baseline	Slow and Slallow	Fast and Shallow	Medium	Deep	Two-stage
2020	Energy saving	%	2	4	7	7	13	7
	CO_2 saving with slow decarbonisation	%	5	7	9	10	16	10
	CO_2 saving with fast decarbonisation	%	28	29	31	31	35	31
2050	Energy saving	%	9	34	32	48	68	71
	CO_2 saving with slow decarbonisation	%	18	40	38	53	71	73
	CO_2 saving with fast decarbonisation	%	71.7	79.3	78.6	83.8	89.9	90.7

Table 2. Overall results to 2020 and to 2050 (the percentage are calculated in reference to 2010)

In all the scenarios, the estimated CO_2 emission reduction by 2050 is determined by the energy savings but also by the decarbonisation of the energy supply sector. It is interesting to note that in the deep and two-stage scenarios there is a 71-73% CO_2 emission reduction even under the slow decarbonisation assumption, a figure which is close to the CO_2 emission reduction for the slow and shallow scenario under the fast decarbonisation assumption. This highlights the role of renovation measures in the decarbonisation strategy. The decarbonisation of the energy supply sector is significantly eased by decreasing the energy demand of buildings and is importantly more sustainable. Moreover, the costs for decarbonising the energy generation system will be significantly less if the consumption patterns of the building sector will dramatically reduce.

In terms of cost-effectiveness to consumers, the shallow and the deep scenarios are similar in terms of the Internal Rate of Return (based on the net saving each year, in other words cost saving less investment required in a given year) when considered over the period to 2050, all falling into the range 11.5-12.5%. This is slightly better than the baseline scenario of 10%, though not as good as the two-stage renovation scenario, which achieves 13.4%.

In the Figure 12, the present value investment and energy savings are compared; the difference provides the net savings to consumers. The fast and shallow scenario has a higher level of energy cost savings than the slow one, due to savings arising earlier, but suffers the penalty of a too rapid ramping up of activity before the impact of cost reductions through greater experience (Figure 11) helps to bring the price of the moderate and deep renovations down. Indeed, the investment required for fast scenario is greater and the net savings to consumers lower. Further, a fast ramping up of the renovation activities as modeled in the fast and shallow scenario may also overload the supply side, both in terms of materials and services provided. The actors in the building renovation value chain would have to make significant and fast investments to satisfy the growing market demand. There are, however, recent examples of other sectors delivering significant growth rates, such as the European renewable energy industry where turnover grew by a factor of 7 between 2005 and 2010. The EU policy framework to support renewable energy systems played a crucial role in achieving this growth.

While both the deep and the two-stage scenario achieve almost the same level of CO_2 reduction, the deep scenario requires a significantly higher absolute investment level and, on the other hand, it also generates higher energy cost savings. However, the net savings are smaller than in the two-stage scenario. The high investment needs of the deep scenario are caused by a fast increase in deep renovation measures in the first decade. The two-stage scenario requires a lower investment due to a slower increase in the number of deep renovations while benefiting from a longer learning period which leads to cost reductions. Indeed, as a result of the learning curve cost reductions, particularly for the deeper renovations, the cost of achieving a deep or nZEB renovation will be substantially less in 2035 than if it had been undertaken 20 years earlier. The overall investment is therefore considerably lower than for the deep scenario. In present value terms, a cost reduction of nearly 40% is achieved, despite achieving slightly higher levels of energy and CO_2 savings in 2050. Consequently, the net savings are significantly greater than for the deep scenario.

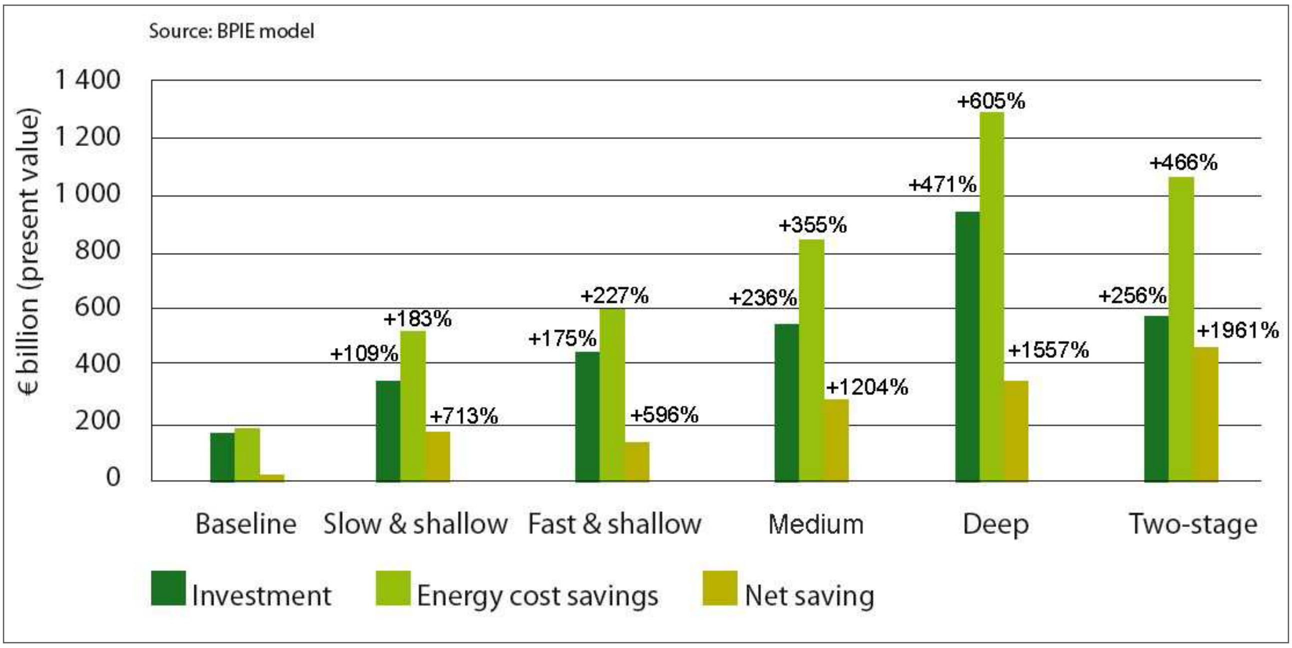

Figure 12. The comparison between the present value investment and energy savings; the difference provides the net savings to consumers; the percentage values are calculated in reference to baseline scenario

Figure 13 shows the employment impact resulting from the investment in improving the energy performance of Europe's building stock, as an average over the period. It can be seen that, while continuing with baseline scenario would employ fewer than 200 000 people over the next 40 years, the accelerated renovation scenarios would generate between 500 000 and over 1 million jobs. In particular, in deep scenario the impact on employment creation is the highest of all other ones. Indeed, activated by the relatively fast increase in the renovation rate and by applying deep renovation measures, this scenario leads to the creation of 1.1 million direct jobs per year on average for 40 years. This is more or less equivalent to employing 1.1 million people for their full working life time.

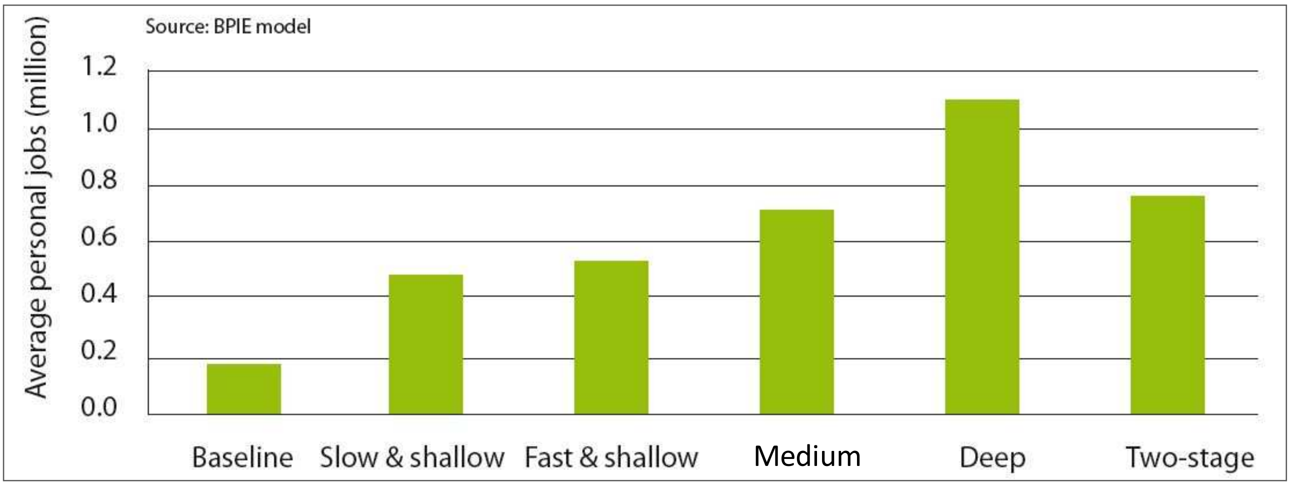

Figure 13. Average employment generated in 2011-2050 [30]

Taking into consideration the three most relevant factors, i.e. achievement of CO_2 reduction targets, investment considerations and positive employment effects, it seems that the results of the two-stage scenario provide the best balance of these factors, comparing all scenarios.

Each of the scenarios represents a significant ramping up in renovation activity compared to the baseline situation. When looked at purely in terms of the investment required, these range from around double the baseline level for scenario slow and shallow, through to over five times the baseline level for the deep scenario. These are significant increases, but certainly achievable if governments across the EU were to agree and implement respective policies and market stimulation mechanisms. This action is fundamental because the current practice is clearly not sufficient to trigger a renovation wave across Europe which would deliver the societal, economic and environmental benefits possible. At a time of rising unemployment and increased energy dependency, the employment and energy-saving benefits to consumers from an accelerated renovation plan would provide a welcome boost to many countries continuing to suffer economic difficulties following the credit crunch.

The exploitation of Reference Buildings to test the energy saving potential of European buildings stock

Also at national level different studies are developed in order to contextualize the results of the analyses conduct at European level described above. The definition of Reference Buildings (RBs) as baseline and representative models of the national building stock is the key element that allows this contextualization.

RBs can be exploited as a basis for analysing the energy saving potential by retrofitting national building stock both in fast analyses (as that described in this paragraph and in Paper I) and also in more detailed analyses (as that described in Chapter 9).

EBPD Guidelines establish that “the main purpose of a Reference Building is to present the typical and average building stock in a certain Member State, since it is impossible to calculate the cost-optimal situation for every individual building. Hence the RBs established ought to reflect as accurately as possible the actual national building stock so that the cost-optimal methodology can deliver representative calculation results” [21].

In order to examine in depth, below the description of what is a Reference Building and the methodology for its definition is reported an excerpt from the draft of the First Report of Rehva Task Force “Reference Buildings for Energy Performance and Cost-Optimal Analysis”, *Reference Building for cost-optimal analysis: A shared methodology for their definition and ongoing activities*, that it is edited by the author of this Thesis with S. P. Corgnati, V. Monetti and M. Airaksinen [44].

According to Annex III of the EPBD recast, RBs are “buildings characterized by and representative of their functionality and geographic location, including indoor and outdoor climate conditions”. They aim to represent the typical and average building stock in terms of climatic conditions and functionality (e.g. residential buildings, schools, etc). […]

Generally speaking RBs aim to characterize the energy performance of typical building categories under typical operations. In particular, in compliance with the EPBD recast, RBs are required for the purpose of cost-optimal methodology. They need to reflect as accurately as possible the actual national building stock to ensure that results from cost-optimal calculations are representative. Moreover they can be used to evaluate the achievable reduction on energy consumption under a certain energy policy applied to a selected building category in a national territory.

Especially the EPBD recast demands MS to define at least two RBs for the existing buildings subjected to renovation and one for new buildings. The considered building categories are Single-family buildings, Apartments blocks/Multi-family buildings, Office buildings and the other non-residential buildings listed in Annex I of the EPBD recast. MSs can choose to define a RB for each non-residential building category or define a RB can be considered representative of two or more building categories. Overall the number of RBs demanded to each MS has to be equal or superior to 9.

In the past many studies pursed the definition of typical buildings but with different final targets. While some works were aimed to the creation of representative buildings to be used for the evaluation of energy saving possibilities in existing dwellings, others pursued the definition of typical buildings in order to develop benchmark energy consumption of certain categories of buildings. [...]

At European level some studies have been carried on with reference to the theme of RBs. Especially some RBs, mostly within the residential category, were developed and they are shortly described below. In *particular two recent projects within the "Intelligent Energy Europe" program (IEE), TABULA and ASIEPI, hold a reference position with regard to the definition of typical residential buildings.*

Due to the EPBD requirements, RBs have hence become a crucial topic for studies assessing the energy performance. The Buildings Performance Institute Europe (BPIE) drew up a set of principles concerning the nZEB. Within its study, BPIE outlined the boundaries of the current nZEB definition and produce a set of possible improvements, referred as principles that can be applied to guarantee a better road towards the implementation of nZEB by MSs. In particular two RBs were created across three representative European climates (Copenhagen, Stuggart and Madrid), in order to assess the principles defined: a single-family house and a multi-storey office building. [...]

European building stock is very heterogeneous in terms of climatic zones, building styles and usage. In fact within the same category, building use can vary widely if analyzed into different MSs. Climate conditions have a relevant influence into the construction technologies and the energy needs that characterize the building. It is thus important to take these differences into account in order to identify a proper methodology to be used by all MSs. This paragraph outlines a fair and harmonized methodology to be used to determine them.

In past and recent years several studies using RBs as a starting point, were carried out, hence RBs do not represent a new area of interest at all. However, MS follow approaches that are very unlike in terms of methodology and degree of detail in the creation of RBs since there is still no standardized methodology to refer to. Some MS have developed a comprehensive catalogue (Germany), others are dealing with example buildings (Denmark), others are defining them just for a few building categories and others still do not have them in a project development.

To create a RB is a quite complex operation and its accuracy mostly depends on the level of detail pursued in defining the building. In fact a common and main problem usually faced is the lack of information requested for defining properly RBs as it is difficult to find reliable sources to refer to. Usually a common approach is to extract, when available, data from official statistics at national or regional level. The high need of information relies also on the methodology used for the assessment of energy performance in buildings. In order to achieve reliable results, the Guidelines suggest MS to perform calculation using a dynamic method. It is thus recommended to carry out calculations by means of dynamic energy simulation with appropriate calculation programs (e.g. EnergyPlus). Dynamic energy simulation requires detailed building energy models and faces several problems associated mostly with the several pieces of information necessary as input data for the modeling process. Thereby, as the level of information required is high, a solid foundation of data about the building stock is the starting point to create RBs, especially when using dynamic energy simulation.

The data collected for creating RBs, can be gathered into four main areas of investigation as listed below: form, envelope, system, operation.

Data from each one of these four areas form a sub-set of the features of a building. All four sub-set gathered together constitute a wider set of features that match with a RB model. The sub-set “Form” regards the building type (e.g. office, school, etc), size and general geometry of the building. The second sub-set, “Envelope”, regards the construction technologies and the material used in the building, providing a description of the thermo-physical features of building envelope. The sub-set “System” concerns the heating and cooling systems, the mechanical ventilation systems (when applicable), the generation systems and the production from renewable sources within the building. In conclusion “Operation” sub-set consists of the operational parameters affecting the usage of the building and it is also expressed through a set of schedules (i.e. lighting schedule, equipment schedule, heating temperature schedule, etc).

The structure of the four sub-sets of features […] takes inspiration from the methodology for establishing RBs used by the Department of Energy (DOE) of United States. In fact DOE RB models are defined gathering the data into four main area of investigation: program, form, fabric and equipment, that match respectively with the sub-set operation, form, envelope and system outlined above.

Moreover, as also recommended into the Guidelines, collected data are subsequently gathered in terms of age, location and type.

Once collected the data within the 4 sub-sets, in order to create RBs, the process of gathering all data together is a crucial task. It is important to understand the typology of data available depending on the sources used. It is possible to collect data from statistical analyses or to base RBs on experts’ assumptions. The EPBD guidelines point out as input documentation for the establishment of RBs, the work carried out within the IEE TABULA project, in which three methodologies to classify RBs are defined:

I. *Creation of an “Example (Reference) Building”. This methodology is used when no statistical data are available, and it thus relies on the basis of experts’ assumption and studies. Information from different sources but all based on experience and experts’ inquiries are properly combined to provide a building that is the most probable of a group of buildings, within a selected location and age.*

II. *Selection of a “Real (Reference) Building”. The RB is the most typical building in a certain category. It is a real existing building, with average characteristics based on statistical analysis. To define a Real Building it is therefore necessary to have a large amount of information on the building stock.*

III. *Creation of a “Theoretical (Reference) Building”. This method processes statistical data in order to define a RB as a statistical composite of the features found within a category of buildings in the stock. The building is therefore made of the most commonly used materials and systems.*

Figure 2 illustrates the methodologies described above. In particular the input data for the creation of an Example (Reference) Building model are derived from handbooks, design manuals, standards and codes, and appropriately selected on the basis of the experts’ assumptions. This building is thus a fictional building.

On the contrary, the methodologies that refer to the building stock in order to derive a RB are outlined in the bottom part of Figure 2. First of all, it should be noted that only a sample of a national/regional building stock is known from surveys, energy certificates, etc. This is the reason why only a sample of the building stock can be used as the input data of a RB definition.

Generally, data on the building stock sample, are processed by statistical tools in order to have a synthetic representation of this sample (mean conditioned area, mean U-value of opaque components, etc). These statistical results can be treated aggregately or separately. In the first case, it is possible to select from the building stock sample, the building that is the most close to the statistical results: this is a Real RB.

On the contrary, in the second case, the process of selection from the building stock sample is made for each of the building features the statistical analysis has been disaggregated into. The RB will be made in this case of a summation of various features of real buildings, but will not represent a real building itself. This process is similar, for example, to the creation process of a test reference year.

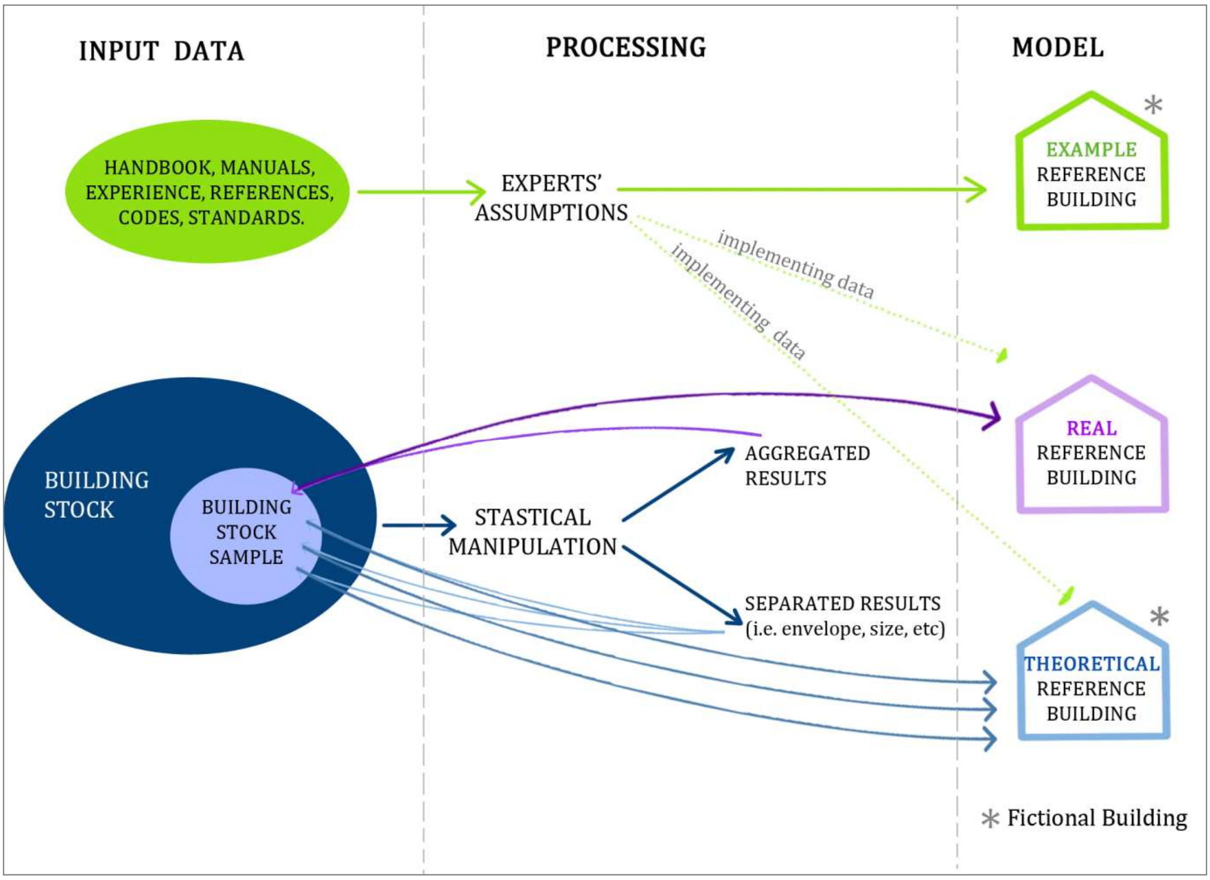

Figure 2 - General methodology for establishing Reference Building models

These methodologies can be applied to each of the four sub-sets mentioned previously. For instance it is possible to characterize the general geometry of a residential building as well as to indentify the main heating system as the most typical of that building category referring respectively to empirical data and to statistical analysis. Depending on the available data, it is possible to use just one of the above methodologies for all models (I, II and III) in a RB, or apply them differently to each model of the same RB.

This is the reason why in Figure 2 a dashed arrow goes from the experts' information to the Real and Theoretical RB models: for some of the sub-set of features that made a complete RB model, the statistical data may not be available and other sources should be used. This is typically the case of the features of the operation sub-set (e.g. internal gains, occupancy, etc), where reference to standards can avoid the uncertainty due to the real observations of the building stock or the lack of information. […]

As mentioned above, RBs can be exploited as a basis for analysing the energy saving potential by retrofitting national building stock. Paper I shows the first outcomes of the IEE TABULA project [45], that was a project within the European program "Intelligent Energy Europe" (IEE) with the participation of thirteen European countries. Its main objective was to create a harmonized structure of the European building typologies and to identify representative building types. This purpose has come from the need to assess the energy consumption of the national building stock and consequently to predict the impact of different energy efficiency measures in order to select effective retrofit strategies on the existing buildings. Analyzing the results of this project it has been possible to have a first approximate valuation of energy saving potential derived by the retrofitting of the European residential buildings stock. It was analyzed the residential building stock because it constitute the biggest segment of the EU's building stock and is responsible for the majority of the sector's energy consumption.

Starting from global statistics at national and regional level and from the corresponding available residential building samples divided in classes, some reference building types have been selected in order to obtain a relevant characterization of the analyzed buildings. These RBs were exploited as a basis for analysing the national housing sector of MSs participant to the project. The methodology provided by the European standards supporting the Energy Performance of Buildings Directive was applied for the evaluation of the energy demand of the selected building types and to assess the energy saving potential due to energy retrofit actions. In fact, for each reference building type two refurbishment measures were considered: a standard refurbishment through the application of measures commonly applied within the country; an advanced refurbishment through the introduction of measures that reflect the use of the best available technologies. Finally additional information about the number and the frequency of each specific building type had made possible the application of statistical models in order to estimate the overall energy performance, energy saving potentialities, carbon dioxide emissions reductions of the building stock at national level.

As general rule, it is noted that the standard refurbishment is associated with high relative percentage of energy saving: the energy saving due to a standard refurbishment is bigger than the saving variation between a standard refurbishment and an advanced refurbishment. Even with standard refurbishments, energy saving over 45% can be achieved. In fact, national building stock is often characterized by low energy performance and even the application of basic energy renovations may provide significant increases in energy performance and consequent reduction of CO_2 emissions. Thereby from an economic point of view it is more convenient to apply standard refurbishment measures at the national building stock than advanced ones that are the most expensive.

This kind of studies highlights the significant energy and, consequently, CO_2 emissions saving potential that is connected to the retrofit of existing buildings because of their very poor energy performances. Nevertheless, these fast analyses provide some basic guidelines but don't specify anything about which energy efficiency measures are the most cost-effective. Afterwards the EPBD recast has identified the cost-optimal analysis as the right tool to obtain this kind of information.

8 Factors affecting the taking up of retrofit measures

Despite the retrofit of existing buildings offers so high potential in terms of savings as described in the previous chapter, there are many reasons why investments in energy saving measures in buildings are often rejected or only partially realized. Numerous barriers that contrast the uptake of renovation measures have been identified. The main categories of barriers deal with financial factors, separation of expenditure and benefit, institutional and administrative factors, awareness, information and technical expertise. Furthermore applying retrofit measures to the existing building stock is determined by the decisions of a large number of people. As described in Chapter 6, there are millions of building owners and also very large numbers of decision makers, who decide what happens in buildings, and particularly in multi-family, commercial and public buildings. What is important for policy making is to better understand the factors that affect those decisions in order to design and implement policies that will more effectively promote energy efficiency investments and actions, and also to have clear indications from the European scientific community about what energy efficiency measures are cost-effective and incisive in order to hit the 2050 targets. Indeed existing buildings renovation on large scale requires policy guidance, financial assistance (with financial and/or fiscal instruments) and technical support for the implementation of energy efficiency measures

Financial factors

In simple economic terms, the fact that there is a large unexploited cost-effective potential for improving the buildings energy performance is evidence that consumers and investors are not ready to invest in energy saving. Undoubtedly, any investment in renovation requires money; consequently financial barriers are significant. Even though in most cases retrofit measures will be cost-effective over the long period with a positive net present value, the initial investment costs can be high and this is seen as an obstacle to consumer investment decisions. Lack of funds and inability to secure finance on acceptable terms is generally one of the most essential barriers to investing in energy efficiency measures. This applies at the level of the individual householder, businesses, social housing providers and the public sector, particularly in this period of credit crisis.

As analyzed above, since the low demolition rate the age of the European buildings stock is high; so the energy efficiency of the European buildings is inadequate. The consequent high investment cost necessary to improve energy performances and the annual limit on most incentives have the consequence that the refurbishments are spread over a long time period, which is a barrier to take up retrofit measures.

Indeed, many businesses don’t consider non-core investments that do not pay for themselves within 3-5 years. They give their priority to what are perceived as core investments in staff and equipment over energy costs, which (with the exception of energy intensive businesses) typically represent only a small fraction of business costs.

Furthermore, since for most households home energy bills account for 3-4% of disposable income, they represent a great concern and additional outlay for the home are support with difficulty. For householders, investments in energy saving measures have to battle with the latest electronic gadgets or a new kitchen or bathroom, which are not particularly cost-effective investments but are perceived as associated with higher social benefit. Indeed, many energy efficiency measures are not visible which makes them less attractive as investment options. The lack of attractiveness is sometimes reinforced by more generous financial incentives which, for example, are more readily available for PV systems compared to other energy efficiency measures.

If the financial subsidy associated with investing in energy savings measures was sufficiently considerable, householders, businesses and the public sector would have a higher propensity to undertake such investments. Hence it is important to institute financing mechanisms which try to ensure that the benefit from energy efficiency improvements are paid by those that benefit from them (e.g. recovering initial capital over 25 years through the energy bill). In this current period in which financial crisis is hitting all European countries, investing in energy efficiency measures has been verified that is a prudent path compared to many alternative forms of investment. Moreover it's fundamental to uptake buildings renovation measures also because investing in energy efficiency now offers some protection against increasing energy prices in the future.

Factors related with separation of expenditure and benefit

This is a particular and important financial barrier worth to separately present due to its influence in retrofit strategies. This is probably the most complex and long-standing obstacle relating to existing buildings, particularly in European countries where there is a high share of rental accommodation in the residential sector, but also because of the structure of occupancy in the non-residential sector. The problem derives from the fact that one person or organization owns a building and someone else uses it. For the owner, any investment has to bring a benefit. If it is a situation where the landlord pays the energy bills, also the taking up of an energy efficiency measure represents a benefit. However the most common situation is that where the energy efficiency measures have to be paid by the landlord and the energy bills has to be paid by the tenant. Furthermore, since the tenant does not own the facility, any investment in lowering energy bills has to be seen as financially advantageous for both actors. This often leads to an impasse with nothing happening, because nobody wants to spent money if he doesn't have a benefit. There are many examples where the party investing in a building may not be the party reaping the financial returns. It is the case where landlords investing in a property where tenants pay the energy bill; or where landlords' inability (through legislative restrictions or other reasons) to raise rents after a building renovation; or where stakeholders construct a new building or renovate an existing one in a moment in which the market prices do not reflect the energy performance of the building.

Institutional and administrative factors

There is a wide range of barriers related to institutional and administrative issues that have an effect on the rate and ambition of building stock renovation.

There is a great number of regulatory and planning barriers. These obstacles derive from the various degrees and speeds at which EU Directives, including the EPBD, have been implemented autonomously by regions within a Member State. European standards for buildings energy efficiency have been adopted more slowly than planned and those standards have not been adapted to national needs. Because of the delays, no common software for building energy efficiency calculations for designers and engineers was available. The case of Italy is symbolic of this trend; fragmentation, delay and gaps in the regulatory action of public planning have not allowed the public sector to be the driver for improved energy efficiency in buildings that instead it should be.

Various administrative obstacles exist where there are multiple owners and/or occupiers of buildings. It's noted that there is an unequal ability of owners to pay for renovations and some groups (e.g. pensioners) showed no interest in investment. Ownership and responsibility can be unclear, while it can be very difficult to agree on energy saving investments in multi-family residential buildings if many different property owners have to either approve a decision or make a financial contribution.

Factors related with awareness, information and technical expertise

There are many barriers relating to awareness, information and technical expertise. Deep renovation projects ask decision that can only work if the right energy expert advice to take action is available and that the energy efficiency service industries are capable of delivering those measures and finally that sufficient satisfaction levels can be guaranteed for the consumer. Without this right combination of necessary conditions, the consumer usually only choose to undertake renovation measures when it is absolutely necessary, as is the case for the replacement of system components when they break down. Moreover, current Energy Service Companies (ESCOs) are not designed to deliver deep renovation projects because they are discouraged by complex process, small project size and multi-stakeholder involvement.

In spite of all the years of experience and the public campaigns, nowadays awareness of cost-effective energy saving opportunities is still low. Rapidly advancing in technological development complicate the question because it can be difficult even for professionals to stay updated with them. Due to miscommunication issues, in some cases consumers are not aware of or do not fully comprehend the effectiveness of specific technologies. Moreover, too often the focus is on individual products and not on entire holistic solutions. This may lead to scepticism over implementing a technology especially if two or more professionals give conflicting advice as to the best way to uptake retrofit measures.

Although there is a general certainty that energy saving is a good thing, there remains a lack of understanding of the energy, cost and carbon savings from different measures. This leads to the fact that few concrete actions are performed to achieve the 2050 targets. For example, householders think that they are helping the planet by installing compact fluorescent lamps (CFLs), without realizing that the real problem in residential buildings is the lack of thermal insulation or of systems efficiency. The distorted notion that the CFLs installation helps to save the planet may also be reinforced by energy supply companies which, in the past, had provided free or low cost CFLs. This behavior has meant that focusing on less priority and effective measures, which are also less expensive.

Another obstacle is that lack of knowledge and competence exists in both the contractor market responsible for effective installation of energy saving measures, as well as in professional services, with few architects and engineers that know what the more appropriate retrofit actions are.

Factors related with construction industry and technical and organisational issues

Nowadays the construction sector is unprepared to face a strong demand for low energy buildings renovations. Consequently, if conditions were to change suddenly and demand for low energy renovations increased rapidly there would inevitably be issues regarding shortages of materials and systems components and lack of full-formed human resources. Indeed most new construction materials and their related construction techniques go usually through a long period of testing and development before they gain approval for widespread application in new buildings and in low energy renovations. Another effect of a significant increase in demand could be the rapid growth of contractors offering to undertake low energy renovation work, which if not appropriately regulated or managed, could give rise to poor workmanship and even some serious short term failures.

Another barrier that has yet to emerge is related with the practical organization of the renovation works. The problem is constituted by what happens to the building occupiers when a major renovation is being undertaken. In most cases deep renovation can only be implemented in a vacant building which will involve practical and financial barriers associated with re-locating the occupant for the period of the retrofit.

9 Cost-optimal methodology

Given the many barriers to the spread of the application of retrofit measures on a large scale, it is necessary to use more detailed analyses in order to give precise and solid information to the stakeholders and to the policymakers. The results derived from these detailed analyses are expected to give some information also about which energy efficiency measures are the most cost-effective for retrofitting a specific RB; this is the data that didn't resulted from the fast analyses of scenarios described in Chapter 7. The European Commission established that the cost-optimal analysis responds to this need. In particular, the EPBD recast included a provision that national ambitious minimum energy performance requirements should be set with the view to achieving cost-optimal levels by applying a harmonized calculation methodology [46]. The Commission requests MSs to use and apply this methodology to calculate the required cost-optimal levels for their specific country and compare them with the national requirements they have set in their national building regulations. A cost-optimal level is defined as the energy performance level which leads to the lowest cost during the estimated economic lifecycle. It must be calculated in accordance with a comparative methodology framework that is based on the global cost method. Cost-optimal analysis is born with the aim of individualizing minimum energy performance requirements and those energy efficiency measures that are energy-effective and that have to be also cost-effective; its purpose is being a support decision tool that must however be coupled with political, financial/fiscal and communicational instruments in order to overcome the numerous pinpoint barriers.

Hereinafter, a description of cost-optimal methodology is reported. In particular, for each step that constitutes the analysis the elements of complexity are highlighted.

The comparative methodology framework (Figure 14) shall require Member States to:

- step 1: define Reference Buildings that are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions; the reference buildings shall cover residential and non-residential buildings, both new and existing ones;

- step 2: define energy efficiency measures (EEMs) to be assessed for the Reference Building; these may be measures for individual buildings as a whole, for individual building elements, or for a combination of building elements;

- step 3: assess the final and primary energy need of the Reference Building and the Reference Building with the defined energy efficiency measures applied;

- step 4: calculate the costs of the energy efficiency measures during the expected economic lifecycle applied to the Reference Building, according with the European Standard 15459:2008 [22].

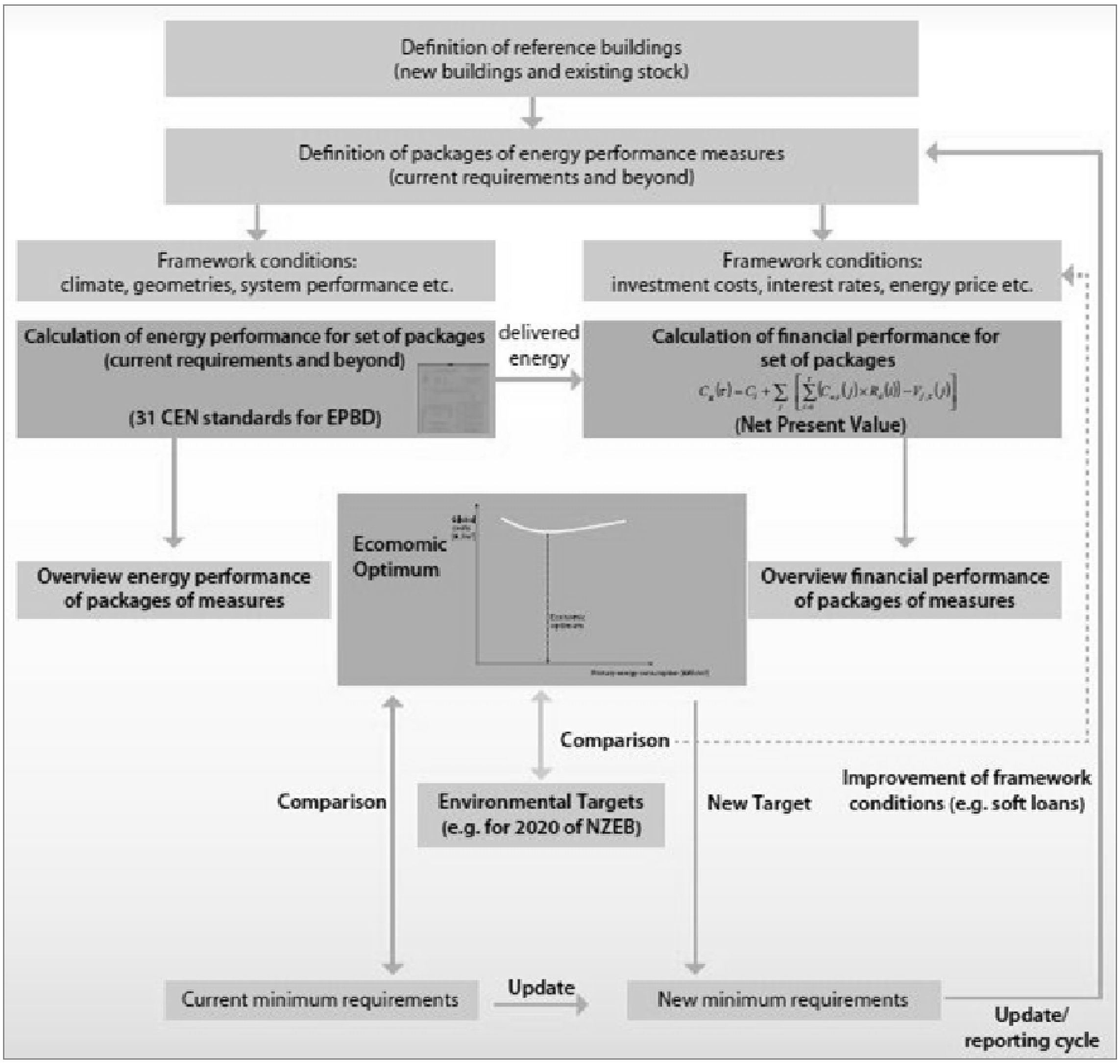

Figure 14. The flowchart of cost-optimal methodology elaborated by BPIE [47]

The first step of the methodology regards the definition of Reference Buildings that has been treated extensively in the previous chapter. The choice of appropriate and representative Reference Buildings is fundamental for the accurate estimation of the global savings referred to the whole national buildings stock.

The second step consists in the definition of the energy efficiency measures [48]. An EEM can be a single measure or constitute a package of measures. Measures acting on one system can affect the energy performance of another system. For example, the insulation level of the envelope affects the capacity and dimensions of the building systems. This interaction between different measures has to be addressed when defining packages/variants. It is therefore recommended that measures be combined in packages of measures and/or variants, since meaningful combinations of measures can create synergy effects that lead to better results, in terms of costs and energy performance, than single measures. Variants are defined for the purpose of the delegated act as a “global result and description of a full set of measures/packages applied to a building that can be composed of a combination of measures on the building envelope, passive techniques, measures on building systems and/or measures based on renewable energy sources”[21].

Despite it might therefore be difficult to exactly draw the line between a package of measures and a variant, it is clear that the variant refers to complete sets of solutions needed to fulfill existing high performance buildings etc. Variants to be considered can include well-established concepts that are used to construct (e.g. a Passive house, a 3-litre house) or any other set of measures that has been established to achieve very high energy efficiency. It should however be noted that the purpose of the cost-optimal methodology is to ensure a fair competition between different technologies and is not confined to calculating the global cost of already established and proven packages/variants. Indeed, the more packages/variants are used the more accurate the calculated optimum of the achievable performance will be. Therefore, the determination of the finally selected packages/variants consists in an iterative process in which a first calculation of selected packages/variants reveals the need to add further packages.

In the definition of EEMs a first element of complexity of cost-optimal analysis resides. Indeed, one of the main challenges of the calculation methodology is to ensure that on the one hand all measures with a possible impact on the building primary energy are considered; at the same time as on the other hand the calculation exercise remains manageable and proportionate. Applying several variants to several Reference Buildings can quickly result in thousands of calculations. In particular, EPBD Guidelines [21] establish that the number calculated and applied to each Reference Building should certainly not be lower than 10 packages/variants plus the reference case. Various techniques can be used to limit the number of calculations. One is to design the database of energy efficiency measures as a matrix of measures which rules out mutually exclusive technologies so that the number of calculations is minimized. The possible energy efficiency measures and measures based on renewable energy sources can be presented in a matrix and unfeasible combinations eliminated. Stochastic methods for energy performance calculation can be used effectively for presenting the effects of particular measures and their combinations. From that, a limited number of combinations of most promising measures can be derived. Moreover, a discriminating factor for the choice of EEMs is the technical feasibility. Finally, another element of complexity in the choice of EEMs is that this choice has to be guided also by some comfort-related issues that are not directly translate in terms of energy and emissions savings in the cost-optimal analysis. For example, in case of a serious violation of indoor air quality or other aspects, a measure might also be excluded; or the choice of construction materials might be driven by the basic European requirements for construction products [49] or by the guidelines of green-building rating systems. Therefore who makes the cost-optimal analysis, and in particular the choice of EEMs, must be an expert in the field of building construction, such as an architect or an engineer.

The third step of the methodology consists in the assessment of final energy needs of the RB and the RB with the selected EEMs applied. The objective of the calculation procedure is to determine the annual overall energy use in terms of primary energy, which includes energy use for heating, cooling, ventilation, hot water and lighting. According to the EPBD Guidelines [21], electricity for appliances and plug loads may be included in order to have more accurate results (especially in the case of these buildings in which the appliances use is relevant, such as in offices), but this is not mandatory. The 31 CEN Standards that have been developed for the EPBD provide possible rules for calculating the amount of energy. Under Annex I to the Regulation [14], the calculation of energy performance involves first the calculation of final energy needs for heating and cooling, then the final energy needs for all energy uses, and thirdly the primary energy use. The direction of the calculation is from the needs to the sources, from the building energy needs to the primary energy. According to the EPBD Guidelines [21] for the purpose of the cost-optimal methodology, on-site energy production using locally available renewable energy sources is not considered part of delivered energy. As a result, the RES-based active technologies enter into direct competition with demand-side solutions, which is in line with the purpose and intention of the cost-optimal calculation to identify the solution that represents the least global costs without discriminating against or favoring a certain technology. This would lead to a situation where certain RES-based measures show better cost efficiency than some energy demand reduction measures. If a Member State would want to clearly avoid the risk that active RES installations replace energy demand reduction measures, the calculation of cost-optimality could be done in steps gradually expanding the system boundary to the four levels given in Figure 15; energy need, energy use, delivered energy and primary energy. With this, it will become clear how each measure/package of measures contributes to the buildings energy supply in terms of costs and energy.

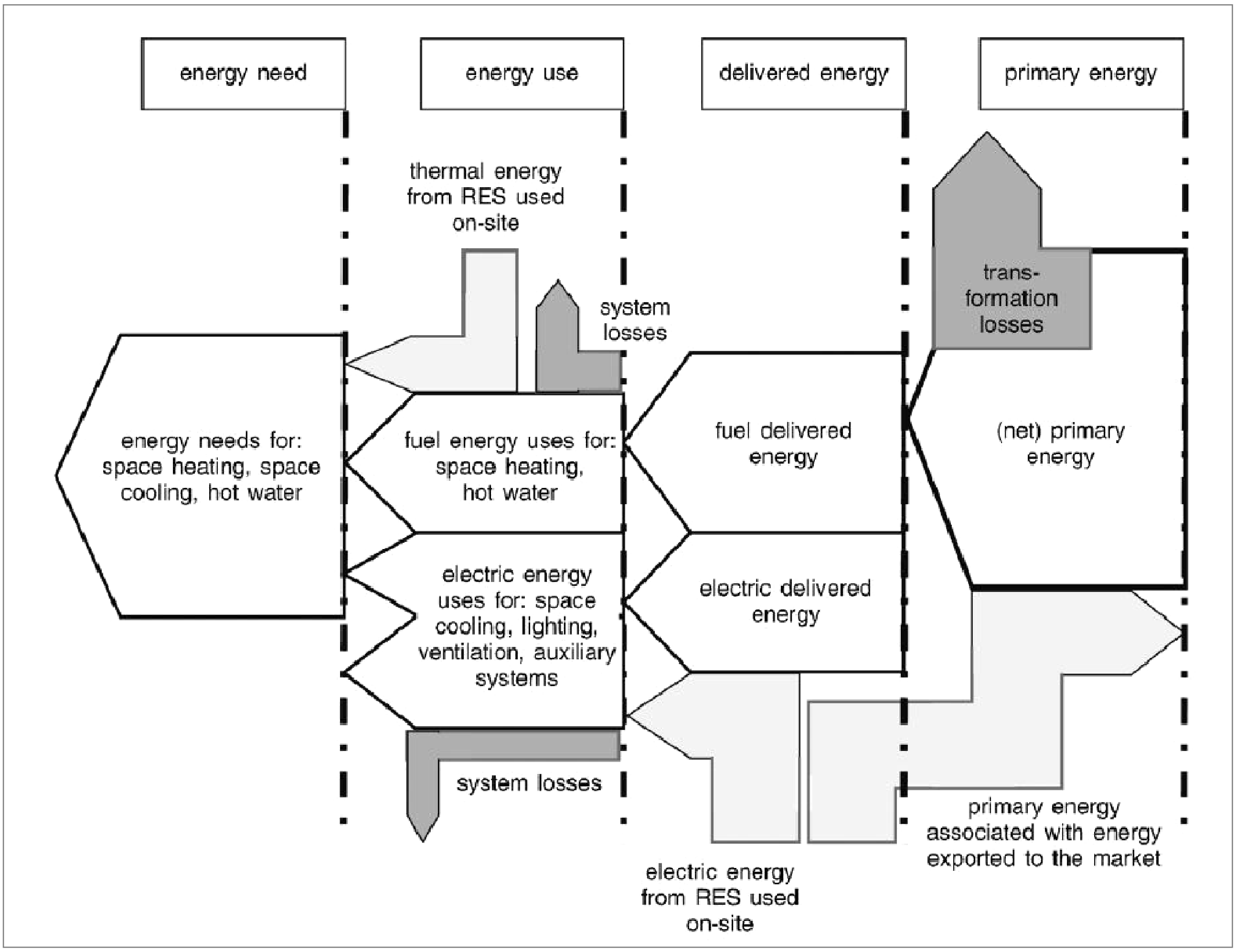

Figure 15. Schematic illustration of the calculation scheme for energy taken from EPBD Guidelines [21]

In detail, the methodology for the calculation of energy performances consists in the following phases.

- Calculation of the building net thermal energy needs. The energy need in winter is calculated as energy losses via the envelope and ventilation minus the internal gains (from appliances, lighting systems and occupancy) and solar energy gains.

- Subtraction from the net thermal energy needs of the thermal energy from RES generated and used on-site (e.g. from solar collectors).

- Calculation of the energy uses for each end-use (space heating and cooling, hot water, lighting, ventilation) and for each energy carrier (electricity, fuel) taking into account the characteristics (seasonal efficiencies) of generation, distribution, emission and control systems.

- Subtraction from electricity use of the electricity from RES, generated and used on-site (e.g. from PV panels).

- Calculation of the delivered energy for each energy carrier as sum of energy uses (not covered by RES).

- Calculation of the primary energy associated with the delivered energy, using national conversion factors.

- Calculation of primary energy associated with energy exported to the market (e.g. generated by RES or co-generators on-site).

- Calculation of primary energy as the difference between the two previous calculated amounts (primary energy associated with the delivered energy - primary energy associated with energy exported to the market).

There are three different possible calculation methods: a monthly quasi-steady state calculation method, a simple hourly calculation method and a detailed simulation method. This last method is the more accurate, but it is also the more complex and incorporates several disciplines to obtain a precise finish product. Indeed, making a precise energy model capable of estimating the building energy uses is difficult because of the assumptions that have to be made and evaluated through the modelling process. Therefore learning about energy modelling means more than simply constructing a building in a software program. It means being familiar with ASHRAE, for example, and other resources, and working with the HVAC engineer and designer, to make good assumptions that result in an accurate energy model. But they always remain modeller assumptions [52-56].

In Paper II is presented a work on simulation model in which the manipulation of input data is exploited in order to send to convergence the results (in terms of primary energy for space heating and cooling) of a steady-state model and these of a dynamic model. This work is reported in order to demonstrate how the input data assumptions in a dynamic model influence the output obtained (e.g. in the case of energy need for space heating is registered a difference of 16%).

The last step of the cost-optimal methodology consists in the calculation of the global cost of the different packages/variants in order to establish which of them has the lowest global cost and, consequently, represents the cost-optimal level. The global cost method considers, for each EEM, the initial investment, the sum of the annual costs for every year and the final value, all with reference to the starting year of the calculation period. In Figure 16 the cost categorisation according to the framework methodology is depicted.

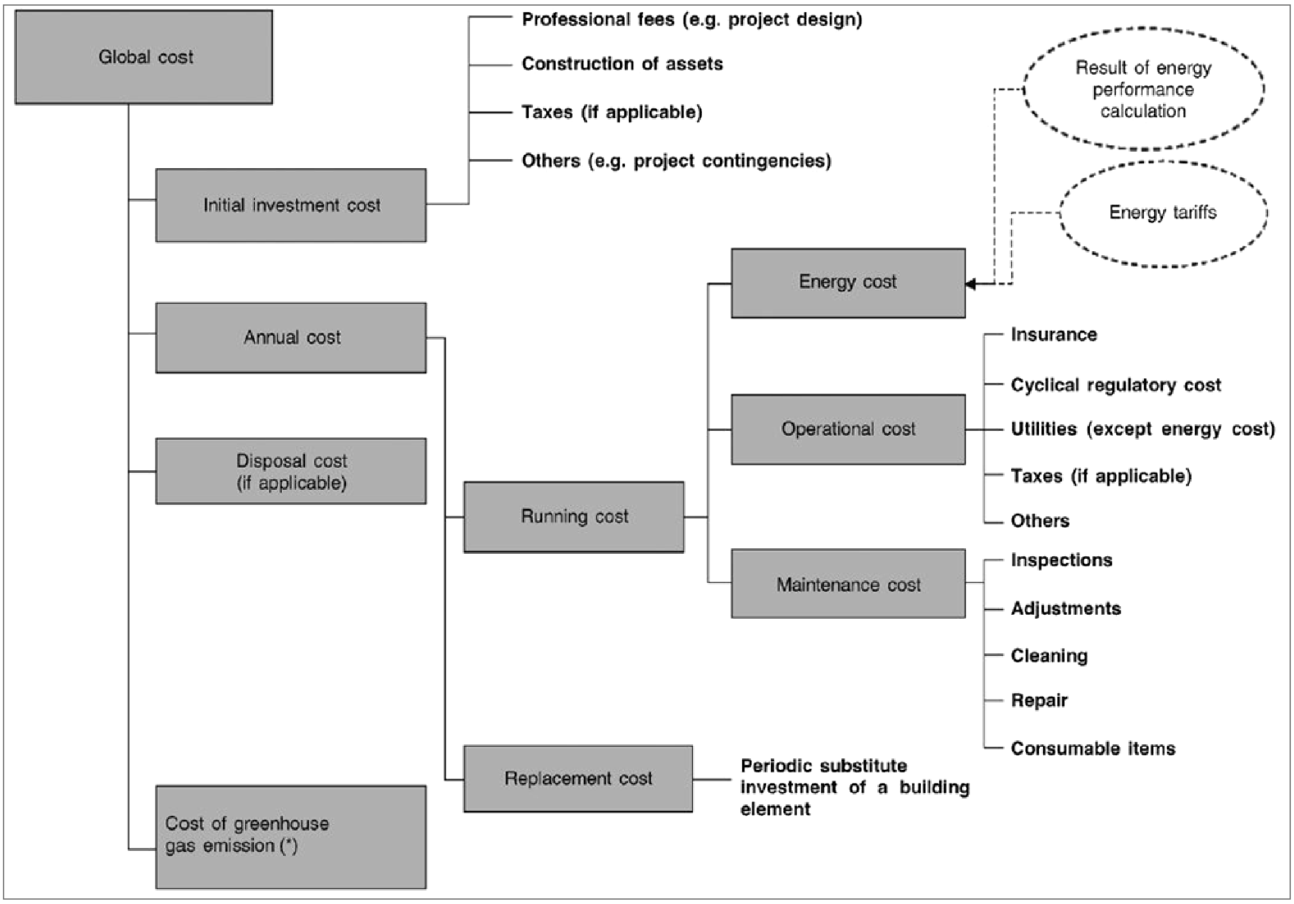

Figure 16. The costs categorization according to the framework methodology [21]

The methodology takes into account the investment costs of measures that are related to the energy performance of a building. These include investments related to the efficiency of the building envelope (e. g. measures to reduce the thermal transmittance of building elements, low-energy windows and doors, measures related to air tightness, etc.), investments in energy supply systems for space heating and cooling, for domestic hot water, for lighting, for ventilation, for appliances. Investments comprise also the installation costs of systems and components.

Annual costs include costs for energy carriers that cover the demand for space heating and cooling, ventilation, domestic hot water, lighting and appliances, including auxiliary energy. Income from produced energy (e.g. photovoltaic systems) can be subtracted from the costs for energy carriers. They also include operational costs, maintenance costs and costs for periodic replacement. Information about systems maintenance costs are reported in European Standard 15459:2008 [22].

To ensure a lifecycle perspective, final values are taken into consideration for components with lifetimes that are longer than the chosen calculation period. For components that have a shorter lifetime than the chosen calculation period, the replacement of the component needs to be taken into account. The lifetime of measures should be set according to the information set out in the above mentioned European Standard [22].

EPBD Guidelines [21] states that cost data must be market-based (e.g. obtained by market analysis) and coherent as regards location and time for the investment costs, running costs, energy costs and if applicable disposal costs. Cost data need to be gathered from one of these sources; evaluation of recent construction projects, analysis of standard offers of construction companies (not necessarily related to implemented construction projects) and use of existing cost databases which have been derived from market-based data gathering.

For the calculation of the macroeconomic cost optimum (perspective of societal as a whole), the category of global costs is to be expanded by a new category, the cost of greenhouse gas emissions defined as the monetary value of environmental damage caused by CO_2 emissions related to the energy consumption in a building. Moreover, it should be noted that the global cost methodology as prescribed in the EPBD Guidelines does not include costs other than energy (e.g. water costs) as it follows the scope of Directive 2010/31/EU. The global cost concept is also not fully in line with a complete life cycle assessment (LCA) that would take into account all environmental impacts throughout the lifecycle including so-called grey energy and energy embodied in construction materials.

In Paper III a precise and complete description of a global cost calculation is reported. The computation has been carried out according to the European Standard 15459:2008 [22] and has been applied to compare different building envelope technologies. The global cost calculation described in this work is then utilized in the following Papers IV and V that described two different cost-optimal analyses the results of which are examined in the next chapter.

Based on the calculations of primary energy use (step 3) and global costs (step 4) associated with the different packages/variants of measures (step 2) assessed for the defined Reference Building (step 1), the cost-optimal graphs can be drawn. This describe primary energy use (x-axis: kWh/(m^2 year)) and global costs (y-axis: €/m^2) of the different solutions. A measure or package/variant of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result, taken over the expected life of the measure. The cost-optimal result represents that retrofit action or combination of actions that minimized the global cost. From the number of EEMs assessed, a specific cost curve can be developed; it represents the lower border of the area marked by the data points of the different EEMs (Figure 17). The lowest point of the curve represents the economic optimum for a combination of packages. Its position on the x-axis automatically gives the cost-optimal level of minimum energy performance requirements.

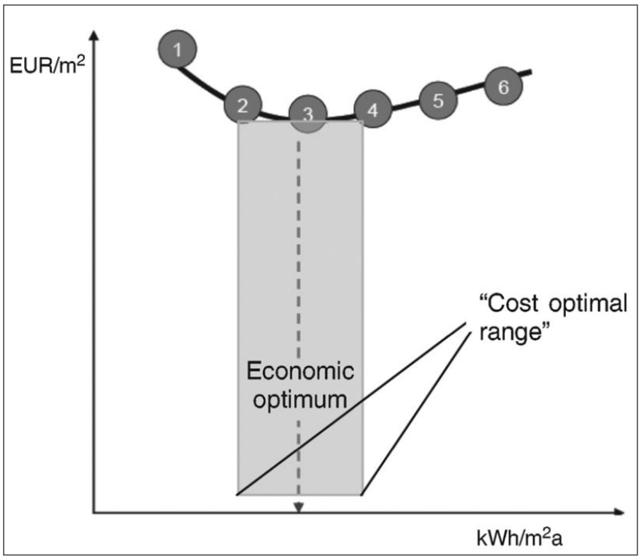

Figure 17. Cost-optimal curve and cost-optimal level of minimum energy performance requirements [21]

The current requirements at Member State level need to be compared to the calculated cost-optimal level. The difference between the calculated cost-optimal levels of minimum performance requirements and those in force should be calculated as the difference between the average of all the minimum energy performance requirements in force and the average of all the calculated cost-optimal levels resulting from the variants applied to all the comparable reference buildings and building types used. If this difference shows that the current minimum energy performance requirements are significantly less efficient (exceeding 15%) than the cost-optimal ones, Member States are required to justify this gap in writing to the European Commission. If the gap is not justifiable, a plan for reducing it has to be drawn up [21].

10 A critical review of cost-optimal analysis

In Papers IV and V two complete cost-optimal analyses are described. The studied Reference Buildings are an existing residential building (Paper IV) and an existing office (Paper V), both customized to the Italian contest. In the two papers the cost-optimal analyses are described in detail. Following in this chapter, an examination and a critical review about their results are reported in order to test their completeness, especially in terms of information reported on the global cost graph, and robustness.

In both two studies, the global cost method was applied to the RB in order to assess the cost-optimal levels. In detail, different packages of energy efficiency measures, which consist in the implementation of envelope thermal insulation and the improvement of systems efficiency, were considered. Moreover, in both cases, the utilization of renewable energy sources was taken into account with the installation of PV system on buildings roof. Then, the energy consumptions of the RBs and the impact of the EEMs were assessed. Finally, the costs of the different packages were estimated, according to the European Standard EN 15459:2008 [22], in order to establish which of them has the lowest global cost and, consequently, represents the cost-optimal level. In these two cases, the cost-optimal analysis was used in order to have some information about which EEMs are the most cost-effective, and it was not specifically aimed to identify minimum energy performance requirements that is the scope for which it was born. After the analysis phase, in order to find the cost-optimal level, the primary energy consumption (x-axis) was plotted versus the global cost (y-axis). Both quantities are divided per the net conditioned floor area. From the variety of specific results, a cost curve can be derived. The lowest part of the curve represents the economic optimum for a combination of EEMs. The Figure 18 and Figure 19 show the results of the cost-optimal analysis for the residential building and the office respectively; a red vertical line in correspondence to the RB shows the maximum possible energy consumption. The global cost associated to RB consists in costs necessary to keep it as it is for the next 30 years (that constituted the calculation period).

In both graph a great results scattering is highlighted. This makes difficult to draw the trend of the dotted broken line that represents the cost curve, the minimum of which may be considered the cost-optimal level. In order to simplify this action a great number of energy efficiency measures have to be studied. However the analyses here presented are not parametric, but are characterized by the use of dynamic simulation in order to accurately estimate the energy demand for heating, cooling, electric lighting and appliances, and electricity from renewable sources. Given the use of dynamic simulation and the inherent calculation times, a study based on a limited amount of technically feasible packages of energy efficiency measures, rather than a parametric study, is practicable. Therefore it’s important to underline in each cost-optimal analysis that the drawn dotted broken line represents the cost curve of this specific set of examined EEMs.

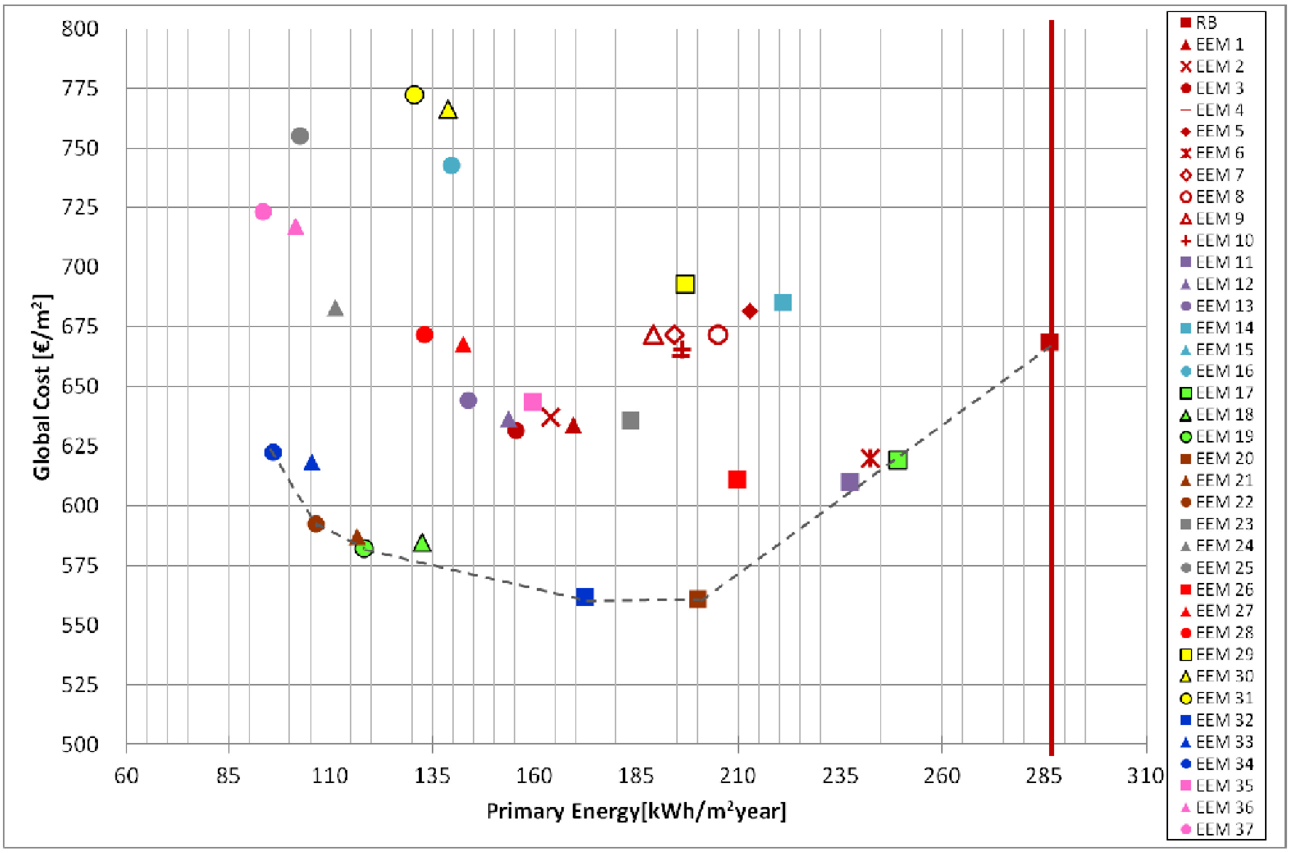

Figure 18. Global cost graph for the residential existing building

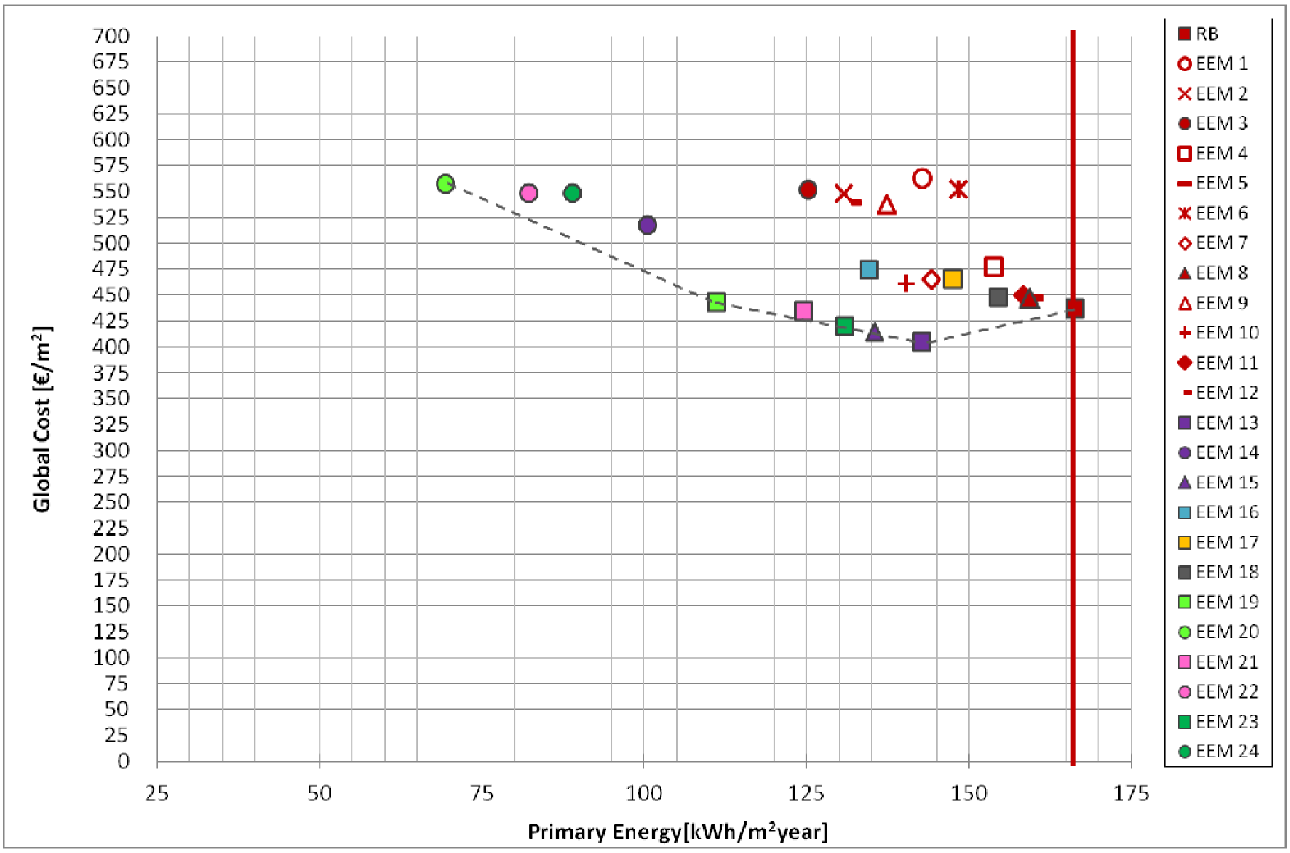

Figure 19. Global cost graph for the existing office

In these graphs cost-effective and cost-optimal EEMs are reported. The concepts of cost-efficiency and cost-optimality are related, but different. Cost-optimality is a special case of cost effectiveness. A measure or package of measures is cost-effective when the cost of implementation is lower than the value of the benefits that result over the expected life of the measure. Both are based on comparing the costs and (priced) savings of a potential retrofit action. Future costs and savings are discounted to the investment year. The cost-optimal result is that retrofit action or combination of actions that minimized the global cost. In reference to the graphs in the Figures 18 and 19 all the EEMs that have a global cost minor than RB one are cost-effective (for the particular set of EEMS studied in the calculation); in Figure 18 EEMs 20 and 32 represent the cost-optimal for these particular set of analyzed EEMs; in Figure 19 the optimality correspond to EEM 13. Cost-optimality is relatively easy to determine for single measures operating in well-defined conditions (for example, the optimal insulation thickness for an external wall). It is a considerably more difficult process for a complete building, and even more so for combinations of buildings such as those of a national building stock.

Cost-effectiveness is related with the concept of payback period that it is implicitly represented in global cost graph. Payback period in capital budgeting refers to the period of time required for the return on an investment to repay the sum of the original investments. The time value of money is not taken into account. Payback period measures how long something takes to pay for itself; shorter payback periods are preferable to longer payback periods. Despite of some recognized limitations payback period is widely utilized because of its ease of use. Analyzing, for example, the graph of Figure 19 and the Table 3 it’s noted that the EEMs with the lowest payback period (minor than 11 years) are the same that have the lowest global cost, minor than that of RB (e.g. EEM 13, 15, 21, 23). For this specific study payback period is calculated considering investment cost for building envelope and systems, and cost savings of natural gas and electricity; for this last one feed-in tariff (for selling and buying) and incentive for the electricity consumed on site are included in the estimation.

	EEM 1	EEM 2	EEM 3	EEM 4	EEM 5	EEM 6	EEM 7	EEM 8
Payback Period [year]	106.2	77.1	70.3	99.1	41.5	124.9	64.5	38.7
	EEM 9	EEM 10	EEM 11	EEM 12	EEM 13	EEM 14	EEM 15	EEM 16
Payback Period [year]	85.2	55.1	40.4	75.6	0.7	46.2	10.4	17.2
	EEM 17	EEM 18	EEM 19	EEM 20	EEM 21	EEM 22	EEM 23	EEM 24
Payback Period [year]	17.7	14.4	12.4	33.6	10.7	37.4	7.2	39

Table 3. Payback period of different energy efficiency measures calculated for the existing office

The global cost represents a single value associated to a specific EEM that encloses within it many cost items (investment, replacement, etc.); this makes it easy to compare different EEMs. However it gives for each EEM no information about the single cost items and consequently it’s no possible a comparison between these one. In order to have this kind of data it is necessary to couple global cost with another graph, like this reported in Figure 20 for the existing office. In this graph a breakdown analysis of cost items is shown. In detail, there are reported investment cost related to the envelope and to the systems, maintenance costs, replacement costs (in which final value is also considered, with a minus sign) and energy costs (in which there is also the subsidy for the electricity consumed on site and the feed-in tariff for the electricity exported on grid, with a minus sign), all with reference to the starting year of the calculation period (that is equal to investment year). Obviously, the identification of which EEM is the most cost-effective coincides with that reported in the global cost graph (EEM13). The breakdown analysis highlights that heavy retrofit measures on the building envelope (see Paper V) with their high investment costs greatly influence global cost. This is evident also if investment cost (x-axis: €/m^2) is plotted versus global cost (y-axis: €/m^2) as in Figure 21. Indeed, all EEMs that are collocated in the high part of the graph on the right represent deep retrofit action concerning building envelope (see Paper V).

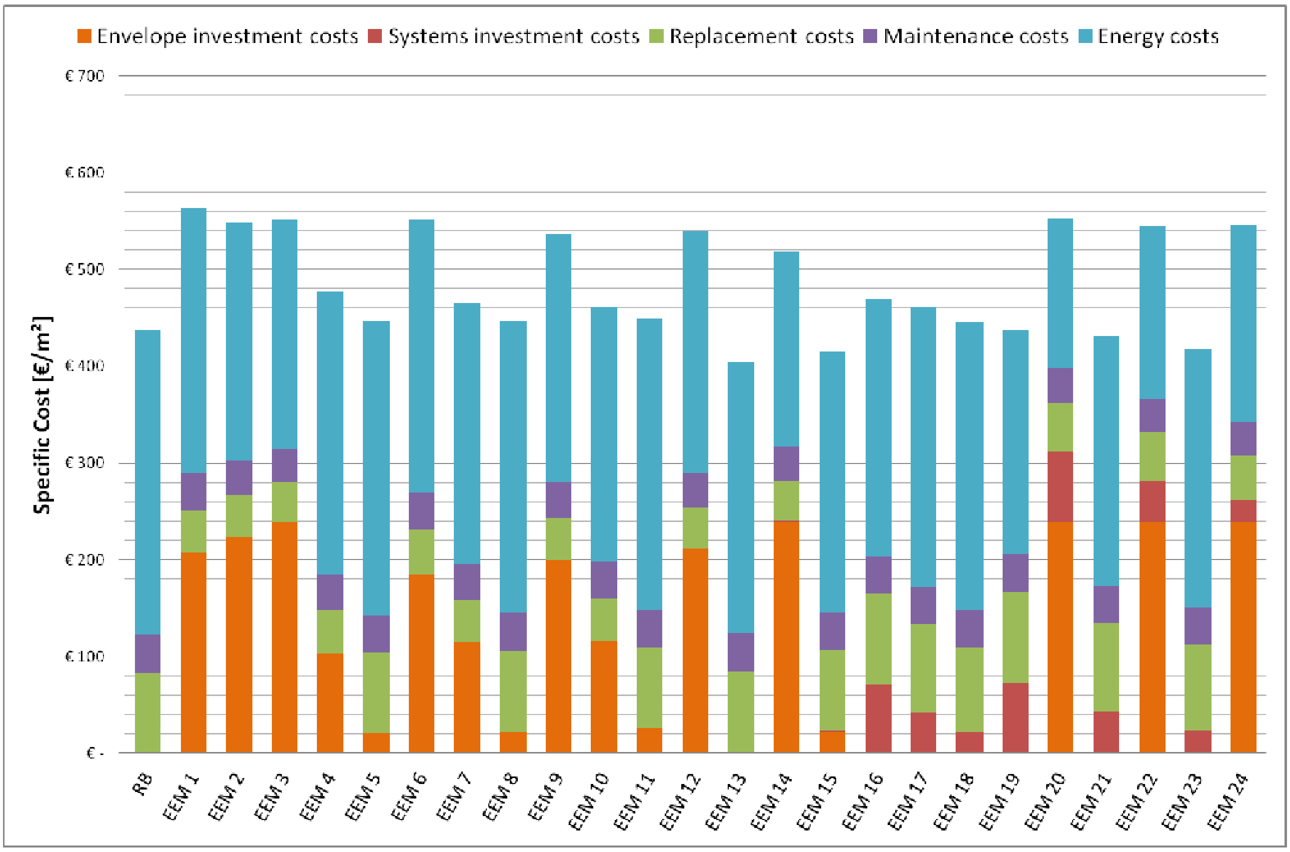

Figure 20. Costs breakdown analysis for RB and different EEMs for the existing office

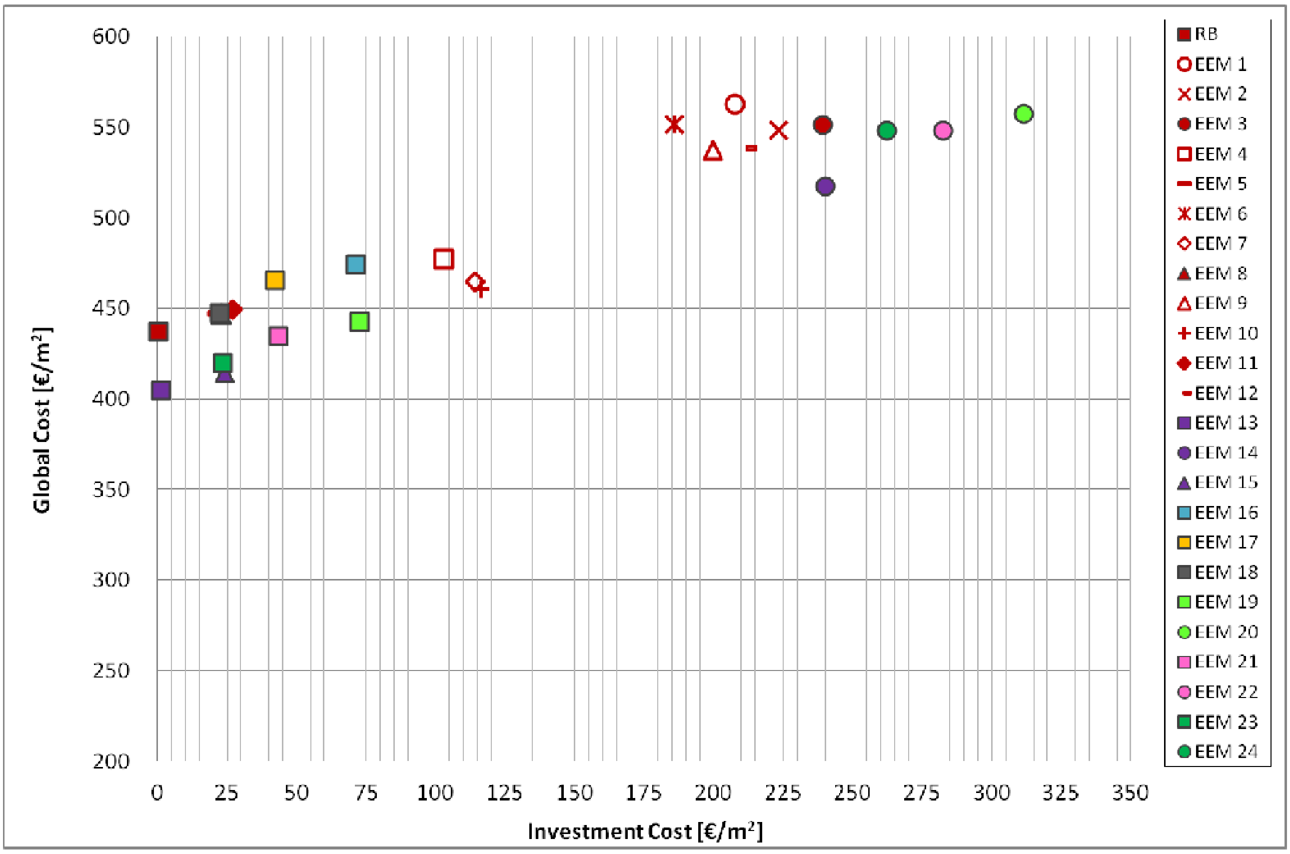

Figure 21. Global cost vs investment cost for existing office

Moreover, it is interesting to have information about what is the cost of the kWh of saved energy. This data is not reported in the global cost graph. Therefore another graph is necessary; an example is reported in Figure 22. Saved primary energy (x-axis: kWh/(m^2 year)) is plotted versus cost of one kWh of saved primary energy (y-axis: €/kWh) for the different EEMs. The cost of kWh includes the EEMs investment cost for envelope and systems improvement.

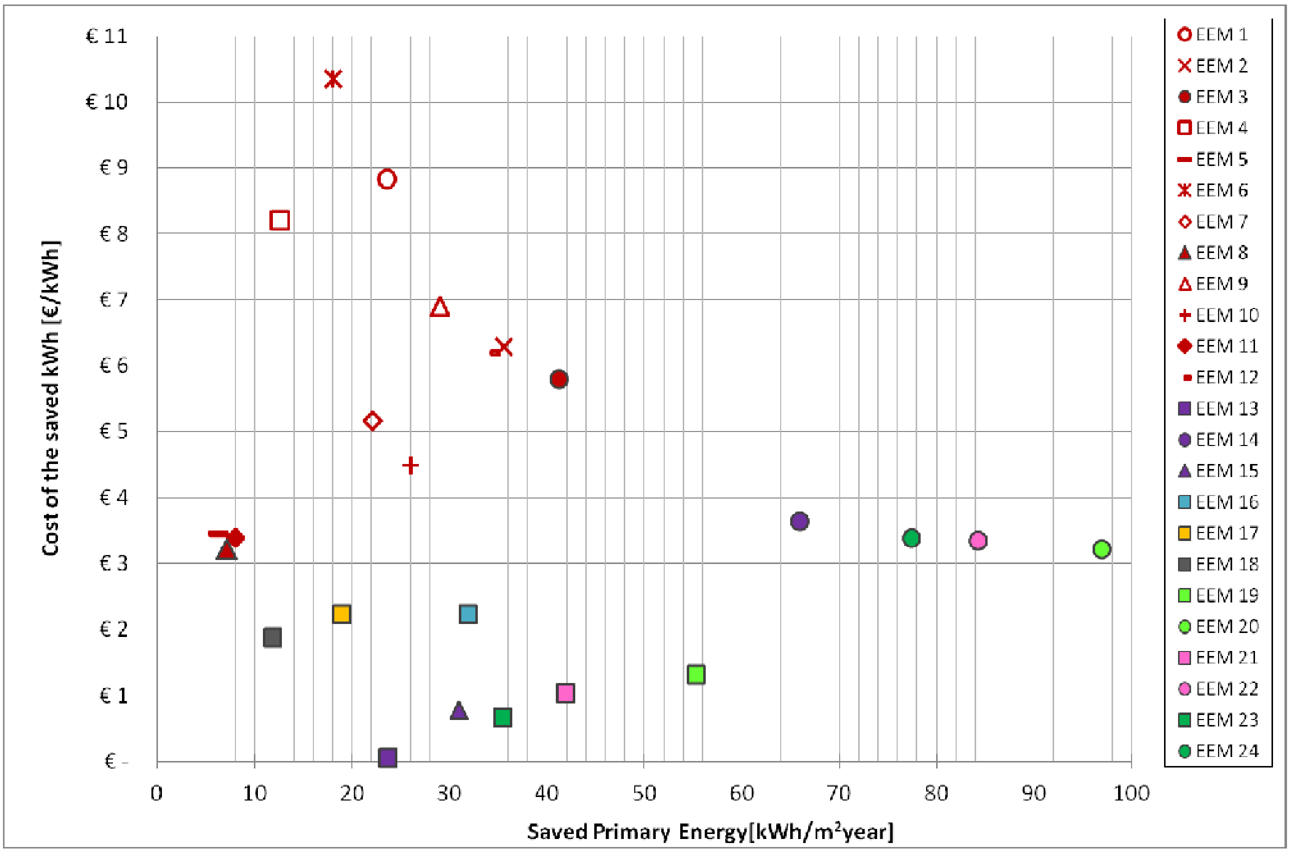

Figure 22. Cost of the saved kWh in function of saved primary energy for the existing office

In a graph like this of global cost there is no information about the achievement of 2020 targets. Analyzing the two global cost graphs of Figures 18 and 19, it may be useful to add a vertical line (in green) in correspondence of a primary energy saving of 20% that is one of the 2020 target. Only the EEMs that are on the left of this line hit the target of 20% of energy saving in reference to RB; it is clear that these EEMs don't correspond with the cost-optimal level in the case of existing office (Figure 24), unlike the case of residential building (Figure 23).

On current implementation trends by Member States it is clear that our saving objective by 2020 is in serious danger of not being met; the first hand information on the evolvement and the implementation of existing building stock renovation suggests that the energy saving potential is not being realized fast enough. Consequently, retrofit measures that are taking up now must allow to save a quantity of primary energy equal to 30% [2]. Afterwards, on the graph of Figures 23 and 24 a grey vertical line in correspondence of the target of 30% of energy saving (in reference to RB) has been drawn. In the case of residential building EEMs that represents the cost-optimality hit also this more restrictive target. In the case of office the EEM that corresponds to cost-optimal level doesn't hit neither target.

In this way the graph is divided in three areas that identify three different types of investors with dissimilar possibilities in terms of capital to invest in energy retrofitting. "Green investors" are those ones that put money in retrofit measures that allow primary energy savings of 30% or more; often these retrofit actions are quite expensive and consequently this type of investors have at their disposal large amounts of capital.

“Wise investors” are those that invest in retrofit measures that permit restrained energy savings (almost 20%); because of their not high capital disposal they put their money in the most cost-effective measures. “Unconscious investors” are those that because of their not awareness of which renovation actions are the most suitable invest their money in some retrofit measures that required often low capital and that are not energy-effective. In the case of residential building, EEMs which are cost-optimal are in the field of green investors that in this way can leverage their high capital disposal to apply those EEMs as many buildings as possible. In the case of office, even if investors put their capital in the EEM that correspond to cost-optimality, they don’t hit energy saving target wasting their money and for this reason they may be defined “unconscious”.

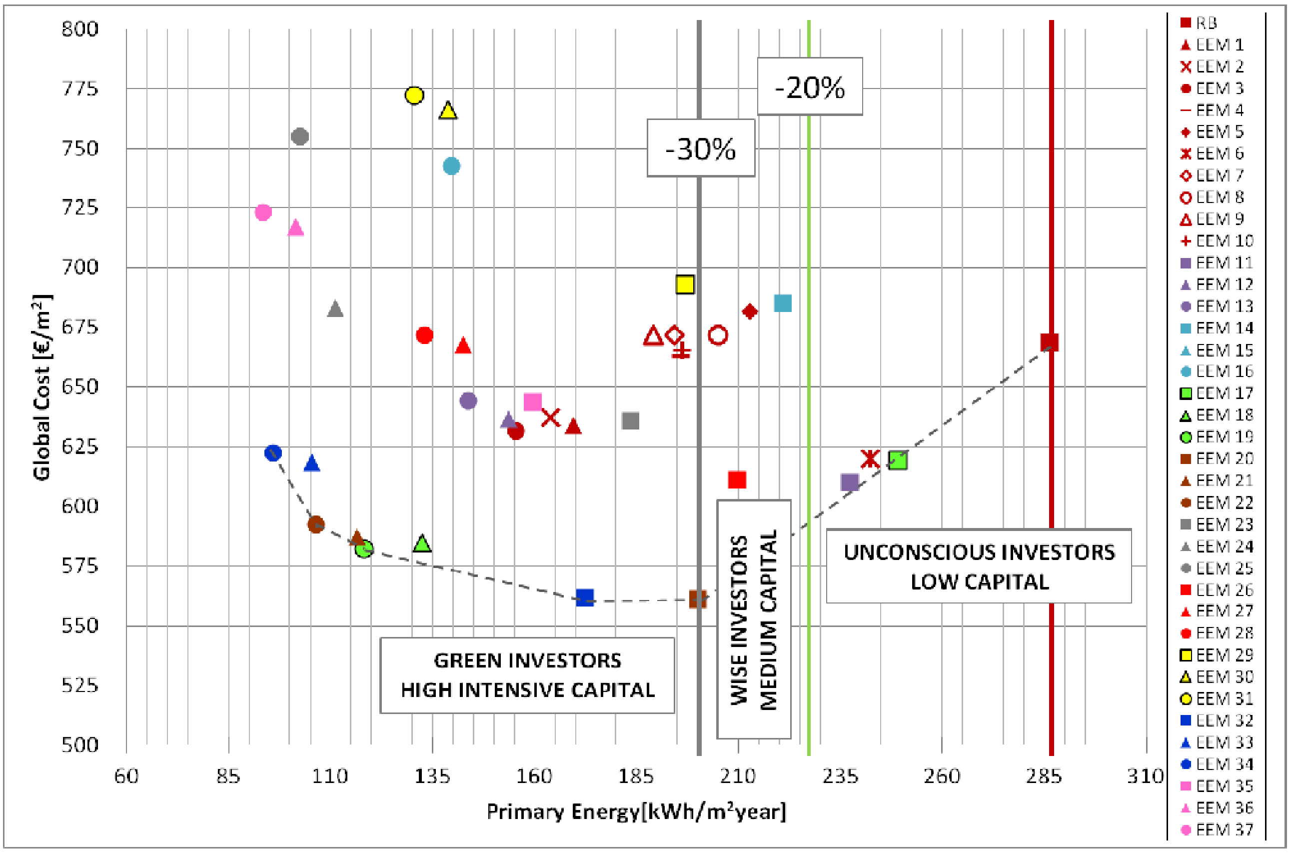

Figure 23. Primary energy saving target of 2020 on the global cost graph for the existing residential building

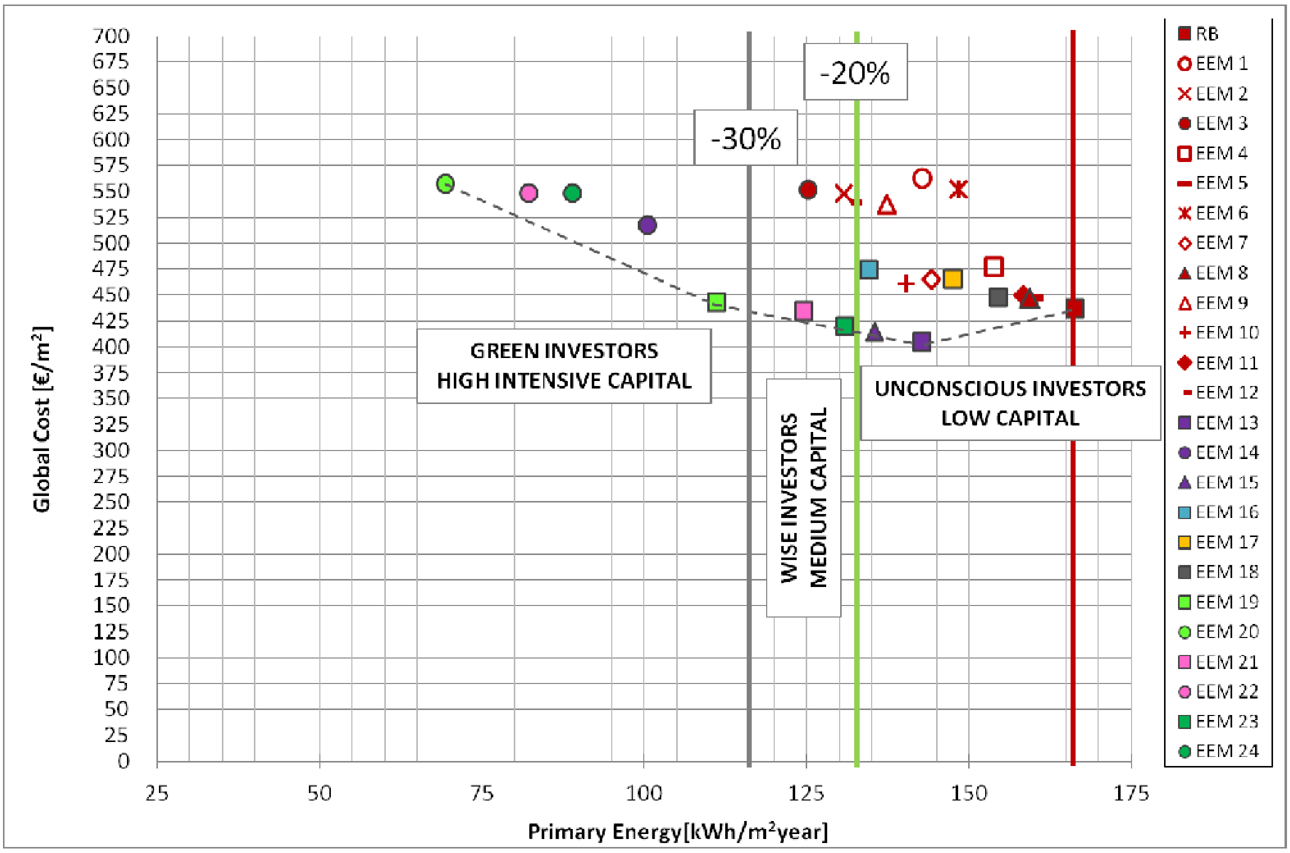

Figure 24. Primary energy saving target of 2020 on the global cost graph for the existing office

More complex process is associating different EEMs that appeared in the global cost graph with the CO_2 emissions saving in order to understand if 2020 target of reducing greenhouse gas emissions by 20% (compared to 1990 levels) is hit. In absence of other indications, since the analyzed case studies are two buildings existing since 1990, it's possible to say that CO_2 emissions saving must be equal to 20% in reference with RB one. The complexity of the depiction of this performance indicator is determined by the fact that it's connected not only with energy savings but specifically with utilized energy sources. It's also related with the exploitation of renewable energy sources (RES), that is another significant information that doesn't emerge from global cost graph. From energy point of view is very different if retrofit measures allow to save a quantity of primary energy reducing the building energy demand or installing RES on the building. According to EPBD Guidelines for the purpose of cost-optimal methodology, on-site energy production using locally available renewable technologies enter in competition with reducing energy demand solutions. In order to give this information it's necessary, for example, to couple the global cost graph with another one in which CO_2 emissions saving (compared with RB emissions) are shown. Another possibility is to put a tag for each EEM on the global cost graph with reported the CO_2 emissions saved in reference to the RB and the percentage of energy demand cover with RES; an example is given for the existing office in Figure 25. The CO_2 production coefficients utilized for the estimation are extrapolated from EN 15603:2007 [46].

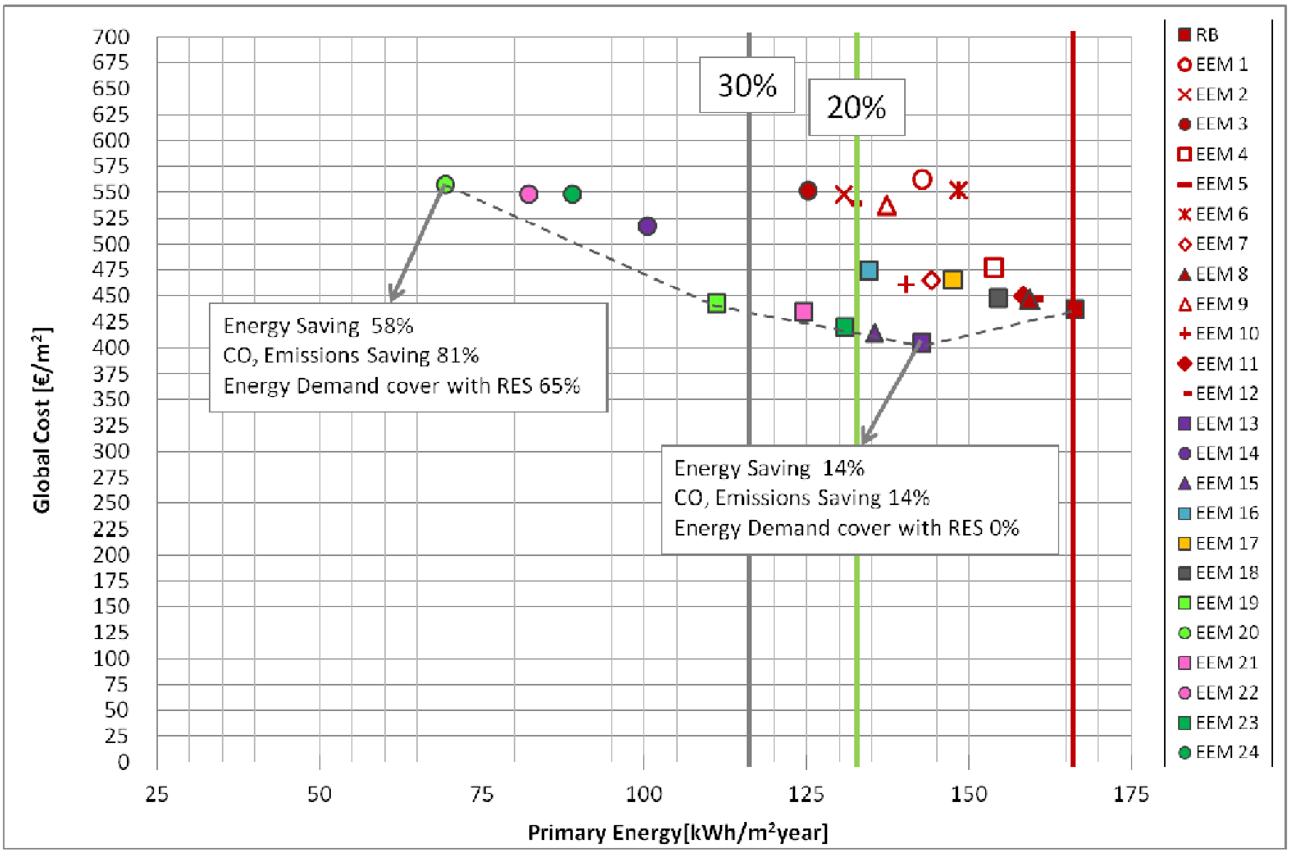

Figure 25. Example of additional information (reported in form of tag on the global cost graph) about energy saving, CO_2 emissions saving and percentage of energy demand cover with RES for the existing office

According to EPBD Guidelines [21] in order to test the robustness of the of global cost methodology, some sensitivity analyses are necessary. Following an example of these are reported for the case of existing office.

First of all, the calculation period has been changed from 30 to 20 years and to 5 years. Given the major relevance of the results of the analysis with calculation period of 5 years, only these are reported in Figure 26. Comparing this last graph with that of Figure 19, it is clear that global cost of RB and each EEM has been decreased of a variable quantity ranged between 80% (for EEM 13) and 54% (for EEM 14, that consist in the retrofit of the whole envelope with the application of thermal insulation with the maximum thickness and in the installation of the artificial lighting control). In the graph, in blue is reported the new cost curve referred to the calculation period of 5 years, in grey that referred to the calculation period of 30 years. Comparing grey and blue cost curve it is evident that all EEMs with a global cost minor than RB one with a calculation period of 30 years assumed now (with a calculation period of 5 years) quite the same position of RB on the y-assis; indeed their global cost is almost equal to RB one. This highlights that if the calculation period is reduced one of the most cost-effective actions is to keep unchanged the Reference Building. All EEMs with a global cost almost similar to RB one consist (in this specific case) in systems retrofit measures, and in detail in installation of artificial lighting control or of PV panels, so technologies that have a very low investment costs (artificial lighting control) or related with financial incentives (PV panel).

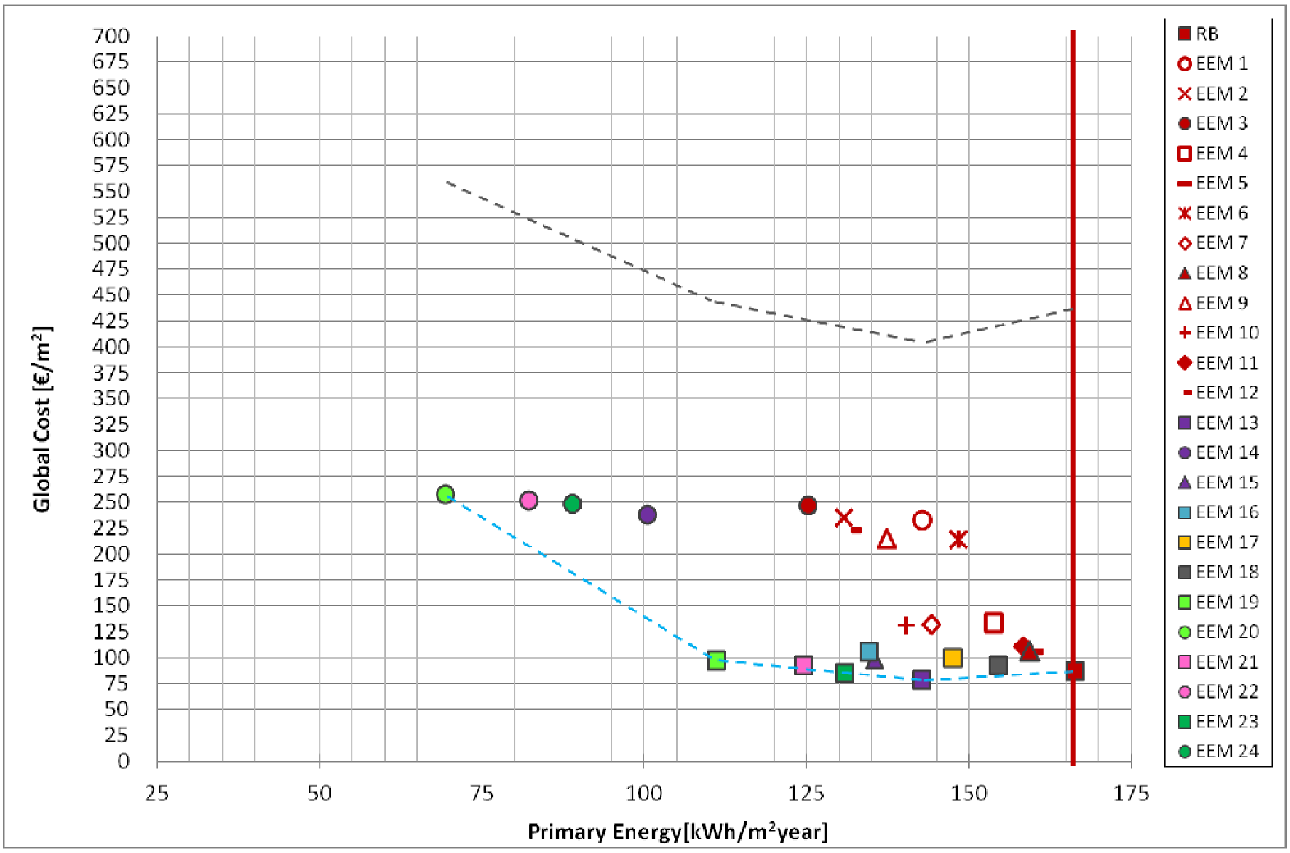

Figure 26. Global cost graph with a calculation period of 5 years for the existing office

Making a costs breakdown analysis of the global cost resulting from an analysis with a calculation period of 5 years, it's clear that there is a reduction of energy costs and of replacement costs. These are negative, because in reference to a calculation period of 5 years it has to be considered no replacement but only final value, in this specific case study, of windows and systems components that are substituted or installed in the investment year. Envelope and systems investment costs remain the same, as depicted in Figure 27.

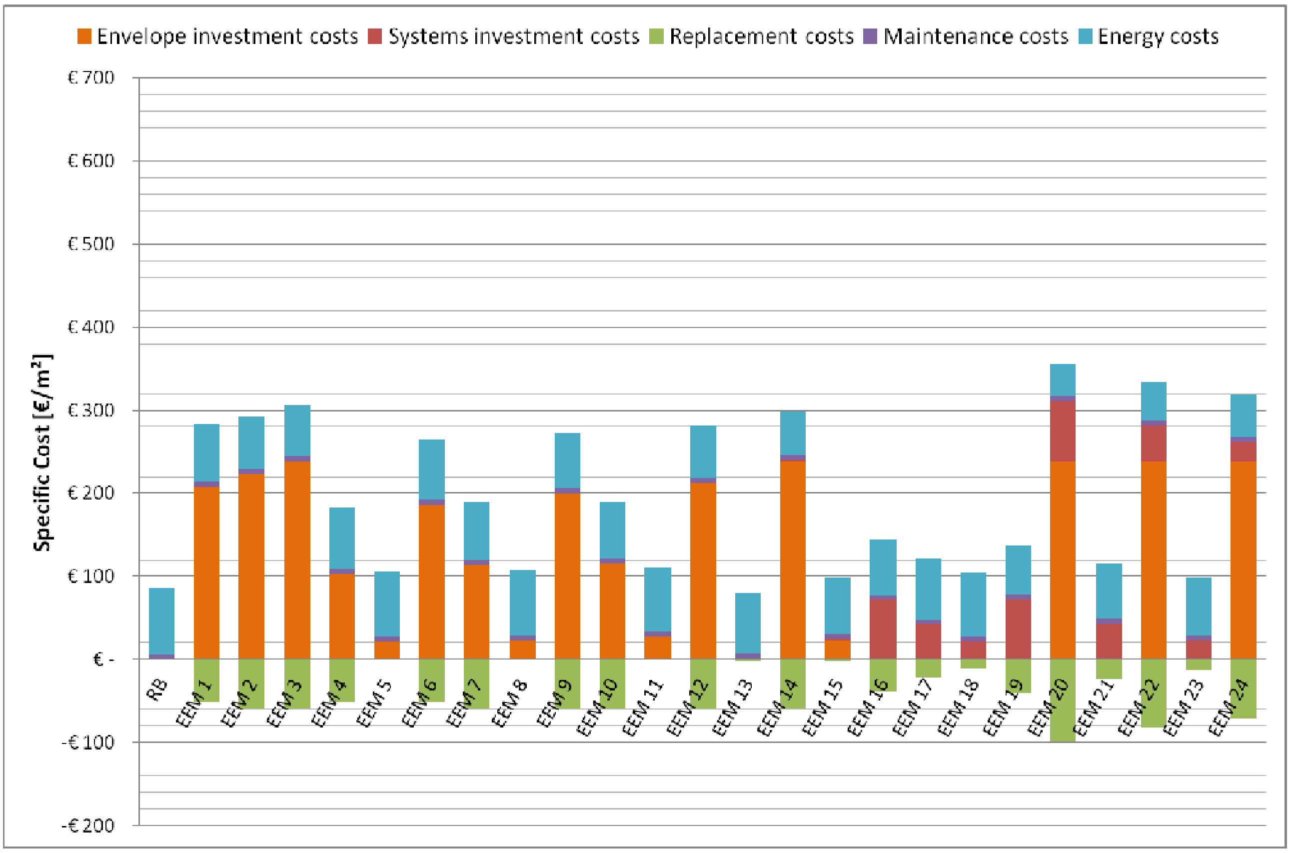

Figure 27. Costs breakdown analysis for RB and different EEMs for the existing office with a calculation period of 5 years

Considering the results of this sensitivity analysis, the EEM that represents the cost-optimal level doesn't change. This is a demonstration that the cost-optimal methodology is born in order to define national minimum energy performance requirements and not specifically to give precise information at the investors. Indeed, cost effectiveness and cost-optimality can be considered from several different perspectives that are described in detail in the next chapter. Three possible perspectives are:

- of societal as a whole: the "macro" economic perspective
- of individual end-users
- of idealized end-users (private): the "micro" economic perspective

EPBD Guidelines [21] established that MSs must carry out both the micro and the macro calculations, but they still have the prerogative to decide which perspective will be the final national benchmarks. Macro-economic calculation levels can include costs of greenhouse gas emissions and exclude taxes and subsidies. In macro-economic perspective a reduction of the period of calculation doesn't change the considerations about the final results, because it's the primary energy the element that has major interest (in order to fix minimum energy performance requirements). In micro-economic or individual end-users perspective the economic indicator, so the global cost, is the most significant value. For individual end-user, such as big business companies, the calculation period of 20 years is too long; they are interest in a retrofit action perspective of few years, maximum 5 like these of the analysis here presented. In this last case it may be interesting for investor to put a value that indicates the percentage of investment cost that can be cover with financial and/or fiscal instruments.

In line to EPBD Guidelines [21], MSs must determine the discount rate after having performed a sensitivity analysis with at least two different rates, one of which should be with 3% (in particular, for the macro-economic calculation). In the original cost-optimal analysis for the existing office, the discount rate was fixed equal to 4%. The same analysis with a discount rate of 3% is reported in term of global cost (Figure 28). In blue is reported the new cost curve, in grey that referred to the discount rate of 4%. The final results don't change in a meaningful way.

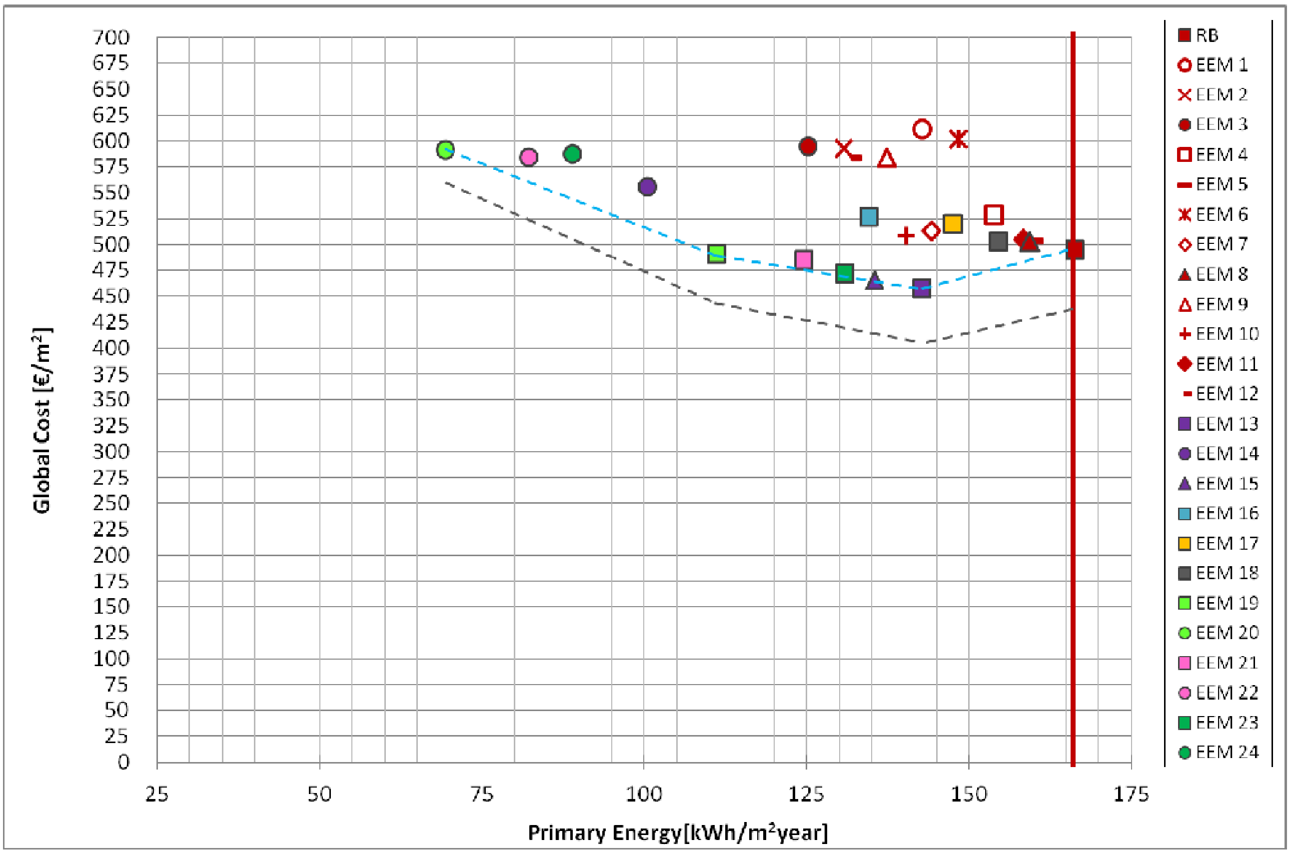

Figure 28. Global cost graph for the existing office with a discount rate of 3%

Other key factors that have to be tested with sensitivity analyses consist in energy prices. Energy price development trends give information about the estimated long-term price developments for oil, gas, coal, and electricity. Member States must take this information into account when determining the costs for energy carriers for the purpose of their cost-optimal calculations. The European Commission publishes biannual updates of these trends until 2030 [51]. These trends may be extrapolated beyond 2030 until more long-term projections become available. The latest update implies a 2.8% annual increase in gas prices, a 2.8% annual increase in oil prices, a 2% annual increase in coal prices and a 2% annual increase in electricity prices [41]. In the cost-optimal analyses presented in the two papers the increase of energy price is considered equal to the inflation rate that has been fixed equal to 2.17%. In order to test the results the same analyses have been conducted with an annual increase in gas prices of 2.8% and in electricity prices of

2%; the inflation rate has also been considered and put equal to 2.17%. The results in term of global cost for the existing office are presented in Figure 29; in grey the cost curve referred to the previous analysis, in red the grey cost curve shifted above (in correspondence to the new RB position) and in blue that referred to the analysis with the new energy price. With the energy prices growth the global cost of RB and of each EEMs increases of a quantity ranged between 10% (for EEM 20, that is the measure with the major primary energy saving) and 24% (for RB) as depicted in Figure 30. More the energy saving of a specific EEM is high less is the increasing in global cost if there is an annual boost in energy prices. In Figure 30 observing the specific cost items only a boost of energy cost is underlined; the other one remain unchanged; the saving in energy costs is calculated in reference with Figure 20.

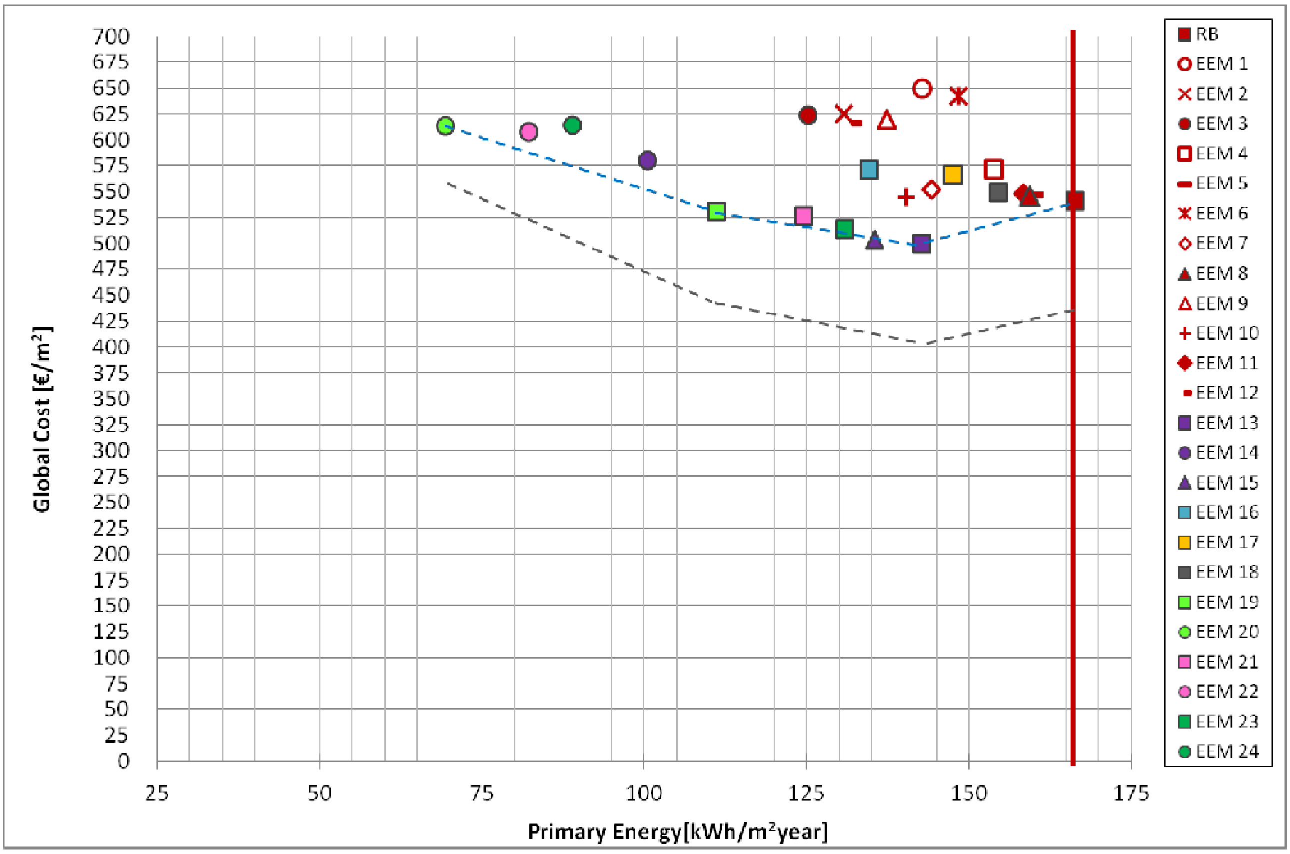

Figure 29. Global cost graph for the existing office with an annual increase in gas price of 2.8% and in electricity price of 2%

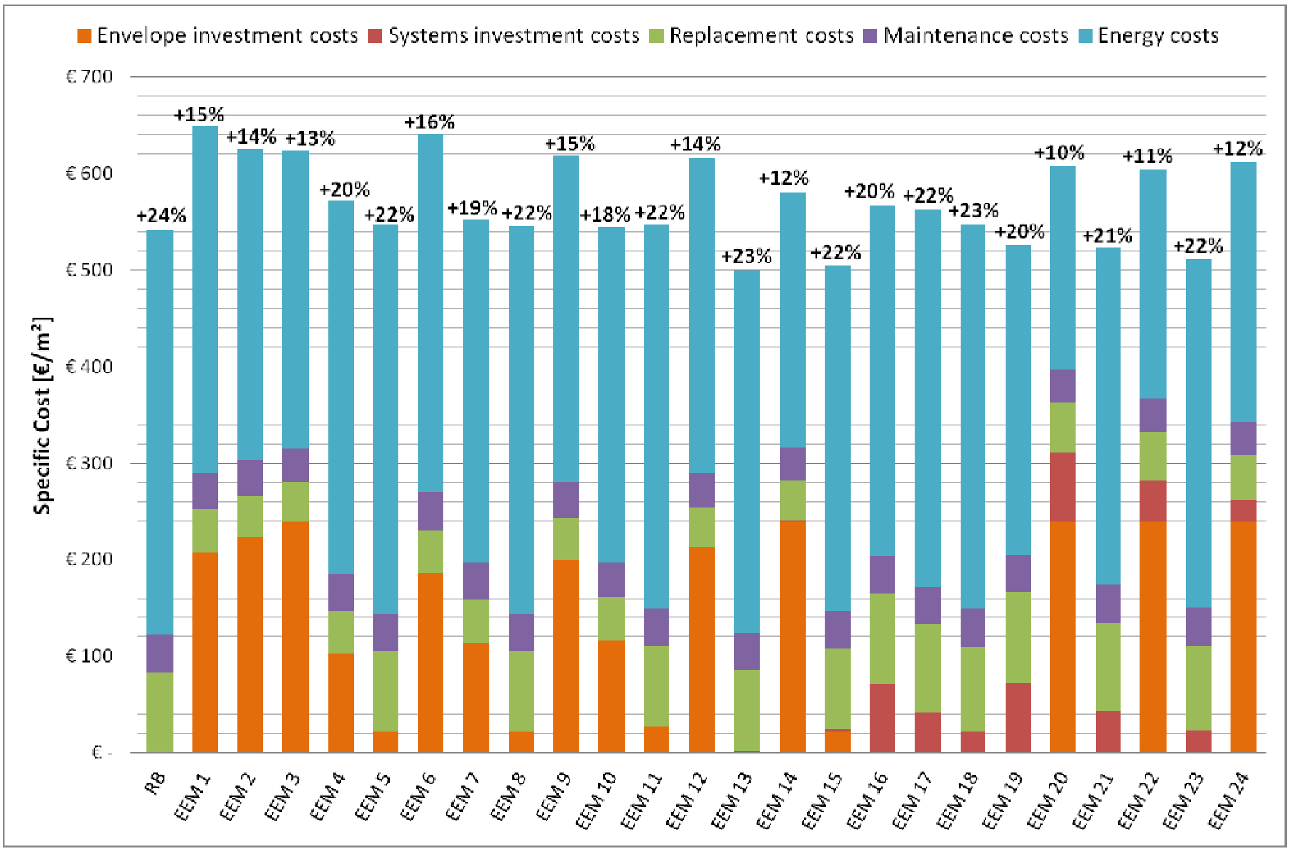

Figure 30. Costs breakdown analysis for RB and different EEMs for the existing office with an annual increase in gas price of 2.8% and in electricity price of 2%

This trend is confirmed also if a decreasing the energy prices in reference with the first analysis presented in Paper V is presumed. In Figure 31 the results of a cost-optimal analysis for the existing office with an energy price development of 1% (both for gas price and for electricity price; inflation rate is included) are presented; in grey the cost curve referred to the original analysis and in blue that referred to the analysis with the new energy price. With a reduction of energy prices development (from 2.17% of the first cost-optimal analysis to 1% in this case) the global cost of RB and of each EEMs decreases of a quantity ranged between 4% (for EEM 20, that is the measure with the major primary energy saving) and 9% (for RB) as depicted in Figure 32. More the energy saving of a specific EEM is high less is the decreasing in global cost. In Figure 32 the saving in energy costs is calculated in reference with the Figure 20; all the cost items remain unchanged, except for the energy costs.

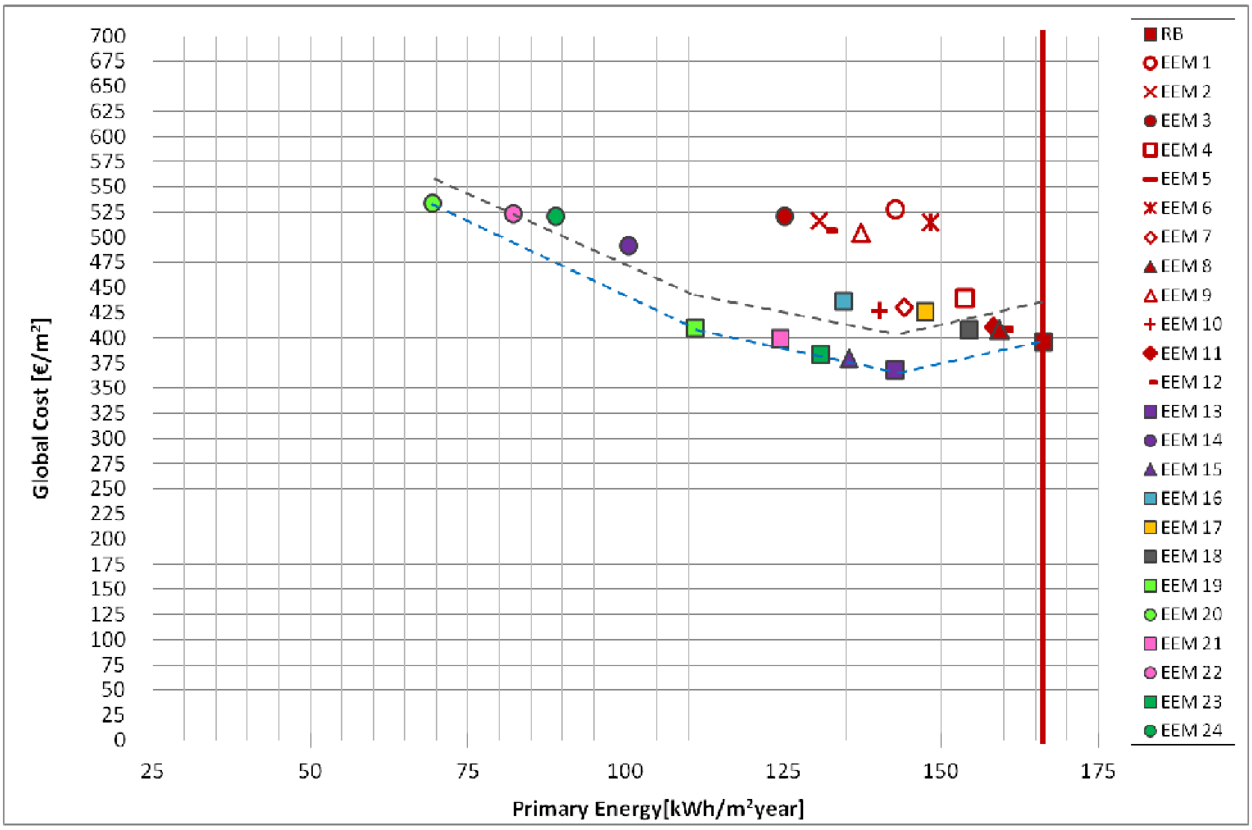

Figure 31. Global cost graph for the existing office with an annual increase in gas and electricity price of 1% (inflation rate included)

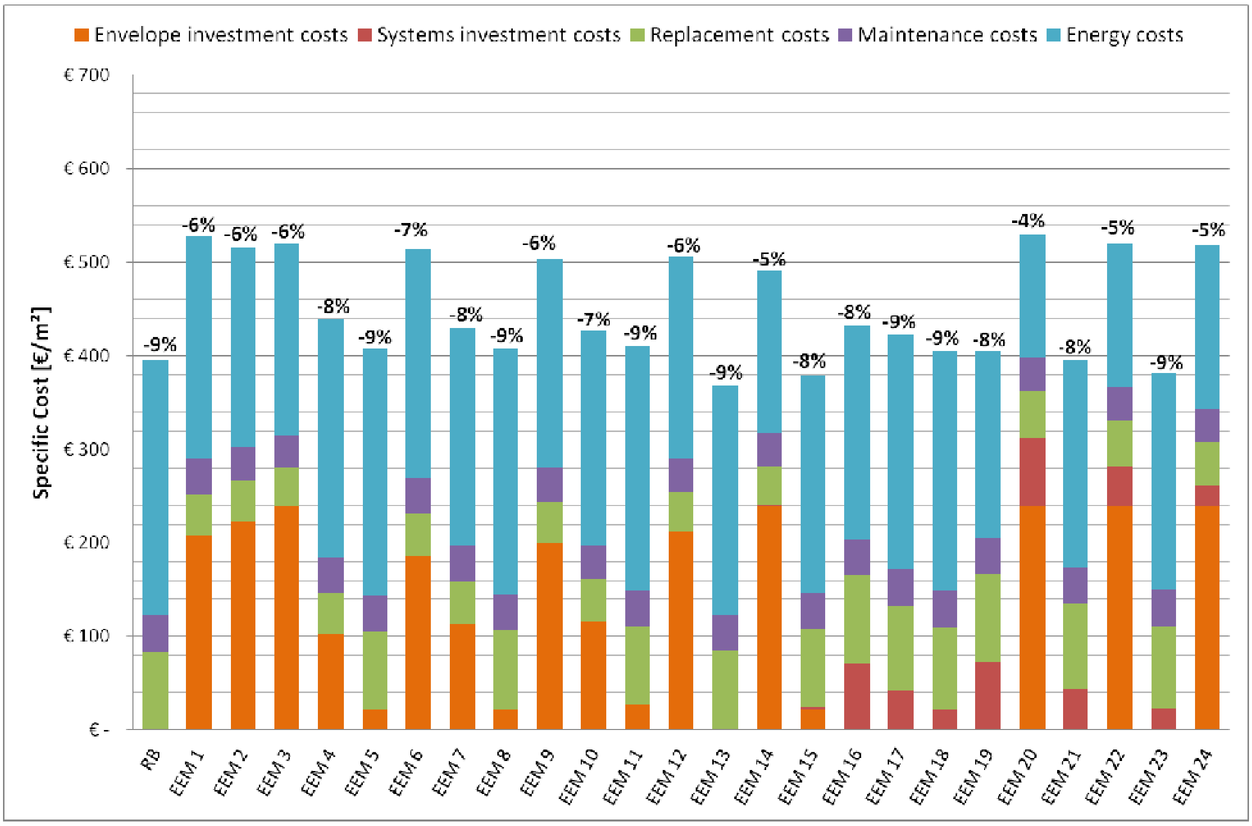

Figure 32. Costs breakdown analysis for RB and different EEMs for the existing office with an annual increase in gas and electricity price of 1% (inflation rate included)

EPBD Guidelines encourage MSs to perform sensitivity analyses also on other input factors such as the projected trends in future investment costs for building technologies and building elements or on any other input factors that are believed to have significant influence on the result (e.g. primary energy factors, etc.). Although it is true that a future price development will not impact on investment costs occurring at the start of the calculation period, the assessment on how the market uptake of technologies might influence their price level is very useful information for policymakers. Indeed, BPIE study on EU building stock renovation cost reduction factors have been applied for the different supposed scenarios. Therefore, technology price development is a key factor because in cost-optimal analysis costs related to the maintenance and replacement of energy systems in buildings are strictly connected with it.

11 Conclusions

After the critical review of cost-optimal analysis of the previous chapter it's possible to make some observations on the methodology and its application.

As the aim of the EPBD and its recast is to accelerate energy savings in buildings, in particular in the case of existing ones by retrofitting the building stock, the question may be if cost-optimality by minimizing the global cost value is an appropriate tool for doing that. The cost-optimal methodology has been chosen by European Commission as being the best balance between investments and benefits. Higher targets imply more upfront investment costs that need to be financed. In order to realize the ambitious goals of reducing the primary energy consumptions and the CO_2 emissions by 20% each and increasing the renewable energy supply by 20% by the year 2020, the focus should probably be to maximize the energy savings in buildings while still being cost-effective. This has of course to take into account safety margins for future changes in energy prices and interest rates.

Cost-optimality as a theoretical concept is well and clearly established. However, its application is far from easy and straightforward. In particular, there are choices of methodology, such as the kind of perspective to use for the analysis, which have significant impact on the outcomes. There is no glaring right or wrong approach to this type of choice as each addresses a different issue and, according to EPBD Guidelines, different MS place different emphasis on each issue. More detailed procedural decisions, such as the choice of Reference Buildings, also affect outcomes. These last ones are also conditioned from the uncertainty of much of the input data some of which constitute the outcomes of other complex calculation such as energy dynamic simulations. Consequently, there is general inevitable uncertainty about the outcomes of cost-optimal analysis. In addition, often although a cost-optimal calculation is being developed and some energy efficiency retrofit measures are individualized, there are no effective instruments, in term of energy policies and financial tools, to drive the market to increase the rate of deep renovations.

In regard to different perspectives, as mentioned in the previous chapter, cost-optimality can be considered from several different points of view, each of which will usually provide a different result. Therefore it's fundamental to establish the objective of the cost-optimal analysis in order to customize calculation in term of input data and of expected kind of outcomes.

In line with EPBD recast [14], the methodology is born as addressed to national authorities not to investors, and the cost-optimal level is not calculated for each building, but for developing generally applicable regulations at national level. In reality, there will be a multitude of cost-optimal levels for different investors depending on the individual building and the investor's own perspective and expectations of what constitute acceptable investment conditions. Therefore it's important to underline that the cost-optimal levels identified will not necessarily be cost-optimal for every single building/investor combination. For example, considering the case of rented buildings and the related problem of the split incentives or the situation where the rent is fixed and cannot be increased beyond a certain limit (e.g. for social policy reasons), it is not desirable to have different requirements for buildings depending on if these are rented out or not, as the status of the occupant is independent of the building which is the focus of the calculation. Moreover, there might be certain groups of investors who will not be able to take full advantage from a full cost-optimal investment. This issue, often called the owner-tenant dilemma, will need to be addressed by MSs as part of wider energy efficiency and social policy objectives and not within the cost-optimal methodology. However the cost-optimal analysis can provide Member States' authorities with the information on the financial gap that exists for certain investor groups and so can inform policies. For example, the difference between the cost optimum calculated in two different perspectives might give advices regarding the necessary funding and financial support that might still be needed to make energy efficiency investments economically interesting for the investor.

It is also important to acknowledge that there is a distinction in social acceptance between requirements for new and existing buildings. In the case of new buildings, the owner cannot really observe the cost efficiency, since there is no clear reference. For the existing buildings, this is quite different: on project level, the savings can and will be compared with the investment from the perspective of the investor/owner. Therefore, it is much more sensitive to setting minimum energy requirements in case of major renovation. Of course, societal acceptance is an important consideration for policy makers.

In addition to the fact that numerous and various individual perspectives and investment expectations exist, there is also the question of scope of costs and benefits that are taken into account. Considering different perspectives it's possible to contemplate only the immediate costs and benefits referred to the investment decision or also other indirect costs and benefits (often called externalities) that are provoked by an energy efficiency investment and that apply to other market actors than the investor. Indeed, apart from improving energy efficiency, retrofitting of a building offers great opportunities for increasing staff productivity, reducing maintenance costs and enhancing indoor comfort. It may also help to improve a national energy security and so reduce exposure to energy price volatility, create job opportunities and increase the real estate value of a building. A great challenge is how to consider these externalities in the calculation procedure, because nowadays there are no examples of parameters, such as market price, that can be used for this purpose. Consequently, it is necessary to devise "shadow prices" that reflect estimates of the value of such implications. However, in practice it's not be possible to capture all societal direct and indirect benefits, as some are intangible or non-quantifiable, or cannot be monetized. Moreover, it should be noted that the global cost methodology as prescribed in the Regulation [14] does not include costs other than energy (e.g. water costs). Indeed, the global cost concept is also not fully in line with a complete life cycle assessment (LCA) that would take into account all environmental impacts throughout the lifecycle (including so-called grey energy).

The three main possible perspectives are:

- of societal as a whole: the "macro" economic perspective
- of individual end-users
- of idealized end-users (private): the "micro" economic perspective

For all the perspectives cost-optimal analyses share the same basic structure, but differ in their scope and the appropriate values of some parameters. All three perspectives consider costs and benefits over the assumed life of a building. All apply discount rates to future benefits and costs so that those which occur further into the future have a smaller influence than those close to the present time.

The societal macro-economic perspective is a basic approach to regulatory policy-making from an economic perspective. It is used when the justification for introducing energy performance regulations is to make organizations or individuals take actions that do not reflect their own direct interests, and are therefore unattractive as investments, but that can be shown to be beneficial for the society as a whole. An alternative or complementary approach would be to use taxation and financial policy to better align users perceptions with societal aims. This approach takes into account all the costs incurred by any part of society and all the benefits that result, independently where they occur. There is no distinction here between costs and benefits that fall on different sections of society, because it is the net balance that is important. The macro perspective includes benefits and costs of externalities, for example damage from climate change associated with carbon dioxide emissions; as described above, nowadays there are no examples of parameters that can be used for this purpose. Future costs and benefits are discounted at a “social discount rate” which is typically quite low; the indication of EPBD Guidelines is 3% per year. With the macro-economic approach, taxes and subsidies are ignored, since they represent a transfer of money from one part of society to another, rather than an aggregate cost or benefit. For all perspectives not only for the macro-economic case, there is also the risk that taxes and subsidies will not be maintained over the building lifetime.

The end-user perspective is important when the objective of the regulations is to cut down market barriers that prevent owners and occupants from taking actions that are in their direct interest, but which they do not recognize as being so. It is also important as a means of assessing the risk that regulations will be seen as unfair by significant groups of those subjected to them. End-users face a number of practical constraints when considering energy efficiency investments. As described in Chapter 8, these include lack of information, lack of motivation, limited access to or alternative calls on capital, uncertainty about whether an investment will increase the market value of the building, and the division of costs and benefits between owners and tenants. Therefore, acceptance can be a problem as the user knows the energy bill, the investments and savings and if they do not converge it will increase discussions, and also if the building will be sold. Split incentive between actors in case of selling, for example adding property value, may be a solution. Minimum building energy performance requirements can bypass some of these barriers by demanding a certain level of investment. This perspective only includes costs and benefits that are faced by the potential investor, which include taxes and subsidies. The cost of obtaining capital is generally significantly higher than the discount rates assumed in societal assessments. In addition, apparently similar households or businesses in identical buildings can have very different occupation patterns and internal temperature requirements, resulting in equally varied energy demands. Since the direct costs of building energy efficiency measures don’t take into account occupant behavior, a package of measures that is cost-effective or cost-optimal for one set of occupants may not be so for others. The extent of objections to regulatory requirements will depend on the number of end-users who feel disadvantaged, and by what extent. Detailed assessment of the end-user perspective is complex and difficult and it is rarely attempted when setting building energy standards, but it can be used in order to identify which energy efficiency measures are the most cost-effective for retrofitting a specific building stock. With this scope, this perspective may be interesting for real end-users group, for example, big business companies, that owing large estate. In this case, if the cost-optimal analysis is customized for a real specific context its outcomes could be more accurate and precise because of reduction of input data uncertainty. For example, dynamic simulations can be calibrated on the real energy consumptions and it's possible to use price lists that are the usual reference for that specific end-user. In this case, it is suitable that calculation period is shorter than that indicated in EPBD Guidelines (maximum 5 years) and consequently the prevision of some economic input data (e.g., inflation rate, energy price development, etc.) is more reliable.

Because of the difficulty of assessing the detailed end-user perspective or extrapolating one end-user perspective out of numerous ones, it is common practice instead to use an idealized end-user perspective. This typically involves the definition of typical users and the assumption that the market barriers described in Chapter 8 can be neglected. This makes the analysis more tractable but, in effect, it hides differences between different groups of end-users. In principle, prices for both idealized and real end-user perspectives should be those that are currently practiced in the marketplace. However, the idealized end-user perspective is often used with a discount rate that is below the market cost of capital.

Concerning procedural decisions that affect outcomes, from the experience of several countries, it seems a satisfactory approach to have experts, in consultation with the market, define a number of not too complicated Reference Buildings for different user typologies. Based on these buildings, sensitivity studies can lead way to cost-optimal levels. As described in Chapter 7 and Paper I, in line with Annex III of EPBD recast [14] states that MS shall define Reference Buildings that are characterized by and representative of their functionality and geographic location, including indoor and outdoor climate conditions. Ideally Reference Buildings are defined based on the characteristics of the building stock and the research purpose they are intended for. They can have two main purposes: to represent the aggregate stock of buildings affected by regulation and to identify sectors that would be disadvantaged by requirements that might, nevertheless, be generally cost-optimal. Due to the limited statistical knowledge about the building stock, the choice of Reference Buildings has a more arbitrary nature. This arbitrary element in picking Reference Buildings might be a source of deviation and inconsistency in the cost-optimal comparison. Also the use of different service systems in comparably constructed buildings and as well as different user typologies will multiply the number of Reference Buildings. Additionally, the building size might have an influence on the results. Therefore, it could make sense to further categorize building types such as blocks of flats (small multi-family houses vs. high-rise blocks of flats), office buildings (small office buildings vs. large office towers), etc. The size in part also influences the necessary or possible building service systems. Some cost-saving technologies might not be useable in bigger size buildings while other might become cost-effective especially in large buildings.

As regard to uncertainty of much of the input data that are used in cost-optimal analysis, it depends from the fact that many of them are related with future development (e.g. inflation rate, energy price, etc.). For these reason sensitivity analyses are an integral part of the methodology, as demonstrated in Chapter 10. Other input data constitute the outcomes of other complex calculation such as energy simulations. In Paper II is demonstrated that the use of a different method with several levels of detail to calculate the energy use for building space heating and cooling leads to different results even if the input data have been established in order to converge; for example in the case of energy need for space heating the difference is equal to 16%.

All the observations reported above concern the methodology itself. However there are some other considerations that is necessary to make. The energy savings targets are not obligatory and this affects the effectiveness of the implementing measures. Recent policy pronouncements from the EU show that Europe is not going to achieve the 2020 energy savings target without new policies and without better implementation of current policies and without the exploitation of financial instruments. As proof of this, as reported in Chapter 10 in the results of cost-optimal analysis there is a lack of information about hitting of 2020 and/or 2050 targets for each EEM. One of the major weaknesses of the 2010 recast of the Energy Performance in Buildings Directive has been on existing buildings. While a cost-optimality calculation is being developed and while there are some definitions for energy efficiency retrofit measures, there are no effective instruments to drive the market to increase the rate of renovation for more energy savings and to increase the rate of deep renovations (as described in Chapter 7).

Concerning energy policies, the main point to note is that, while the existing policy mix in a given Member State may have been effective in increasing deployment of particular types of energy efficiency measures, no Member State currently has the policy measures in place to get ready for renovation activity to the extent required to effect a transformation in national building renovation activity. Consequently, 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 observed.

Furthermore, 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. All Member States have on-going programs to support the energy performance of buildings, either in form of conventional or innovative financing or through the help of external funding. Some Member States have a large range of financial support options, reflecting the needs of their wide range of building types. However, the level of ambition of financial programs should be increased in order to create more impact and to unlock further private investments in deep renovation. Very few programs have set ex-ante goals and objectives, and few have an evaluation of their effectiveness. Few programs have a constant monitoring process throughout their implementation. Financial instruments most frequently used rather than fiscal incentives; the form of grants/subsidies appears to be the most frequently chosen; nowadays, often grants and subsidies are combined with preferential loans and tax reduction with tax credit measures. Most instruments are for existing buildings and mainly for residential buildings; this is true for financial incentives as well as for fiscal incentives. Many financial instruments target specific technologies or building aspects, although about one-third of the financial instruments support a holistic approach; however, financial measures appear to have a more comprehensive approach giving more support to non-technological measures such as energy audits, education and training activities. Undoubtedly, more innovative ideas and initiatives will be necessary. For example, in the autumn of 2012, the UK has started its Green Deal, an innovative financial mechanism eliminating the need to pay upfront for energy efficiency measures, in which the cost of the measures should be covered by savings on the electricity bill. Moreover, the European Commission is actively trying to provide a larger percentage of Structural Funds to be used for improvements in the energy performance of buildings and to work with Member States who are currently underutilizing their potential allocation. New strategies to secure sufficient financing for the deep renovation of the European building stock are needed which ideally bring together private and public investment streams. Policy-makers and the relevant stakeholders in the building sector should elaborate which policy framework would enable the necessary investments. This would not only create new investment opportunities for the private sector but would also reduce the load on public budgets.

Limitations and recommendations for future studies

This research has tried to critically analyze the cost-optimal analysis in order to establish if this methodology proposed by European Commission may be an appropriate tool for evaluating cost effectiveness of energy efficiency retrofit measures. Only few sensitivity analyses have been conduct on two cost-optimal studies. Consequently for examining in depth the results robustness and their uncertainty level is necessary to develop other sensitivity analyses on much more case studies.

Concerning the methodology, further details are to be developed; for example, energy price forecasts and their updates need to be supplied by the Commission, distinction between end-users and macro-economic perspectives needs further elaboration, CO_2 emissions could be a useful additional indicator for comparison with greenhouse gas reduction targets. In this process of defining and agreeing on all the details of the methodology, it is very important that Member States and all other stakeholders (industry, project developers, homeowner associations, scientific organizations, etc.) are actively involved. This ensures that the various perspectives are taken into account to make the methodology on cost-optimal requirements a powerful tool for promoting smart and efficient buildings in Europe. Furthermore, feedback loops between government and market through survey studies and consultation are essential to achieve an effective approach. Learning cycles mirroring legislation with reality are crucial for effective implementation. This also implies that modification of legislation over the years is important.

However the methodology and its implementation deal with some challenges. First of all examining the costs should not imply that future environmental targets are ignored; these targets need to be taken into consideration in a methodology that matches financial and environmental benefits. All further boundary conditions such as technical requirements and comfort issues also need to be considered. Several details of the methodology (like the task of making suitable energy price forecasts) are not yet fixed and need proper consideration to ensure the success of the approach. A common understanding of all stakeholders is crucial to make sure that calculations and the interpretation of the results are made in a uniform and comparable way; this requires clear guidelines around the process and regular exchange between the Member States.

12 List of references

[1] European Commission, *Communication "A Roadmap for moving to a competitive low carbon economy in 2050" COM(2011) 112 final*, Brussels, 2011

[2] European Commission, *Communication "Energy efficiency: delivering the 20% target" COM(2008) 772 final*, Brussels, 2008

[3] European Commission, *Communication "20 20 by 2020 – Europe's climate change opportunity"" COM(2008) 30 final*, Brussels, 2008

[4] European Commission, *Communication "Energy 2020 A strategy for competitive, sustainable and secure energy"*, COM(2010) 639 final, Brussels, 2010

[5] European Commission, *Communication "Limiting global climate change to 2C - the way ahead for 2020 and beyond" COM(2007) 2 final*, Brussels, 2007

[6] European Commission, *Directorate general for energy and transport: European energy and transport. Trends to 2030 – Update to 2007*, Brussels, 2007

[7] Blesl M., Kober T., Bruchof D., Kuder R., *Effects of climate and energy policy related measures and targets on the future structure of the European energy system in 2020 and beyond*, in «Energy Policy» 38, 2010

[8] Klessmann C., Held A., Rathmann M., Ragwitz M., *Status and perspectives of renewable energy policy and deployment in the European Union – What is need to reach the 2020 targets?*, in «Energy Policy» 39, 2011

[9] Annunziata E., Frey F., Rizzi F., *Towards nearly zero-energy buildings: the state of art regulation in Europe,* in «Energy» in press, 2013

[10] Capros P., *European energy and CO_2 policy after the economic crisis*, in proceedings of the 10th Conference of the International Association for Energy Economics, Vienna, 2009

[11] Simpson C., *Energy efficient renovation makes economic sense*, Build Up, 2012

[12] Eurostat, http://epp.eurostat.ec.europa.eu

[13] European Parliament, *Directive 2002/91/CE of the European Parliament and of the Council of 6 December 2002 on the energy performance of buildings*, Brussels, 2002

[14] European Parliament, *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*, Brussels, 2010

[15] Economidou M., *Energy performance requirements for buildings in Europe*, in «The Rehva European HVAC Journal», Brussels, March 2012

[16] Building Performance Institute Europe (BPIE), *Energy efficiency policies in buildings – The use of financial instruments at Member State level*, Brussels, 2012

[17] Building Performance Institute Europe (BPIE), *A guide to developing strategies for building energy renovation*, Brussels, 2013

[18] Maldonado E., *Moving towards a new paradigm for the building sector*, in «The Rehva European HVAC Journal», Brussels, March 2012

[19] Wittchen K. B., Thomsen K. E., *Implementation of the cost-optimal methodology according to the EPBD recast*, in «The Rehva European HVAC Journal», Brussels, March 2012

[20] European Commission, *Commission Delegated Regulation (EU) No 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 (recast) by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*, Brussels, 2012

[21] European Commission, *Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU 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*, Brussels, 2012

[22] European Standard 15459:2008, *Energy performance of buildings – Economic evaluation procedure for energy systems in buildings*, 2008

[23] Ma Z., Cooper P., Daly D., Ledo L., *Existing building retrofits: methodology and state-of-the-art*, in «Energy and Buildings» 55, 2012

[24] Annex 50, Prefabricated systems for low energy renovation of residential buildings, http://www.ecbcs.org/annexes/annex50.htm

[25] S. Barlow, D. Fiala, *Occupant comfort in UK offices – how adaptive comfort theories might influence future low energy office refurbishment strategies*, in «Energy and Buildings» 39, 2007

[26] S. Roberts, *Altering existing buildings in the UK*, in «Energy Policy» 36, 2008

[27] ACC, *Building Refurbishment Guide,* Adelaide City Council, Australia, 2007

[28] Magyar Z., *Buildings in the key role in the EU Energy Efficiency Action Plan*, in « The Rehva European HVAC Journal », special issue for ACREX India 2012 exhibition, Brussels, 2012

[29] European Commission, *Accompanying document to the Proposal for a recast of the energy performance of buildings directive (2002/91/ EC) - Summary of the impact assessment, SEC(2008) 2865*, Brussels, 2008

[30] Building Performance Institute Europe (BPIE), *Europe's building under the microscope*, Brussels, 2011

[31] *Energy Efficiency Plan 2011*, http://ec.europa.eu/energy/efficiency/action_plan/action_plan_en.htm

[32] *Energy Efficiency in Buildings,* http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

[33] *Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries,* http://ec.europa.eu/energy/efficiency/studies/doc/2009_03_15_esd_efficiency_potentials_final_report.pdf

[34] *Low energy buildings in Europe: Current state of play, definitions and best practice*, http://ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf

[35] *European Energy Efficiency Plan*, http://europa.eu/rapid/pressReleasesAction.do?reference=IP/11/271&format=HTML&aged=0&language=en&guiLanguage=en

[36] *Impact Assessment Energy Efficiency Plan 2011,* http://ec.europa.eu/energy/efficiency/action_plan/doc/20110308_efficiency_plan_impact_assesment_en.pdf

[37] *Progress report of the Energy Efficiency Action Plan 2006,* http://ec.europa.eu/energy/efficiency/action_plan/doc/20110308_efficiency_plan_progress_report.pdf

[38] *European council 4 February 2011 Conclusions,* http://europa.eu/rapid/pressReleasesAction.do?reference=DOC/11/1&format=HTML&aged=0&language=EN&guiLanguage=en

[39] *Action Plan for Energy Efficiency: Realizing the potential*, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0545:FIN:EN:PDF

[40] Wahlstrom A., *Is it possible to achieve zero energy demand while rebuilding multi-dwelling buildings?*, in « The Rehva European HVAC Journal », Brussels, August 2011

[41] Ecofys, Renovation tracks for Europe up to 2050 – Building renovation in Europe – What are the choices?, Summary report, 2012

[42] Fraunhofer-Institute for Systems and Innovation Research (Fraunhofer ISI) and partners. *Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries*, Final Report for the European Commission Directorate-General Energy and Transport, 2009

[43] Ecofys, *Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC)*, Summary report, 2009

[44] Becchio C., Corgnati S. P., Monetti V., Airaksinen M., *Reference Building for cost-optimal analysis: A shared methodology for their definition and ongoing activities*, First Report of Rehva Task Force "Reference Buildings for Energy Performance and Cost-Optimal Analysis", Torino, September 2012

[45] TABULA Project, www.building-typology.eu

[46] Wittechen K. B., Thomen K. E., *Introducing cost-optimal levels for energy requirements*, in «Rehva Journal», March 2012

[47] Building Performance Institute Europe (BPIE), *Cost optimality – Discussing methodology and challenges within the recast Energy Performance of Buildings Directive*, Brussels, 2010

[48] Mills B., Schleich J., *Residential energy-efficient technology adoption, energy conservation, knowledge and attitudes: an analysis of European countries,* in «Energy Policy» 49, 2012

[49] European Parliament, "*Regulation (EU) No 305/2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC*", Brussels, 2011

[50] European Standard EN 15603:2008, *Energy performance of buildings — Overall energy use and definition of energy ratings*, 2008

[51] European Commission, *EU Energy Trends to 2030; update 2009*, Brussels, 2010

[52] Higgins J. A., *Energy modeling basics*, in «Ashrae Journal – The magazine of HVAC&R technology and applications», December 2012

[53] AA.VV., *Energy estimating and modelling methods*, in «Ashrae Handbook – Fundamentals», 2009

[54] Clarke J. A., *Energy simulation in building design,* Butterworth Heinemann, Oxford 2001

[55] Hensen J. L. M., Lamberts R., *Building performance simulation for design and operation*, Spon Press, New York, 2011

[56] Filippi M., Fabrizio E. (a cura di), Introduzione alla simulazione termo energetica dinamica degli edifici, Guida Aicarr, Editoriale Delfino, Milano, 2012

13 Ph. D. Publications

Paper I

Becchio C., Corgnati S.P., Ballarini I., Corrado V. *Energy saving potential by retrofitting residential buildings in Europe*, in « The Rehva European HVAC Journal », ISSN 1307-3729, December 2012

REHVA Journal – December 2012 – Full article

Energy saving potential by retrofitting residential buildings in Europe

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Summary

The national *building typologies* can be used as data sources for forecasting and evaluating the energy saving potential and the carbon dioxide emission reductions for each European country. Thereby the main objective of the IEE TABULA project has been to create a harmonized structure of the European building typologies and to identify representative building types. This purpose has come from the need to assess the energy consumption of the national building stock and consequently to predict the impact of different energy efficiency measures in order to select effective retrofit strategies on the existing buildings. Two levels of building retrofit have been considered: a *standard refurbishment*, applying measures which are commonly used in the country; an *advanced refurbishment*, applying measures which reflect the best available technologies. The evaluation of each reference building type has been performed in each country by using the national EPBD asset rating method and by showing the energy performance before and after the refurbishment.

Additional statistical information about the frequency of constructions and of heating systems types has made possible the use of the reference building types as models for the assessment of the energy performance of the whole national building stock.

The present paper reports the first outcomes of the application of the above described methodology to the national residential building stocks of four countries representative of the North, Middle, South and East European Countries. It summarizes the results presented in the TABULA report "*Application of Building Typologies for Modelling the Energy Balance of the Residential Building Stock*".

Introduction

TABULA (Typology Approach for Building Stock Energy Assessment) [1] was a project within the European program "Intelligent Energy Europe" (IEE) with the participation of thirteen European countries (Germany, Greece, Slovenia, Italy, France, Ireland, Belgium, Poland, Austria, Bulgaria, Sweden, Czech Republic and Denmark). The project objective has been to create a harmonized structure of the European building typologies [2]. Each participant developed a building typology classification that allowed to divide national existing buildings in categories: for each category, a building type was identified as representative of a defined climatic region, period of construction, building size, etc. In many European countries, the classification of building types is a concept already used at national and/or regional level. However, both at national and at European level, a number of problems rise up due to lack of shared definitions, to unknown or not updated data about existing buildings, to the difficulties in defining a common concept of building typology. In practice, it is impossible to compare the types of buildings among European countries without uniform and shared definitions. As a consequence, TABULA firstly aimed to create a harmonized structure to classify building types in Europe: the project focused on residential buildings, but a possible extension to other uses is also possible.

Building typologies developed during the TABULA project can be exploited as a basis for analysing the national housing sector. In fact, a crucial goal of the project has been to estimate the energy consumption of residential building stocks at national level and, consequently, to predict the *potential impact of energy efficiency measures* (addressed to building envelope and space heating and DHW systems) in order to select effective strategies for upgrading existing buildings. In particular, during the TABULA project six of the European partners (Belgium, Czech Republic, Denmark, Germany, Greece, Italy) carried out model calculations aimed to image the energy consumption and estimate the energy saving potentials of their national residential building stocks (Energy Balance Method).

Specifically, as shown in **Figure 1**, starting from global statistics at national and regional level and from the corresponding available residential building samples divided in classes, some reference building types have been selected in order to obtain a relevant characterization of the analyzed buildings. They have been chosen as representative of a large portion of the national residential building stock. Different modelling approaches were chosen by the partners depending on the available statistical data. Some defined a set of synthetic buildings reflecting building stock averages; others applied a set of generic example buildings from the national TABULA typologies.

The methodology provided by the European standards supporting the Energy Performance of Buildings Directive (EPBD, 2002/91/EC) has been applied for the evaluation of the energy demand of the selected building types and to assess the energy saving potential due to energy retrofit actions. In fact, for each reference building type two refurbishment measures have been considered: a *standard refurbishment* through the application of measures commonly applied within the country; an *advanced refurbishment* through the introduction of measures that reflect the use of the best available technologies. Finally additional information about the number and the frequency of each specific building type has made possible the application of statistical models in order to estimate the overall energy performance, energy saving potentialities, carbon dioxide emissions reductions of the building stock at national/regional level.

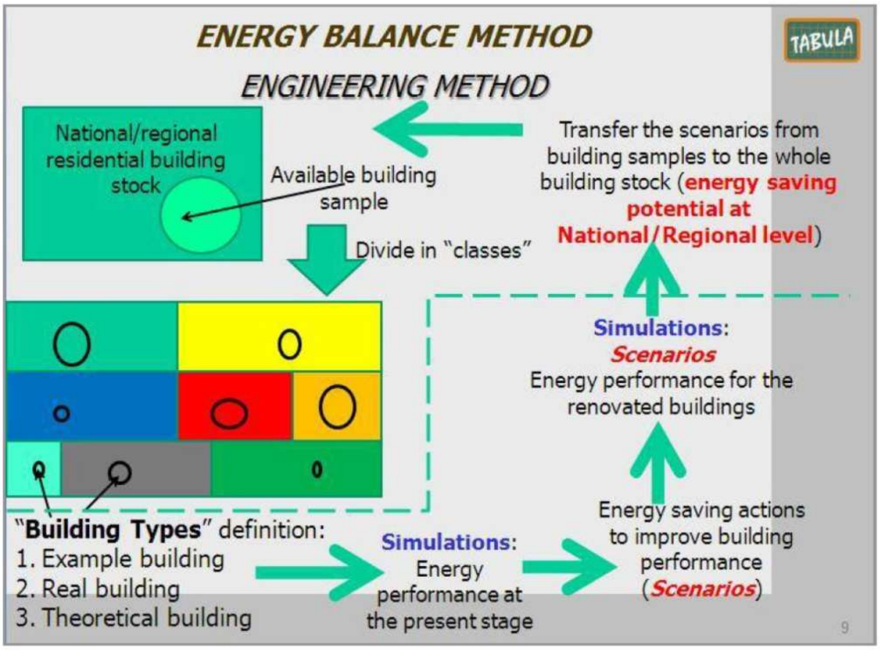


Figure 1. Procedure for Energy Balance Method used in the TABULA project to predict the potential impact of energy efficiency measures on national housing sector.

This paper shows the first outcomes of the application of the above described Energy Balance Method at the national residential building stock of four countries:

- Denmark, as a representative of the North European countries;
- Germany, as a representative of the Middle European countries;
- Italy, as a representative of the South European countries;
- Czech Republic, as a representative of the East European countries.

The data presented in this paper have been extrapolated from the TABULA report "Application of Building Typologies for Modelling the Energy Balance of the Residential Building Stock" [3] and from the "National Scientific Report" on the TABULA project of the four analysed countries [4-7].

Denmark

The energy balance of the Danish residential buildings was calculated using synthetical average buildings. These were split within nine different construction periods and three building types (single family houses SFH, terraced houses TH, block of flats AB).

In order to estimate energy saving potentials the national Energy Balance method was used.

Refurbishment measures were applied only to the envelope and consisted in two different levels of thermal insulation: the standard refurbishment is associated with a high thickness of insulating material (300 mm for the ceiling, more than 100 mm for the wall), while the advanced refurbishment is associated with a higher thickness of insulating material (400 mm for the ceiling, more than 200 mm for the wall). Consequently, the energy saving potential was calculated only in term of net energy demand for heating and DHW. The results of the analysis are presented in term of energy saving and CO_2 emission reduction in **Table 1**.

Table 1. Annual energy saving potentialities (in terms of net energy demand for space heating and DHW) and CO_2 emissions reductions by standard and advanced refurbishment for Danish residential building stock.

Reference building type	Original State		Standard Refurbishment			Advanced Refurbishment		
	$Q_{H,W,p}$	t_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}
	[10^3GWh]	[10^6t]	[10^3GWh]	[-]	[10^6t]	[10^3GWh]	[-]	[10^6t]
SFH and TH	31.5	---	14.6	-46%	---	15.6	-50%	---
AB	12.1	---	5.3	-44%	---	5.9	-49%	---
	43.6	---	19.9	-46%	3.1	21.5	-49%	3.4

Germany

The analysis of the German building stock was conducted on a set of six synthetical average buildings. Two building size classes (single family houses with one or two dwellings and multifamily houses with three or more dwellings) and three construction periods according to different levels of energy saving national regulations were considered (**Table 2**).

Table 2. Classification of the German building stock.

Reference building type		Construction period	Number of buildings
Single Family House	SFH I	until 1978	9'610'000
Single Family House	SFH II	1979 – 1994	2'710'000
Single Family House	SFH III	1995 – 2009	2'670'000
Multi-Family House	MFH I	until 1978	2'340'000
Multi-Family House	MFH II	1979 – 1994	440'000
Multi-Family House	MFH III	1995 – 2009	270'000
			18'040'000

The energy balance model was developed on basis of the available statistical input data. The energy demand for space heating of the considered six building types was calculated according to a seasonal energy balance approach. In this way an estimation of energy saving potentials in the German building stock for heating and hot water supply was carried out.

The refurbishment measures consisted in the application of insulation material on walls, floors and roofs and in the replacement of windows. The standard refurbishment is characterized by U-values of 0.24 W/(m^{2}K) for walls, roofs and upper floor ceilings, U-values of 0.3 W/(m^{2}K) for ground floors and cellar ceilings and U-values of 1.3 W/(m^{2}K) for windows. The advanced refurbishment is characterized by U-values of 0.16 W/(m^{2}K) for walls, U-values of 0.14 W/(m^{2}K) for roofs and upper floor ceilings, U-values of 0.20 W/(m^{2}K) for ground floors and cellar ceilings and U-values of 0.80 W/(m^{2}K) for windows. With reference to the retrofit of the space heating and DHW systems, at the standard level it was considered to replace the heat generator, while at the advanced level the measures consisted in the improvement of efficiency of the distribution and generation subsystem, in the application of an heat recovery ventilation system and in the installation of a solar thermal plant.

Energy saving potential obtained by retrofitting the German residential building stock is reported in **Table 3**.

Table 3. Annual energy saving potentialities (in terms of primary energy for space heating and DHW) and CO_2 emissions reductions by standard and advanced refurbishment for German residential building stock.

Original State		Standard Refurbishment			Advanced Refurbishment		
$Q_{H,W,p}$	t_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}
[10^3GWh]	[10^6t]	[10^3GWh]	[-]	[10^6t]	[10^3GWh]	[-]	[10^6t]
661	136	304	-46%	63	512	-77%	100

Italy

In Italy, six reference building types were created to represent the housing stock for the purpose of Energy Balance analysis, as shown in **Table 4**.

Table 4. Classification of the Italian building stock.

Reference building type		Construction period	Number of buildings
Single Family House	SFH.01	until 1900	1'046'278
Single Family House	SFH.03	1921 – 1945	559'336
Multi-Family House	MFH.04	1946 – 1960	707'563
Apartment Block	AB.05	1961 – 1975	869'056
Apartment Block	AB.06	1976 – 1990	1'214'773
Apartment Block	AB.07	1991 – 2005	358'765
			4'755'771

These reference buildings were chosen according to statistical analysis: they are representative of a suitable significant portion of the entire national building stock considering both the construction age and the building size (i.e. number of apartments, floor area) and they belong to the "Middle Climatic Zone" (from 2100 to 3000 heating degree days), which is the most representative of the Italian climate (about 4250 municipalities on a total number of 8100). Specifically, the first two reference buildings (single family houses) are "Theoretical Buildings", chosen on the basis of statistical data (Piedmont Regional Database of Building Energy Performance Certificates). The other reference buildings (multi-family house and three apartment blocks) are "Example Buildings", i.e. real buildings defined typical according to the experience.

The official national calculation method (Technical Specification UNI/TS 11300 - National Annex to CEN Standards) for energy certificates was applied for the evaluation of the energy demand of the selected reference buildings and to assess the energy saving potential due to energy retrofit actions according to two different scenarios (standard and advanced refurbishment). In regard to the envelope, the refurbishment measures consisted in the application of insulation material on walls, floors and roofs and in the replacement of windows. The considered U-values correspond to the requirements established by the new regulations on energy performance of buildings in Piedmont Region (D.G.R. n. 46-11968), that belongs to the "Middle Climatic Zone". The U-values applied for the standard refurbishment are the U-value limits set by the Piedmont Region regulation (0.33 W/(m^{2}K) for walls, 0.30 W/(m^{2}K) for roofs, ceilings and floors, and 2 W/(m^{2}K) for windows), while the U-values applied for the advanced refurbishment are the optional U-value targets set by the Piedmont Regional regulation (0.25 W/(m^{2}K) for walls, 0.23 W/(m^{2}K) for roofs, ceilings and floors, and 1.7 W/(m^{2}K) for windows).

With reference to the refurbishment of the space heating and DHW systems, some measures were considered in order to improve the efficiency of emission, distribution and generator subsystems and to exploit renewable energies with the installation of a thermal solar plant (advanced refurbishment).

Energy saving potentialities obtained applying the mentioned retrofit measures at the Italian residential building stock are reported in **Table 5**.

Table 5. Annual energy saving potentialities (in terms of primary energy for space heating and DHW) and CO_2 emissions reductions by standard and advanced refurbishment for Italian residential building stock.

Reference building type	Original State		Standard Refurbishment			Advanced Refurbishment		
	$Q_{H,W,p}$	t_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}
	[10^3GWh]	[10^6t]	[10^3GWh]	[-]	[10^6t]	[10^3GWh]	[-]	[10^6t]
SFH.01	50.6	10.3	38.8	-77%	7.9	42.8	-85%	8.7
SFH.03	22.1	4.5	17.8	-81%	3.6	19.4	-88%	3.9
MFH.04	127.2	25.8	98.2	-77%	19.9	105.5	-83%	21.4
AB.05	419.5	85.2	301.2	-72%	61.2	349.9	-83%	71
AB.06	364.3	74	204.4	-56%	41.5	255.4	-70%	51.9
AB.07	76.6	15.6	32	-42%	6.5	42.3	-65%	8.6
	1060.5	215.3	692.5	-65%	140.6	815.4	-77%	165.5

Czech Republic

Six reference building types were created to represent the Czech Republic housing stock for the purpose of Energy Balance analysis. This set of buildings was categorized by size and age as shown in **Table 6**.

Table 6. Classification of the Czech Republic building stock.

Reference building type		Construction period	Number of buildings
Single Family House	SFH.1	until 1979	1'649'756
Single Family House	SFH.2	1980 – 2001	424'172
Single Family House	SFH.3	2002 – 2010	139'293
Multi-Family House and Apartment Block	APT.1	until 1979	1'277'705
Multi-Family House and Apartment Block	APT.2	1980 – 2001	574'438
Multi-Family House and Apartment Block	APT.3	2002 – 2010	165'648
			4'159'902

The buildings are theoretical buildings based on the analysis of available statistical data and on the knowledge of historical standard requirements for the U-values of the building envelope and the usual efficiency of the heating and DHW systems.

The energy balance model was created on basis of the statistical data. The delivered energy and the energy demand for space heating of the considered six groups of buildings was calculated using national calculation method.

In this case the refurbishment measures were fixed on the basis of recent studies. In fact, it was estimated by experts that by achieving U-values prescribed by the latest version of the Czech standard CSN 730540 following amount of energy can be saved:

- 20% of energy in average can be saved by applying ETICS (External Thermal Insulation Composite Systems) to the exterior walls;
- 10% of energy in average can be saved by roof insulation;
- 25% of energy in average can be saved by windows replacement;
- heating control systems would bring savings ranging approximately between 5 and 15%;
- the losses can be reduced up to 50% by insulating properly the pipes.

The above mentioned percentages were considered in the calculation energy balance model and distributed over the categories of buildings. The results are shown in **Table 7**.

Table 7. Annual energy saving potentialities (in terms of primary energy for space heating and DHW) and CO_2 emissions reductions by standard and advanced refurbishment for Czech Republic residential building stock.

Reference building type	Original State		Refurbishment		
	$Q_{H,W,p}$	t_{CO2}	$\Delta Q_{H,W,p}$	Δ% savings	Δt_{CO2}
	[10^3GWh]	[10^6t]	[10^3GWh]	[-]	[10^6t]
SFH.1	11.9	5.5	7.7	-65%	3.6
SFH.2	12.7	5.9	4.8	-38%	2.2
SFH.3	5.5	2.6	1.1	-20%	0.5
APT.1	6.1	2.9	3.2	-52%	1.5
APT.2	15.2	6.5	5.3	-35%	2.3
APT.3	5.4	2.6	1	-19%	0.5
	56.8	26	23.1	-41%	10.6

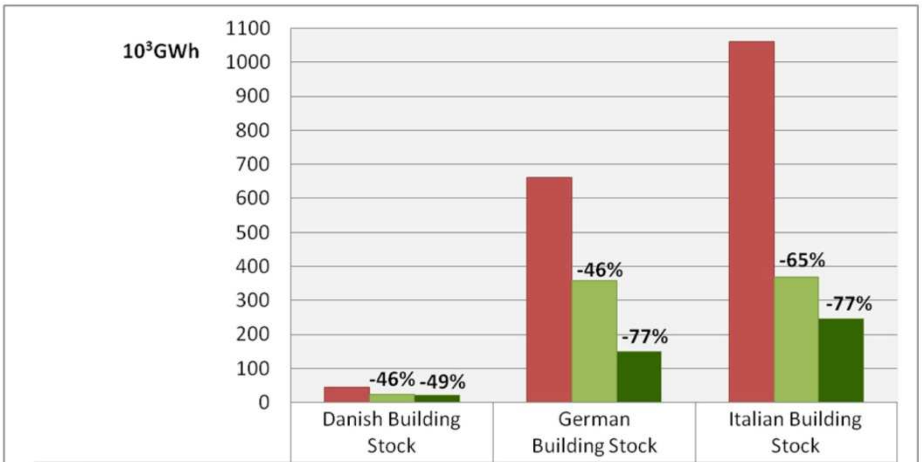
Conclusion

The analysis shows that building typologies can be a helpful tool for modelling the energy consumption of national building stocks and for carrying out scenario analyses beyond the TABULA project. The consideration of a set of representative buildings, which reflect the current state of the building national stock, makes it possible to have a detailed view on various packages of refurbishment measures for the complete buildings stock or for its sub-categories. The effects of different insulation measures at the respective construction elements as well as different system supply measures including renewable energies can be considered in detail with fast analysis.

As general rule, when two different level of retrofit were considered it is noted that the standard refurbishment is associated with high relative percentage of energy saving (**Figure 2**): the energy saving due to a standard refurbishment is bigger than the saving variation between a standard refurbishment and an advanced refurbishment. In fact, national building stock is often characterized by low energy performance and even the application of basic energy renovations may provide significant increases in energy performance and consequent reduction of CO_2 emission (the case of Italy is exemplificative of this trend). Thereby from an economic point of view it is more convenient to apply standard refurbishment measures at the national building stock than advanced ones that are the most expensive.

It was highlighted that, even with standard refurbishments, energy saving over 45% can be achieved. As a consequence of this big saving potential, suitable policies to address energy retrofit actions of existing buildings are crucial.

Finally, the quality of future model calculations will depend very much on the availability of statistical data. For reliable scenario analyses, information about the current state of the building stock and about the current trends is needed. The availability and regular update of the relevant statistical data will be an important basis for the development of energy strategies in the building sector.



	Danish Building Stock	German Building Stock	Italian Building Stock
Original State	43.6	661	1060.5
Standard Refurbishment	23.7	357	368
Advanced Refurbishment	22.1	149	245.1

Figure 2. Comparison between annual energy saving potential by applying a standard refurbishment and an advanced one to the Danish, German and Italian building stock.

References

1. TABULA Project, www.building-typology.eu
2. TABULA Project Team, *Use of Building Typologies for Energy Performance Assessment of National Building Stocks. Existent Experiences in European Countries and Common Approach*, Synthesis Report SR1, June 2010
3. TABULA Project Team, *Application of Building Typologies for Modelling the Energy Balance of the Residential Building Stock*, Thematic Report N° 2, February 2012
4. Corrado V., Ballarini I., Corgnati S., *National scientific report on the TABULA activities in Italy*, Politecnico di Torino, Torino, May 2012
5. Loga T., Diefenbach N., Stein B., Born R., *TABULA - Scientific Report. Germany Further Development of the National Residential Building Typology*, Institut Wohnen und Umwelt GmbH, Darmstadt, October 2012
6. Wittchen K. B., Kragh J., *Danish building typologies. Participation in the TABULA project*, Danish Building Research Institute, Aalborg University, Hørsholm, 2012
7. VV. AA., *National Scientific Report. Czech Republic*, STÚ-K, a.s., Prague, May 2012.

Paper II

Becchio C., Guglielmino D., Fabrizio E., Filippi M. *Metodologie di calcolo del fabbisogno di energia annuale per la climatizzazione: Risultati a confronto*. Proceeding of Congresso Nazionale sull'Edilizia Sostenibile, ISBN: 9788890449703, Torino, 7-8 Ottobre 2009

METODOLOGIE DI CALCOLO DEL FABBISOGNO DI ENERGIA ANNUALE PER LA CLIMATIZZAZIONE: RISULTATI A CONFRONTO

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Argomento di riferimento: Efficienza energetica

Abstract

Il protocollo SBC/ITACA per la certificazione di sostenibilità energetico - ambientale di edifici per uffici individua due requisiti afferenti all'area di valutazione "Energia e Consumo di risorse" (categoria "Energia non rinnovabile richiesta durante il ciclo di vita"), legati alla valutazione dei fabbisogni annui di energia primaria per la climatizzazione invernale ed estiva. Nello specifico, il protocollo attribuisce un punteggio in relazione ad un parametro, definito come il rapporto percentuale tra il valore ottenuto a calcolo (eseguito sul progetto) e il valore limite di legge. Il valore ottenuto a calcolo si determina seguendo il metodo mensile in regime quasi stazionario descritto nella norma UNI/TS 11300:2008, adottata dalla legge nazionale per la certificazione energetica degli edifici (D.P.R. 2 aprile 2009, n°59).
In questo lavoro viene eseguito il calcolo del fabbisogno di energia primaria per la climatizzazione invernale ed estiva applicato ad un caso studio, costituito da un edificio per uffici multipiano con involucro leggero, situato in zona climatica E. Il fabbisogno è stato valutato seguendo due metodi: il primo basato sul calcolo in regime quasi stazionario eseguito con condizioni al contorno standard come indicato dalla UNI/TS 11300:2008; il secondo basato su una simulazione dinamica eseguita con un software di simulazione termo-energetica dettagliato (EnergyPlus).
Gli output di calcolo ottenuti vengono posti a confronto, quantificando le differenze tra il calcolo in regime quasi stazionario e quello in regime dinamico.

1. Introduzione

La recente produzione legislativa nel settore dell'efficienza energetica degli edifici ha portato all'emanazione del D.P.R. 2 aprile 2009, n°59 "Regolamento di attuazione dell'articolo 4, comma 1, lettere a) e b), del decreto legislativo 19 agosto 2005, n. 192, concernente attuazione della direttiva 2002/91/CE sul rendimento energetico in edilizia". In particolare all'interno di tale documento si riconosce nella norma UNI/TS 11300:2008 lo strumento che descrive la procedura di calcolo da seguire per la Certificazione Energetica degli edifici. La parte prima della suddetta norma recepisce la metodologia semplificata per il calcolo mensile dei fabbisogni di energia netta per la climatizzazione invernale ed estiva in regime quasi stazionario proposta dalla norma UNI EN ISO 13790:2008, con alcuni adattamenti relativi alle tipologie costruttive italiane per quanto riguarda i parametri dinamici (fattore di utilizzazione delle perdite, Corrado e Fabrizio, 2007 e 2008). La parte seconda della norma concerne il calcolo del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale e per la produzione di acqua calda sanitaria. E' in fase di emanazione, al momento della stesura del presente testo, la parte terza (conclusa la procedura di inchiesta pubblica), relativa alla determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione estiva.
Il protocollo di certificazione di sostenibilità energetico - ambientale SBC/ITACA, all'interno dell'area di valutazione B denominata "Energia e consumo di risorse", categoria B1 "Energia non rinnovabile richiesta durante il ciclo di vita", individua due requisiti, B.1.1. e B.1.2. corrispondenti ai fabbisogni annui di energia primaria per la climatizzazione invernale ed estiva. Il metodo di calcolo da seguire secondo tale protocollo per il soddisfacimento dei due requisiti citati è quello riportato all'interno della norma UNI/TS 11300.
All'interno della memoria verrà presentata un'applicazione di calcolo del fabbisogno di energia per la climatizzazione invernale ed estiva, eseguito secondo tale metodo su un caso di studio, a confronto con i risultati di un calcolo in regime dinamico eseguito con un software di simulazione termo-energetica. Si propone per tale analisi un caso di studio costituito da un edificio per uffici multipiano caratterizzato da un involucro leggero, con un'elevata percentuale di superficie trasparente rispetto al totale delle chiusure verticali.

2. Il protocollo SBC/ITACA

SBC Italia (*Sustainable Building Council*), in collaborazione con iiSBE Italia (*International Initiative for Sustainable Built Environment*), ITC CNR (Istituto per la Tecnologia delle Costruzioni/Consiglio Nazionale per la Ricerca) e ITACA (Istituto per l'Innovazione e la Trasparenza degli appalti e la Compatibilità Ambientale) ha sviluppato e gestisce, attraverso il Protocollo SBC/ITACA (Tabella 1) un sistema di certificazione della sostenibilità energetico - ambientale degli edifici. Tale sistema è basato sulla metodologia SB-Method, che costituisce uno sviluppo dell'attività GBC (Green Building Challenge) lanciata nel 1996 dal Natural Resources Canada (NRC).
La stesura del protocollo ITACA nella sua prima versione datata 2002 contemplava il patrocinio di tutte le Regioni d'Italia, del Consiglio Superiore dei lavori pubblici, di Environment Park (Torino), del ARPA Regione Sicilia ITACA, del APAT, e del Politecnico di Bari. Attualmente il protocollo fa parte di SBC – Italia ed ha attraversato una serie di rielaborazioni che ne hanno modificato alcuni aspetti, tra cui la definizione di diversi documenti suddivisi in ragione delle destinazioni d'uso degli edifici.

Tabella 1 Indice delle aree di valutazione del sistema SBC/ITACA protocollo per uffici (SBT Uffici 1.1)

Area di valutazione	Contenuto
A. Selezione del Sito, Project Planning e Pianificazione Urbanistica	Condizioni del sito e accessibilità ai servizi
B. Energia e Consumo di Risorse	Energia primaria non rinnovabile richiesta per il ciclo di vita, fonti rinnovabili, uso di acqua, materiali
C. Carichi Ambientali	Emissioni di biossido di carbonio, acque reflue e impatto nell'ambiente circostante
D. Qualità ambientale interna	Comfort termico, acustico, visivo IAQ e inquinamento elettromagnetico
E. Qualità del servizio	Gestione e controllo del sistema impiantistico, domotica, mantenimento delle prestazioni in esercizio

3. Il caso di studio

Il caso di studio è costituito da un edificio per uffici di 20 piani fuori terra (Figura 1), situato in zona climatica E.

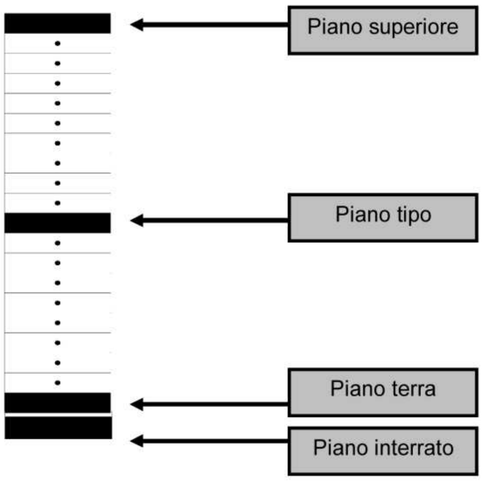

Figura 1 Schematizzazione del caso studio.

Tale oggetto edilizio si presenta con una pianta rettangolare orientata con i due lati maggiori ad Est ed Ovest ed i due lati minori a Nord e Sud. Non sono presenti ostacoli esterni nel contesto in cui l'edificio è inserito. Il volume netto riscaldato dell'intero blocco è pari a 78.500 m^3, mentre la superficie disperdente complessiva è pari a 26.000 m^2. Il rapporto S/V è pertanto di 0,25 m^{-1}. Il piano tipo presenta una superficie lorda di pavimento di circa 1.400 m^2, di cui circa 1.000 m^2 destinati ad ufficio e i rimanenti occupati dai servizi e dalla distribuzione verticale, che costituiscono il nucleo centrale della costruzione; l'altezza interpiano è pari a 3,7 m. Per ogni piano fuori terra, la superficie vetrata a Nord è pari a circa il 50% della chiusura verticale, mentre per le esposizioni Est ed Ovest è pari circa al 70%; a Sud il 35% della parete perimetrale è costituito da una superficie vetrata, che separa gli ambienti interni climatizzati da una serra. Il caso di studio presenta una struttura portante in calcestruzzo armato e solai massivi in calcestruzzo. Nella Tabella 2 si riportano le prestazioni termofisiche dei componenti di involucro opaco e trasparente. Sono previsti dei dispositivi di schermatura on-off che entrano in funzione in relazione all'irradianza solare incidente sulla superficie (tarati a 300 W/m^2).

Tabella 2 Principali parametri prestazionali dell'involucro edilizio

Chiusure opache		Chiusure trasparenti	
U [W/(m^{2}K)]	0,109	U [W/(m^{2}K)]	1,72
m [kg/m^2]	100	g_{gl} [-]	0,35
κ_i [kJ/(m^{2}K)]	22,4	g_{gl+sh} [-]	0,7
ε [-]	0,9	ε [-]	0,4

Il sistema energetico accoppiato all'edificio viene descritto in Tabella 3.

Tabella 3 Caratteristiche del sistema energetico

Sottosistema di emissione	Sottosistema di generazione	
Ventilconvettori a 4 tubi con presa d'aria esterna	Riscaldamento Caldaia a condensazione a gas	Raffrescamento Gruppo frigorifero a compressione di vapore condensato ad aria

4. Modelli di calcolo

Nel seguito vengono presentate le procedure di calcolo rispettivamente con riferimento alla norma UNI/TS 11300:2008 e con il codice di calcolo di EnergyPlus. Il primo step dell'analisi svolta riguarda il calcolo in regime quasi stazionario, per il quale si è applicata la procedura illustrata dalla norma UNI/TS 11300-1:2008 per la determinazione dei fabbisogni di energia netta per la climatizzazione invernale ed estiva. Secondo tale norma si definisce il fabbisogno di energia netta per la climatizzazione invernale come segue:

$$Q_{H,nd} = Q_{H,tr} + Q_{H,ve} - \eta_{H,gn} \cdot (Q_{\text{int}} + Q_{sol}) \quad (1)$$

Le grandezze che definiscono la quota parte di dispersioni all'interno del valore di fabbisogno ambientale netto teorico per il riscaldamento invernale si ottengono rispettivamente come segue:

$$Q_{H,tr} = \left[H_{tr,adj} \cdot (\theta_{\text{int},set,H} - \theta_e) \cdot t\right] + \left[\left(\sum_k F_{r,k} \cdot \Phi_{r,mn,k}\right) \cdot t\right] \quad (2)$$

$$Q_{H,ve} = \left[H_{ve,adj} \cdot (\theta_{\text{int},set,H} - \theta_e) \cdot t\right] + \left[\left(\sum_k F_{r,k} \cdot \Phi_{r,mn,k}\right) \cdot t\right] \quad (3)$$

Le grandezze che definiscono gli apporti gratuiti, moltiplicati per il relativo coefficiente di utilizzazione sono:

$$Q_{\text{int}} = \left[\left(\sum_k \Phi_{\text{int},mn,k}\right) \cdot t\right] + \left\{\left[\sum_l (1 - b_{tr,l}) \cdot \Phi_{\text{int},mn,u,l}\right] \cdot t\right\} \quad (4)$$

$$Q_{sol} = \left[\left(\sum_k \Phi_{sol,mn,k}\right) \cdot t\right] + \left\{\left[\sum_l (1 - b_{tr,l}) \cdot \Phi_{sol,mn,u,l}\right] \cdot t\right\} \quad (5)$$

Per quanto attiene al calcolo del fabbisogno netto per la climatizzazione estiva esso viene definito come segue:

$$Q_{C,nd} = (Q_{\text{int}} + Q_{sol}) - \eta_{C,gn} \cdot (Q_{C,tr} + Q_{C,ve}) \quad (6)$$

Le grandezze che definiscono la quota parte di scambi termici all'interno del valore di fabbisogno ambientale netto teorico per il raffrescamento estivo si ottengono rispettivamente come segue:

$$Q_{C,tr} = \left[H_{tr,adj} \cdot (\theta_{\text{int},set,C} - \theta_e) \cdot t\right] + \left[\left(\sum_k F_{r,k} \cdot \Phi_{r,mn,k}\right) \cdot t\right] \quad (7)$$

$$Q_{C,ve} = \left[H_{ve,adj} \cdot \left(\theta_{int,set,C} - \theta_e\right) \cdot t\right] + \left[\left(\sum_k F_{r,k} \cdot \Phi_{r,mn,k}\right) \cdot t\right] \qquad (8)$$

Le grandezze che definiscono gli apporti gratuiti sono calcolate nello stesso modo rispetto al calcolo per il riscaldamento.

In un secondo momento, il calcolo è stato ripetuto attraverso l'applicazione di un modello di simulazione dinamica. Quest'ultima è stata condotta attraverso il codice di calcolo di EnergyPlus v3.1, nato nel 2001 sulle esperienze dei software statunitensi DOE-2 (implementato dal Department of Energy) e BLAST (implementato dal Department of Defence).
La modellazione della geometria del caso di studio è stata eseguita con il software DesignBuilder versione 2.0.1, che si presenta all'utenza con un'interfaccia user friendly, che consente un più rapido caricamento dei dati di input.

5. Confronto tra i dati di ingresso

I dati di ingresso utilizzati sono fissati coerentemente con un calcolo eseguito con condizioni al contorno standard. Tali dati possono essere suddivisi in quattro categorie: dati relativi all'edificio (caratteristiche tipologiche, termiche, costruttive ed impiantistiche), dati climatici, dati relativi alle modalità di occupazione e di uso dell'edificio stesso e dati relativi all'impianto utilizzato. Al fine di rendere confrontabili i risultati ottenuti attraverso il metodo quasi stazionario e la simulazione dinamica, è necessario che i dati di input siano congruenti per entrambe le simulazioni.

Dalla Tabella 4 emerge come il metodo suggerito dalla norma UNI/TS 11300-1:2008 proponga un calcolo eseguito utilizzando la temperatura esterna media mensile. Tale semplificazione esclude a priori la possibilità di tenere in conto i picchi termici giornalieri, che emergono invece all'interno di un profilo orario, come quello utilizzato dalla simulazione dinamica.

Tabella 4 Confronto sintetico dei dati di input utilizzati

Dati di input		Simulazione in regime quasi stazionario	Simulazione in regime dinamico
Dati climatici: Torino (zona climatica E)		Dati medi mensili ricavati dall'anno tipo IWEC	Anno tipo IWEC
Dati relativi alle modalità di occupazione e di uso dell'edificio	Apporti interni	Si considerano apporti medi globali pari a 6 W/m²	
	Gestione dei dispositivi di schermatura interni mobili	Si considera la schermatura mobile attiva per irradianze solari superiori a 300 W/m²	
	Ventilazione	Si considerano tutti gli ambienti ventilati con un tasso netto di rinnovo pari a 0,3 vol/h	
Dati relativi all'impianto	Periodo di riscaldamento	In funzione della zona climatica	
	Profilo di funzionamento dell'impianto	Continuo sulle 24h	
	Temperatura interna di set point	Pari a 26℃ in estate e 20℃ in inverno	
	Rendimenti dei sottosistemi	Valori tratti dalla simulazione dinamica effettuata con EnergyPlus	

6. Discussione dei risultati

Nella Figura 2 sono riportati i fabbisogni netti di energia per la climatizzazione invernale ed estiva nei due modelli di calcolo. Il fabbisogno netto di energia per riscaldamento è pari a 8,13 kWh/m^{3}anno e a 6,87 kWh/m^{3}anno rispettivamente per il calcolo effettuato con modello quasi-stazionario e con modello dinamico; il fabbisogno netto per raffrescamento è pari a 1,71 kWh/m^3 anno e 1,85 kWh/m^3 anno rispettivamente per calcolo effettuato con modello quasi-stazionario e con modello dinamico.
Nella Figura 3 sono invece rappresentati i fabbisogni di energia primaria. In particolare, l'EP_i risulta pari a 8,64 kWh/m^{3}anno e 7,31 kWh/m^3 anno rispettivamente per calcolo effettuato con modello quasi-stazionario e con modello dinamico; l'$EP_{e,invol}$ risulta pari a 0,74 kWh/m^3 anno e a 0,81 kWh/m^3 anno.
Nelle Figure 4 e 5 si rappresentano invece i confronti con i valori limite di legge dei rispettivi indici. In Tabella 5 sono riportati i rapporti tra gli indici di prestazione energetica, calcolati nei due diversi regimi, e i rispettivi valori limite di legge. In particolare, l'EP_i calcolato in regime quasi stazionario risulta essere pari al 66% del valore limite di legge, mentre quello calcolato in regime dinamico è pari al 54%; l'$EP_{e,invol}$ calcolato in regime quasi stazionario è pari al 17% del valore limite di legge, mentre quello calcolato in regime dinamico è pari al 19%.

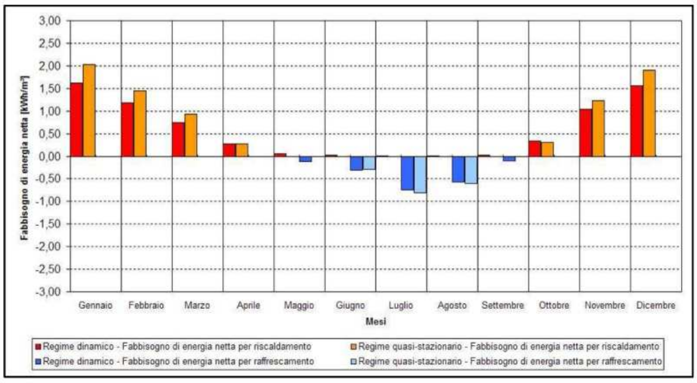

Figura 2 Valori mensili del fabbisogno netto di energia per la climatizzazione invernale ed estiva – Confronto tra calcolo in regime dinamico e calcolo in regime quasi stazionario

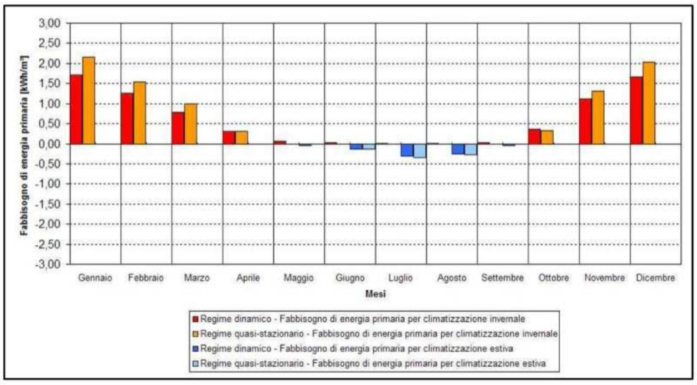

Figura 3 Valori mensili del fabbisogno di energia primaria per la climatizzazione invernale ed estiva – Confronto tra calcolo in regime dinamico e calcolo in regime quasi stazionario

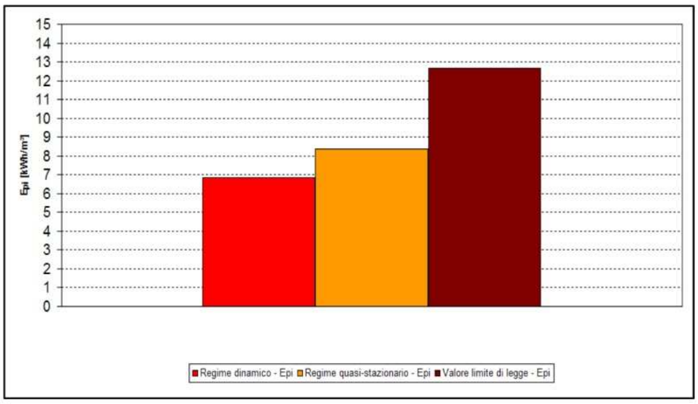

Figura 4 Indici di prestazione energetica per la climatizzazione invernale - Confronto tra calcolo in regime dinamico, in regime quasi stazionario e valore limite di legge.

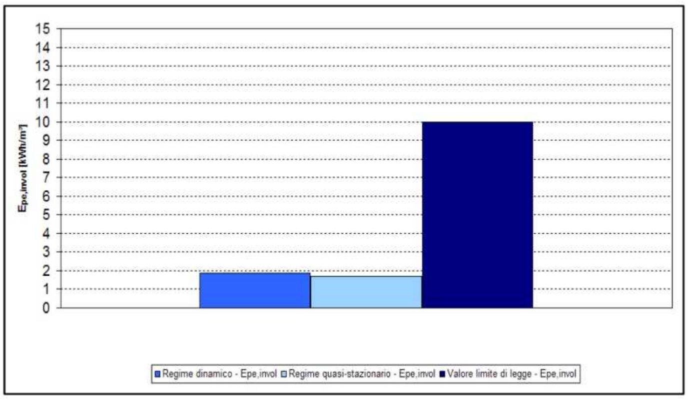

Figura 5 Indici di prestazione termica dell'edificio per raffrescamento estivo ai sensi del DM. 26/06/2009 - Confronto tra calcolo in regime dinamico, in regime quasi stazionario e valore limite di legge.

Tabella 5 Rapporti tra gli indici di prestazione energetica, calcolati in regime quasi stazionario ed in regime dinamico, ed i rispettivi valori di legge

$EP_i / EP_{i\ limite}$		$EP_{e,invol} / EP_{e,invol\ limite}$	
Regime quasi stazionario	Regime dinamico	Regime quasi stazionario	Regime dinamico
0,66	0,54	0,17	0,19

I risultati dell'applicazione del metodo quasi-stazionario, da utilizzarsi nell'SBTool, appaiono conservativi rispetto ai risultati ottenuti attraverso l'applicazione di un metodo dinamico nel caso invernale, mentre leggermente sottostimati nel caso estivo, infatti:
- il fabbisogno di energia netta per la climatizzazione invernale Q_H calcolato col metodo quasi-stazionario è maggiore del 15,5% rispetto a quello calcolato in regime dinamico;
- il fabbisogno di energia netta per la climatizzazione estiva Q_C calcolato in regime dinamico è maggiore di circa l'8% rispetto a quello calcolato in regime quasi stazionario.

Da sottolineare come nella località presa a riferimento per il caso di studio, nel periodo di raffrescamento, i valori di temperatura media mensile non superano mai la temperatura di set point interna. Per tale ragione lo scambio termico mensile di trasmissione e ventilazione calcolato attraverso l'involucro si considera uscente.

7. Conclusioni

In generale, si osserva come nel confronto tra risultati di calcoli provenienti dall'applicazione di diversi modelli, non sia possibile effettuare un confronto *tout-court* tra i dati di fabbisogno energetico ricavati attraverso la simulazione dinamica e quelli di fabbisogno energetico calcolati attraverso il metodo quasi-stazionario. Ciò è dovuto al fatto che vi sono una serie di fenomeni fisici (tra cui lo scambio termico col terreno, lo scambio termico con la volta celeste, l'effetto della capacità termica interna, l'effetto di schermi) la cui modellazione differisce nei due regimi di calcolo, e una serie di condizioni al contorno (tra cui quelle meteoclimatiche) i cui valori variano tra un modello e l'altro. Per poter operare un confronto significativo tra i risultati ottenuti con due modelli di calcolo così diversi come uno di tipo quasi-stazionario ed uno di tipo dinamico, è necessario effettuare una serie di assunzioni volte a neutralizzare l'effetto delle diverse condizioni al contorno e modellazioni di calcolo.

Nel caso studio specifico, avendo fissato in modo il più possibile convergente tutte le condizioni al contorno tra i due modelli (ventilazione, scambio termico col terreno, scambio termico con la volta celeste, gestione della schermatura, dati climatici, ponti termici, scambio termico con ambienti non climatizzati), è stato possibile confrontare i risultati. In molti casi tuttavia ciò comporta l'adozione di semplificazioni coerenti con il metodo meno dettagliato, che possono non essere coerenti con le finalità del calcolo (ad esempio valutare l'influenza di un sistema di ventilazione notturna).

8. Nomenclatura

s	[m]	Spessore
U	[W/(m^{2}K)]	Trasmittanza termica
m	[kg/m^2]	Massa superficiale

ki	[J/(m^{2}K)]	Capacità termica areica interna
ε	[-]	Emissività relativa alla radiazione termica ad elevata lunghezza d'onda
ggl	[-]	Trasmittanza di energia solare totale
ggl+sh	[-]	Trasmittanza di energia solare totale con schermatura utilizzata
$Q_{H,nd}$	[J]	Fabbisogno ideale di energia termica dell'edificio per riscaldamento
$Q_{H,tr}$	[J]	Scambio termico per trasmissione nel caso di riscaldamento
$Q_{H,ve}$	[J]	Scambio termico per ventilazione nel caso di riscaldamento
$Q_{C,nd}$	[J]	Fabbisogno ideale di energia termica dell'edificio per raffrescamento
$Q_{C,tr}$	[J]	Scambio termico per trasmissione nel caso di raffrescamento
$Q_{C,ve}$	[J]	Scambio termico per ventilazione nel caso di raffrescamento
Q_{int}	[J]	Apporti termici interni
Q_{sol}	[J]	Apporti termini solari
$H_{tr,adj}$	[W/K]	Coefficiente globale di scambio termico per trasmissione, corretto per tener conto della differenza di temperatura interno-esterno
$H_{ve,adj}$	[W/K]	Coefficiente globale di scambio termico per ventilazione, corretto per tener conto della differenza di temperatura interno-esterno
$F_{r,k}$	[-]	Fattore di forma tra il componente edilizio k-esimo e la volta celeste
$\Phi_{r,mn,k}$	[W]	Extra flusso termico dovuto alla radiazione infrarossa verso la volta celeste dal componente edilizio k-esimo, mediato nel tempo
$\Phi_{int,mn,k}$	[W]	Flusso termico prodotto dalla k-esima sorgente di calore interna mediata nel tempo
$\Phi_{sol,mn,k}$	[W]	Flusso termico k-esimo di origine solare mediato nel tempo
$\Phi_{int,mn,u,I}$	[W]	Flusso termico prodotto dalla l-esima sorgente di calore nell'ambiente adiacente non climatizzato, mediato nel tempo
$\Phi_{sol,mn,u,I}$	[W]	Flusso termico l-esimo di origine solare nell'ambiente adiacente non climatizzato, mediato nel tempo
$b_{tr,l}$	[-]	Fattore di riduzione per l'ambiente non climatizzato avente la sorgente di calore interna l-esima, oppure il flusso termico l-esimo di origine solare
η	[-]	Fattore di utilizzazione degli apporti gratuiti
$\theta_{int,set,H}$	[℃]	Temperatura interna di set-point invernale
$\theta_{int,set,C}$	[℃]	Temperatura interna di set-point estiva
θ_e	[℃]	Temperatura media mensile dell'ambiente estern o

9. Bibliografia

Corrado V., Paduos S. 2008. *La nuova legislazione sull'efficienza energetica degli edifici*. Requisiti e metodi di calcolo, CELID, Torino.

Carletti C., Sciurpi F. 2008. *Edifici a basso consumo energetico*, in "CDA" n. 10/2008.

Corrado V., Fabrizio E. 2007. *Assessment of building cooling energy need through a quasi-steady state model: simplified correlation for gain-loss mismatch,* Energy and Buildings, ISSN 0378-7788, vol. 39, n. 5 (2007), pp. 569-579.

Corrado V., Fabrizio E. 2008. *Il significato del fattore di utilizzazione nel calcolo semplificato del fabbisogno termico degli edifici, aspetti teorici e applicativi*, Atti del convegno AICARR Torino, 25 novembre 2008.

Corrado V., Ballarini I. 2008. *La nuova normativa tecnica nazionale ed europea quale risposta ai requisiti di accuratezza, semplicità, riproducibilità, e trasparenza nelle procedure di certificazione energetica*, Atti del convegno AICARR Torino, 25 novembre 2008.

Ferrari S., Baldinazzo M. 2008. *Valutazione delle prestazioni energetiche degli edifici: dalle norme sem plificate all'analisi dinamica*, Atti del convegno AICARR Torino 25 novembre 2008.

Fabrizio E. 2009. *Strumenti per la stima dei consumi energetici*, in "CDA" n. 02/2009.

DECRETO LEGISLATIVO 29 dicembre 2006, n. 311 Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia.

MINISTERO DELLO SVILUPPO ECONOMICO DECRETO - 11 marzo 2008 *Attuazione dell'articolo 1, comma 24, lettera a), della legge 24 dicembre 2007, n. 244, per la definizione dei valori limite di fabbisogno di energia primaria annuo e di trasmittanza termica ai fini dell'applicazione dei commi 344 e 345 dell'articolo 1 della legge 27 dicembre 2006, n. 296.*

DECRETO DEL PRESIDENTE DELLA REPUBBLICA 2 aprile 2009, n. 59 *Regolamento di attuazione dell'articolo 4, comma 1, lettere a) e b), del decreto legislativo 19 agosto 2005, n. 192, concernente attuazione della direttiva 2002/91/CE sul rendimento energetico in edilizia.*

UNI 10339:1995 *Impianti aeraulici al fine di benessere. Generalità, classificazione e requisiti. Regole per la richiesta, l'offerta, l'ordine e la fornitura.*

EN ISO 13786:2007 *Thermal performance of building components – Dynamic thermalcharacteristics - Calculation methods (ISO 13786:2007)*

UNI EN ISO 13790:2008 *Prestazioni energetiche degli edifici –Calcolo del fabbisogno di energia per il riscaldamento e il raffrescamento.*

UNI/TS 11300-1:2008 *Prestazioni energetiche degli edifici – Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale.*

UNI/TS 11300-2:2008 *Prestazioni energetiche degli edifici – Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale e per la produzione di acqua calda sanitaria.*