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Technology options for earthquake resistant, eco-efficient buildings in Europe: Research needs

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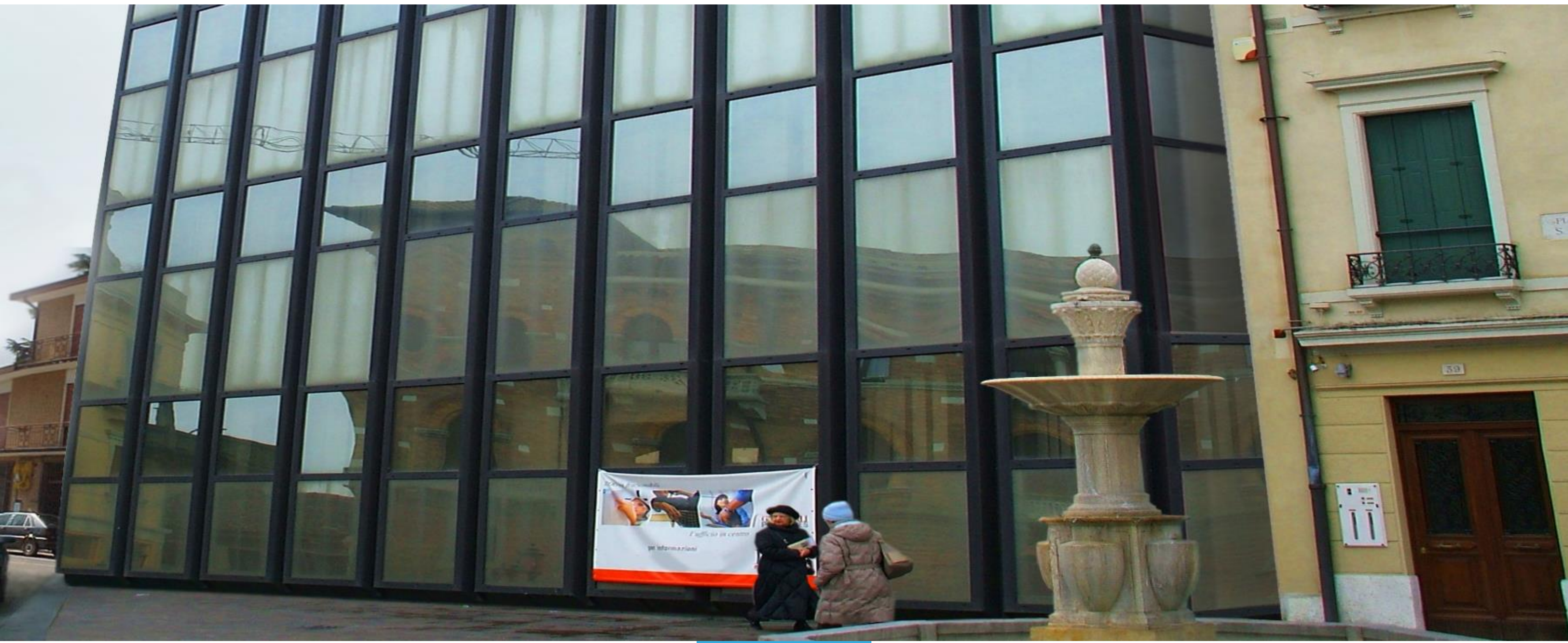

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ABSTRACT

The construction sector corresponds to the largest industrial sector not only in economic terms, but also in terms of resource flow. Moreover, European citizens spend most of their lives inside buildings, therefore buildings turn out to be at the centre of social and economic activity.
In that light, Europe is involved in several initiatives and strategies aimed at making this sector one of the most competitive and innovative, focusing on the achievement of the environmental and energy targets in line with 2020 Europe Strategy and EU 2050 roadmap, but also ensuring safety both in ordinary conditions and in presence of exceptional events, such as earthquakes.
While new buildings can be constructed with high performance levels, the older buildings typically need renovation measures, because of their low energy performance and seismic vulnerability.

This report has the aim to define the research needs for exploiting old buildings potential to deliver energy and CO_2-emission savings and seismic performance improvement, as well as societal and economic benefits, so that energy efficient and earthquake resistant buildings can have a pivotal role in a sustainable future.
In the first part of the report, a detailed analysis of the main characteristics of European buildings in terms of age, size, ownership, location, structural typology is presented in order to define the predominant typology of the European existing building stock; the seismic hazard in Europe and the earthquake vulnerability of European buildings are then analysed; and finally, energy consumptions and environmental impacts in terms of use of resources, construction and demolition (C&D) wastes and CO_2 emissions are described.
The analysis of the present situation turns out to be essential in order to define the starting point to assess the current and new technology options, examined in the second part of the report and necessary to obtain eco-efficient and seismic resistant buildings. In addition, benefits that a renovation project could bring against a demolition and reconstruction programme have been underlined.
Once these inputs have been defined, the requalification needs and the importance to improve renovation strategies, considered as outputs of the analysis, are examined for each of the two abovementioned parts of this study.
Finally, a critical discussion on the importance of considering research needs for this topic has been carried out, with a focus on barriers and challenges that could be found during a renovation programme

CONTENTS

INTRODUCTION

The study of new technology options for the improvement of the techniques in the construction sector should be based on the actual needs of the existent buildings. This requires a sound knowledge of the existing building stock consistency and of the current available technologies.

The analyses of the European building stock show that about 40% of existing buildings in Europe were built before the 60's and are all characterized by very poor energy efficiency, high seismic vulnerability, living discomfort and often low architectural and urban quality.

In particular, the construction sector is one of the key consumers of **energy** in Europe; it is acknowledged to use 50% of materials, to generate 30% of waste and to consume 40% of the total EU energy. Buildings demand energy during their whole life cycle both directly and indirectly. Direct energy demand is necessary for their construction, operation and possible demolition; energy is required and consumed also indirectly for the possible mining, processing and production of the construction materials. Furthermore, the energy performance of the larger portion of the European building stock is generally so poor that the enormous consumed energy levels place the construction sector among the most significant CO_2 emissions sources. The construction sector has therefore a huge impact on the economic, ecological and social environment.

The European targets in terms of efficient use of natural resources and mitigation of the environmental impact require on this sector an immediate virtuous action. Europe 2020 is the European Union ten-year growth strategy to promote the shift towards a resource-efficient, low-carbon economy and aims at creating the conditions for a different type of growth that is smarter, more sustainable and more inclusive than the nowadays growth model. Among the main aims of the Europe 2020 strategy, challenging energy targets have been set for the EU to achieve by the end of the decade, namely: (i) greenhouse gas emissions 20% (or even 30%, if the conditions are right) lower than 1990; (ii) 20% of energy from renewables; (iii) 20% increase in energy efficiency. As a further reference for the European future development, the EU 2050 Roadmap imposes a reduction of the CO_2 emissions by 80-95% by 2050, thus pursuing near total decarbonisation of the energy system.

The recent economic crisis has dramatically reduced investments in the construction sector in all the European countries and the number of new buildings is significantly decreased. With this trend, the sole construction of new structures will not allow to significantly enhance the energy performances of the European building stock, on the contrary in this context the extensive construction of new buildings can only worsen the situation.

For all these reasons, older and more obsolete buildings, representing the vast majority of the European existing building stock, are associated to the largest energy saving potential. Accordingly, they should be the main object of new research proposals and requalification projects in order to meet the envisioned European targets.

Another important issue to take into account in the improvement of the construction technology options is the **structural safety** of buildings. In recent years, the new construction codes (e.g. the new Eurocodes) have strengthened the requirements on both the static and dynamic performances of buildings, therefore the structures built after the introduction of these codes are acknowledged as structurally safe. Main problems arise again in the existent building stock, which is also often structurally obsolete and inadequate.

As a matter of fact, most of the existing buildings have already exhausted their design service life (50 years) and now require structural safety assessment and possible renovation interventions to maintain their service functionality. Most buildings were designed and erected without any seismic safety standard or any reference to good anti-seismic construction practice, and with static loads lower than those currently required. In seismic prone areas, such as in the southern Mediterranean European countries, frequent earthquakes emphasise the serious structural deficiencies of the older structures, and their seismic vulnerability is so high that entire city neighbourhoods are devastated, with intolerable casualties and losses. Furthermore, some concern about seismic risk has been recently raised also in other parts of Europe, not traditionally considered prone to earthquakes.

In this scenario, the only way to satisfy the European energy targets and the safety requirements is the **renovation of European building stock**. This renovation can be pursuit in two ways: 1) with the demolition of the existing buildings and the construction of new buildings with high seismic and energy performances, or 2) with the **refurbishment of the existing structures**. The first solution is certainly easier, because along with the design and the construction of new structures, all codes requirements and suggestions can be satisfied and best construction practice can be implemented, however resulting in extremely high impact on the environment. The real challenge for the research community is therefore to conceive and develop innovative technologies to refurbish the existing building stock, in order to reach at the same time a significant improvement from the energy efficiency and structural safety point of view.

Scope of the present publication is to identify possible research needs for the assessment of the technology options for earthquake resistant, eco-efficient buildings. This aim is achieved by: 1) providing a wide overview on the current state of the art of the European building stock, paying attention to its seismic vulnerabilities, energy deficiencies and to the great impact of the construction sector on the environment, in order to identify the requalification needs that possible new technology options should respond to; 2) presenting strengths and drawbacks of current technology options.

In the First Chapter of this document, the main features of the European building stock are presented (age, size, ownership, location, structural typology) and their energy, seismic and eco-efficient performances are evaluated.

In the Second Chapter, focus is made on the most frequently applied technology options for earthquake resistant, eco-efficient buildings and their strength and drawbacks are critically commented.

Finally, in Third Chapter concluding remarks are drawn, together with a critical discussion of the possible research needs. The salient features of a possible innovative integrated approach aimed at solving all the identified deficiencies of these buildings is illustrated in the concluding paragraphs, together with a brief comment on the possible barriers and challenges that the development of such a renovation strategy could run into.

This document is arranged according to an input-output approach. Each chapter is subdivided in part ‘A’, concerning the state of the art, and part ‘B’, in which remarks and insights on research needs are briefly discussed. This approach is intended to help the reader, who can choose to skip the presentation of the state of the art and directly find in the part ‘B’ the main description of the as-is situation of buildings and technologies and the related comments.

The main sources of information for the development of this report are the documents released by European research centres; all the consulted and quoted documents are listed in the final references.

1. THE CONSISTENCY OF EUROPE'S BUILDINGS TODAY

To assess the technology options for earthquake resistant, eco-efficient buildings in Europe it is important to know the actual consistency of the European buildings and their requalification needs.

Some characteristics are fundamental to determine **the state of preservation and the performances of the European buildings**, namely: the number of buildings and their geographical location, the typology (residential or non-residential, single houses or blocks), the time of construction and size, the housing quality and the construction technology (structural typology and materials). These buildings have then to be studied to define their main deficiencies in terms of seismic and energy performances. Only an analysis of these features can give a comprehensive overview on the requalification needs of the European building stock that are the basis and the reason for any technology option.

Other features should be considered to assess the actual feasibility of the available technology options: the public or private ownership and the tenure of the buildings can influence the rate of refurbishment and the feasibility of any renovation measures; the location of the buildings in the urban context can lead to economies of scale in the case of large-scale renovation programs. These are all important issues that must be reckoned with and taken into account in the assessment of new technology options and in the proposal of new political measures.

In this Chapter an in depth-analysis of the European building stock is reported in part ‘A’, where statistical data on European building stock are collected and commented. Aim of this initial overview is to present the as-is situation and to define a list of the most representative benchmark building types, also accounting for their geographical location. The analysed data were mainly gathered from the Eurostat database and from other national statistical documents; reports released by European Institutes such as BPIE (Building Performance Institute Europe) and OTB Research Institute for the Build Environment (Delft University of Technology) were also considered, together with some already accomplished European projects, such as the IMPRO-Building and the TABULA, both focusing on residential buildings in Europe.

The earthquake vulnerability, the energy performance of the building stock and the impacts on the environment of the construction sector are then discussed in order to assess possible requalification needs. Based on this study, a brief overview of the requalification needs is presented in part ‘B’.

1A 'As is' situation

1A.1 BUILDINGS' TYPOLOGY [1]

Buildings in Europe vary remarkably in terms of their function, typology and main architectural and technological features. Accordingly, the requalification needs of existing buildings can be very different depending on the age of construction, the location, the structural typology and the material characteristics.

It is estimated that there are 25 billion m^2 of **useful floor space** (the dwelling floor area measured inside the outer walls) in the EU27[2], Switzerland and Norway (BPIE, 2011). The gross floor space, that comprehends the total area of all the floors of a building as measured from the exterior surfaces, could be concentrated in a land area equivalent to that of Belgium (30,528 km^2). Dividing the European country into three regions, based on building typology, climatic and market similarities, it is possible to note that half of the total estimated floor space is located in the North & West region of Europe while the remaining 36% and 14% are contained in the South and Central & East regions, respectively (Figure 1) (BPIE, 2011).

Geographical location is of course fundamental as seismic refurbishment is more needed in seismic prone areas, whereas energy efficiency upgrade should be relevant throughout all Europe.

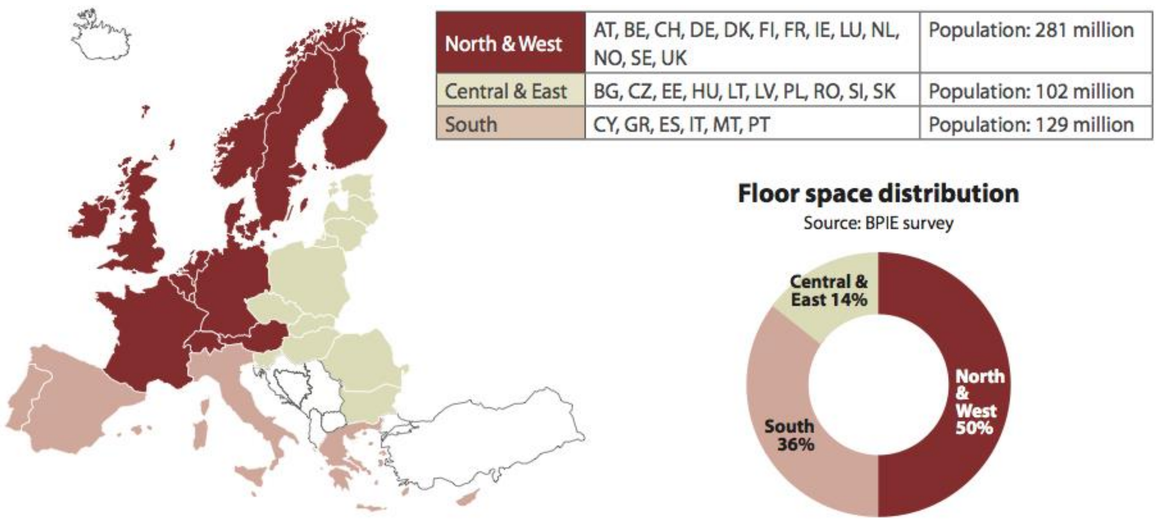


Figure 1 - Floor space distribution and population in the European countries (BPIE 2011)

Annual growth rate in the residential sector is around 1%, while most countries encountered a decrease in the rate of new building construction in the recent years, reflecting the impact of the current financial crisis on the construction sector (BPIE, 2011).

Detailed data about country level population and residential building stock were the basis for a first cataloguing of buildings according to age and size, ownership, location and housing quality. The results of the TABULA research on a representative set of building types for each country were then presented, and for these building types structural typology, materials and secondary element consistency and components were defined.

[1] Data and comments reported in this Chapter are mainly quoted from the BPIE document (BPIE, 2011).
[2] BPIE document, licensed in 2011, makes references to EU27, which refers to the European Union States prior to the access of Bulgaria, occurred in 2013.

Residential and Non-residential

A major division of the European building stock is into residential and non-residential sector, where each sector alone consists of multiple types. A BPIE survey analyses the distribution of the useful floor space per capita for each country in residential and non-residential floor space (Figure 2).

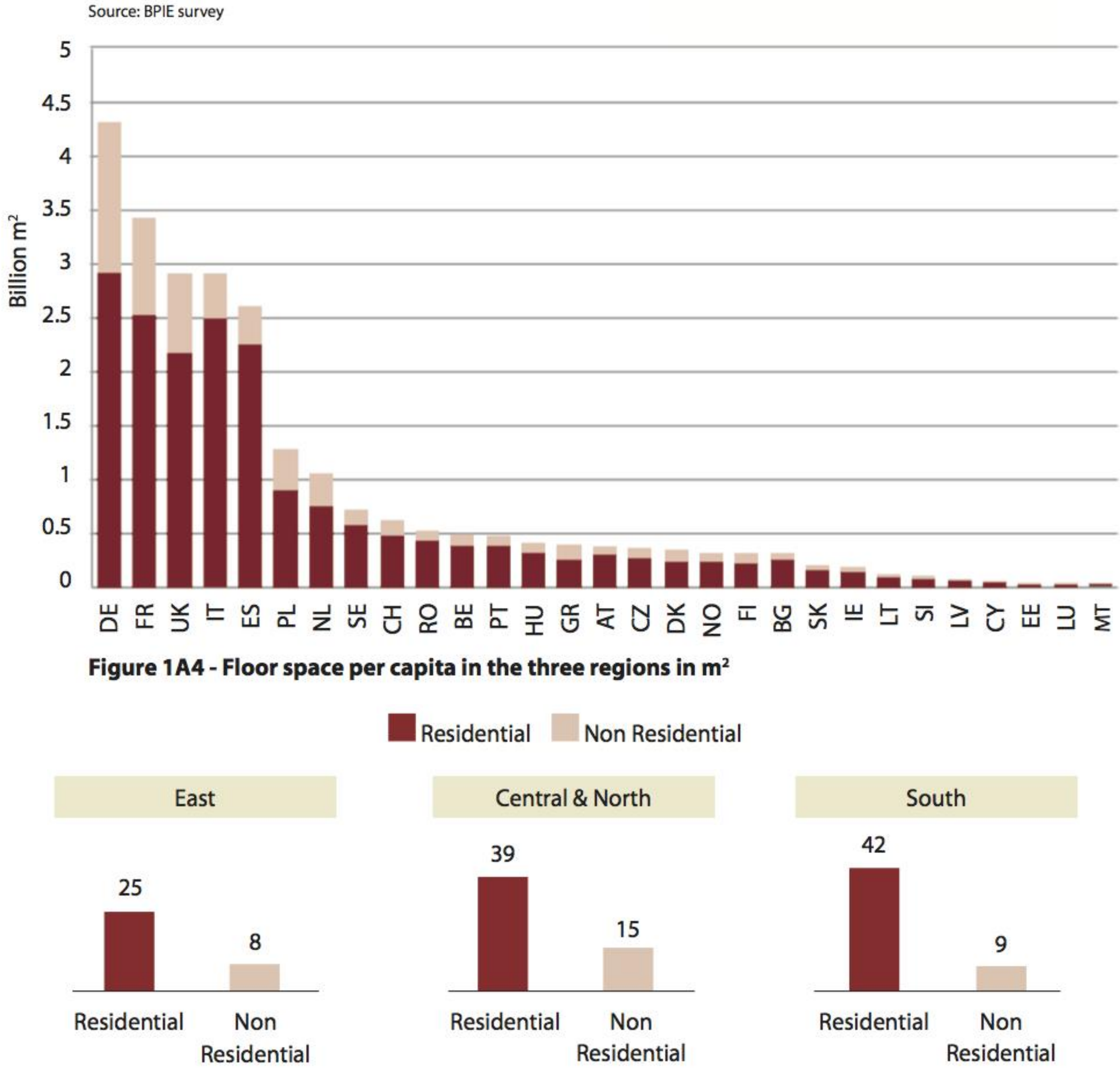


Figure 2 - Floor space distribution per country and floor space per capita in the three European countries in m^2 (BPIE 2011)

From this analysis, it appears that countries in the North & West region have higher **total floor area per person** than in the South and Central & East regions. Upon closer examination, the countries of Eastern Europe tend to have lower **space standards** in terms of dwellings with a floor space of around 25 m^2/person in comparison to the Central & Northern and Southern European countries, which have space standards typically of around 40 m^2/person. With regards to the non-residential buildings, the floor space per capita is nearly double in the North compared to other regions, which may suggest a link between non-residential floor space and economic wealth (BPIE, 2011).

The residential building stock is the biggest segment with a **EU floor space of 75% of the total building heritage**. Within the residential sector, different types of single family houses (e.g.

detached, semi-detached and terraced houses) and apartment blocks are found. Apartment blocks may accommodate several households, typically ranging from 2-15 units or in some cases holding more than 20-30 units (e.g. social housing units or high rise residential buildings). An analysis of this data indicates that, across the focus countries in the study (EU 27[3], Switzerland and Norway), 64% of the residential building floor area is associated with single family houses and 36% with apartments (Figure 3) (BPIE, 2011).

Non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector (Figure 3). 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. Variations in the use (e.g. warehouse versus schools), energy consumption demand (e.g. surgery rooms in hospitals versus to storage rooms in retail), and construction techniques (e.g. supermarket versus office buildings) are some of the factors adding to the complexity of the sector (BPIE, 2011).

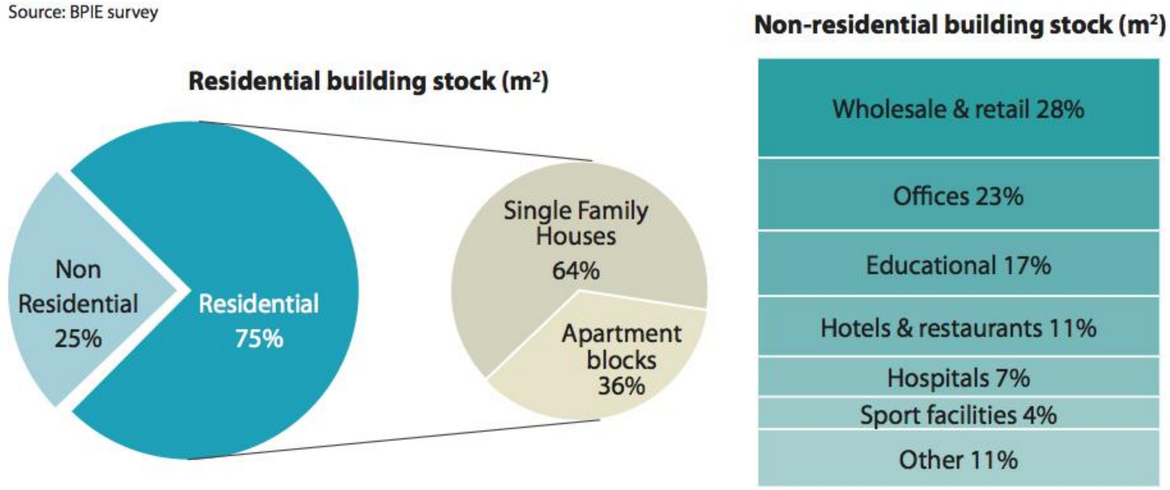


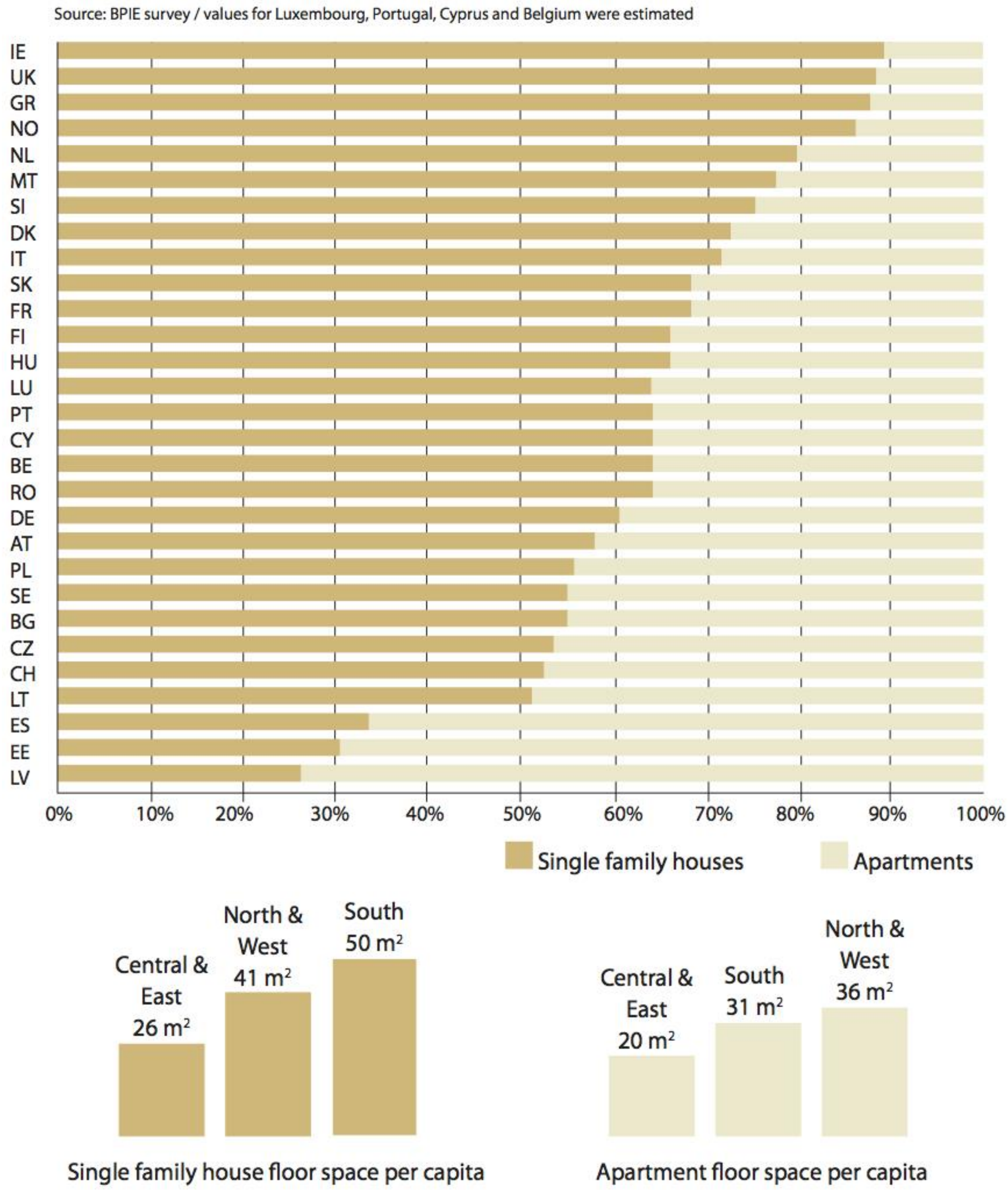
Figure 3 - Residential and non-residential building stock (BPIE 2011)

In residential buildings, the subdivision between the two main **types of residential properties** (single family houses vs. apartments) varies significantly from country to country, as shown in Figure 4. Austria, Bulgaria, Czech Republic, Germany, Lithuania, Poland, Sweden and Switzerland residential buildings are evenly subdivided in terms of floor areas between single family houses and apartments. Greece, Ireland, Norway and the UK have the smallest proportion of floor area of apartments in the residential building stock, whilst Estonia, Latvia and Spain have the highest (BPIE, 2011).

In terms of **floor space per capita**, the Central & East countries are among the countries with the lowest residential space in terms of both single family houses and apartment blocks. North & West countries have the highest residential floor areas per capita compared to other regions. Countries in the South have the highest single family house floor space per capita which perhaps indicates the frequency of holiday houses in those countries (BPIE, 2011).

It is interesting to note that in all European regions, the floor space standards in apartments are lower than in single family houses, a trend which perhaps reinforces the link between floor space and wealth conditions (BPIE, 2011).

[3] BPIE document, licensed in 2011, makes references to EU27, which refers to the European Union States prior to the access of Bulgaria, occurred in 2013.



An apartment block in Europe

A typical single family house in Europe

Figure 4 - Single family and apartment buildings in Europe (BPIE 2011)

Main Features and Characteristics

In addition to typology, buildings vary greatly in terms of age, size and location. Most of the considered statistical data are produced by Eurostat; BPIE documents and the OTB report are other important sources of information, as detailed in the following.

- **Age**

The time of construction of the European building heritage varies significantly and covers many centuries (Figure 5). Such an indicator is very important for the structural assessment of the building stock, because at each construction time interval, different construction technologies are associated and from this information the main structural, seismic and energy performances of buildings can be deduced. Furthermore, provided that the design service life is equal to 50 years, it is important to assess the percentage of the building stock that has exhausted their design service life and now requires technical assessment.

	Year	<1919	1919-1945	1946-1970	1971-1980	1981-1990	1990-2000	> 2000
Austria [1,2]	2009	15.2	8.2	28.0	15.2	11.5	13.6	8.3
Belgium [3,4]	2009	17.1	24.2	24.2	13.7	20.8		
Bulgaria								
Cyprus [5,6]	2001	na	7.4	16.9	20.7	27.4	27.1	-
Czech Republic [1,5]	2005	10.5	14.2	25.4	21.8	15.8	7.9	3.4
Denmark [7]	2009	19.7	16.1	26.4	16.6	9.1	5.4	6.7
Estonia	2009	9.4	14.2	30.0	21.5	19.6	2.0	3.3
Finland [4]	2009	1.5	8.1	27.6	21.5	18.5	11.5	9.8
France [1,8]	2006	17.0	13.2	17.4	25.2	10.2	8.5	8.4
Germany [9]	2006	14.4	13.6	46.3		13.2	9.2	3.3
Greece	2001	3.1	7.2	31.8	24.5	19.1	14.4	na
Hungary [10]	2005	-	20.8	27.2	23.1	17.8	7.9	3.2
Ireland	2002	9.4	8.0	15.9	14.2	13.2	19.5	19.8
Italy [11]	2001	14.2	9.9	36.8	18.8	12.2	7.9	-
Latvia	2008	13.8	13.1	22.1	19.4	20.2	7.0	4.4
Lithuania	2002	6.2	23.3	33.1	17.6	13.5	6.3	-
Luxembourg [3]	2008	21.8	25.6	29.2	11.6	5.1	4.5	2.2
Malta [12]	2005	12.2	10.0	22.1	16.2	19.1	17.0	3.4
Netherlands [13]	2009	6.9	13.9	27.0	17.0	15.4	12.0	7.9
Poland [14]	2002	10.1	13.1	26.9	18.3	18.7	12.9	-
Portugal [3]	2008	7.4	10.0	21.9	16.1	18.8	17.7	8.1
Romania [15]	2002	3.9	11.5	37.3	23.8	14.8	7.3	1.4
Slovak Republic [1,5]	2001	3.4	6.6	35.1	25.6	21.0	6.2	0.6
Slovenia [16]	2004	15.1	7.8	27.7	23.2	16.0	6.9	3.4
Spain [17]	2001	8.9	4.2	33.5	24.1	13.6	15.7	-
Sweden	2008	12.1	14.7	37.0	16.8	9.4	5.5	4.6
United Kingdom [18]	2004/5	17.0	17.0	21.0	21.8	20.0	na	na

Dwellings classified by the period in which the construction of the building containing them was completed.

Figure 5 - Age distribution of the housing stock (Belgium, Luxembourg and Portugal data are estimated) (Dol, Haffner - OTB 2010)

The countries with the largest number of older buildings (<1919) are Luxembourg, Denmark, Belgium, France and UK. While the countries with the highest rate of the construction after World War II (1946-1970) are Germany, Romania, Sweden, Italy and Slovak Republic, with a rate higher than 35%.

The main difference between buildings erected in different periods lays in the technology options. In particular, the transition from the masonry to the reinforced concrete technique, which took place during the first half of the 20th century, represents an important change in the history of construction.

An idea of the amount of buildings at the end of their service life span is given by the BPIE survey, which provides the rate of buildings constructed after the 1960s for each European region (Figure 6).

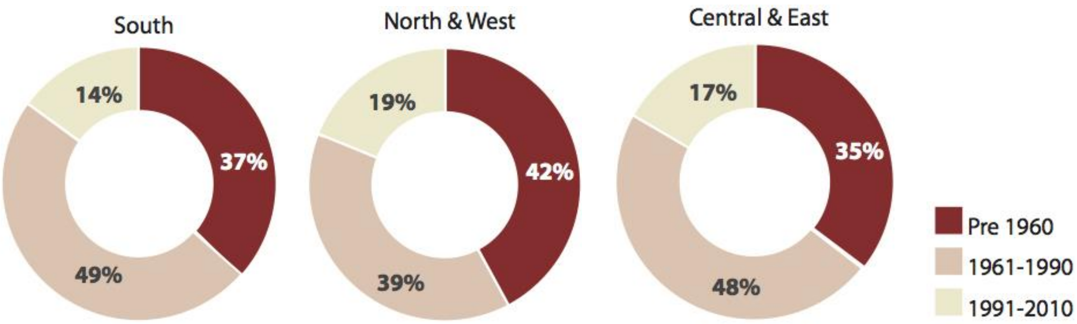


Figure 6 - Age profile of residential buildings in the EU regions (BPIE 2011)

- **Size**

The size of the total European dwelling stock is measured in useful floor area per dwelling (the floor area of dwellings measured inside the outer walls) and varies from 38.7 m^2/dwelling in Romania to 133.5 m^2/dwelling in Luxembourg (Figure 7).

	Year	Total dwelling stock (m^2/dwelling)	Year	Dwellings completed (m^2/dwelling)	Year	Occupied dwelling stock (m^2/person)
Austria	2009	98.5 [1]	2002	101.0	2009	42.9 [1]
Belgium	2001	81.3	2005	105.0	-	na
Bulgaria	2008	63.9	2008	88.2	2008	25.2
Cyprus	-	na	2002	197.6	-	na
Czech Republic	2001	76.3 [2]	2008	107.0	2001	28.7 [2]
Denmark	2009	114.4	2008	131.5	2009	51.4
Estonia	2009	61.2	2009	100.8	2009	29.7
Finland	2009	79.4	2008	101.7	2009	38.9
France	2006	91.0 [2]	2006	99.0 [3]	2006	39.9
Germany	2006	89.9	2008	113.6	2006	42.9
Greece	2001	81.3	2001	124.6 [4]	2001	30.6
Hungary	2005	77.7	2009	88.8	2005	31.2
Ireland	2003	104.0	2003	105.0	2002	35.0
Italy	2001	96.0	2007	73.5	2001	36.5
Latvia	2008	58.5	2008	142.7	2008	27.0
Lithuania	2008	62.9	2003	106.2	2008	24.9
Luxembourg	2008	133.5 [5]	2007	180.4	2008	66.3 [5]
Malta [6]	2002	106.4	-	na	2002	34.3
Netherlands	2000	98.0	2000	115.5	2000	41.0
Poland	2008	70.2	2008	104.0	2008	24.2
Portugal	2001	83.0 [2]	2008	96.2 [5]	-	na
Romania	2008	38.7	2008	70.0	2008	15.0
Slovak Republic	2001	56.1	2009	116.2	2001	26.0
Slovenia	2004	75.6	2004	108.7	2004	30.9
Spain	2008	99.1 [5]	2008	116.0	2008	33.0
Sweden	2008	92.8	2009	99.1	2008	45.2
United Kingdom [7]	2001	86.9	1981-2001	82.7	2001	44.0 [8]

Figure 7 - Average useful floor area per dwelling and per person (Dol, Haffner - OTB 2010)

In Figure 8, the size of non-residential buildings is reported. A BPIE survey showed that the largest non-residential buildings are typically hospitals, followed by educational buildings and sports facilities, while in wholesale, retail, hotels and restaurants the distribution is more even across the different size bands (data was available from 13 countries: AT, BG, CY, CZ, EE, IE, IT, LT, NL, SE, SI, SK, UK) (BPIE, 2011).

All types of consuming non-residential buildings

number	< 200 m²	200 - 1 000 m²	> 1 000 m²
EE	10	50	40
SI	89.8	8.8	1.4
LT	42	55	3
CY	79		21
AT	11	52	37

NOTES
The figures in the above tables are in % and add up to 100%.

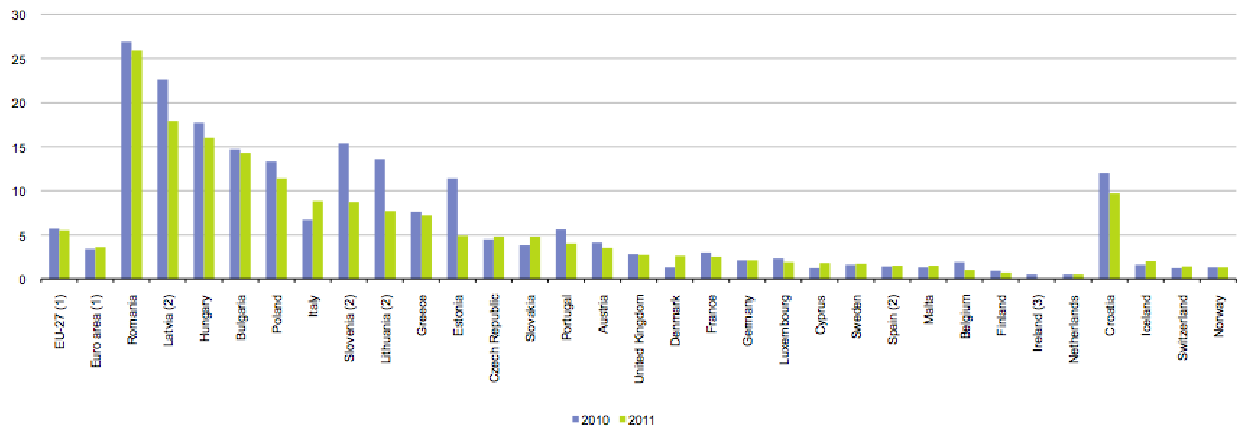
AT: Values based on registered certificates, accounting for 1 007 data sets of non-residential buildings, most of which are office buildings.
CY: Values refer to non-residential building permits issued from 2003-2009 (and % refers to <900 m² and > 900 m² of surface area)
SI: The data refer to all real estate units in non-residential use
EE, LT: Values based on estimations by national experts

Figure 8 - Share of non-residential buildings size (BPIE 2011)

- **Housing quality**

To have an indication about the state of the European building stock, the Eurostat research on the severe housing deprivation is here briefly reported. The severe housing deprivation rate takes into account the housing deprivation measures, such as the lack of a bath or a toilet, a leaking roof in the dwelling, or a dwelling considered as being too dark (Eurostat 2013). All these features are indicators of a bad conservation and characterize the buildings that need the most compelling renovation works.

Across the EU-27 as a whole, 5.5% of the population suffered from severe housing deprivation in 2011, compared to 5.7% in 2010 (Figure 9).



(1) Eurostat estimates, 2011
(2) Break in series, 2011
(3) Not available, 2011
Source: Eurostat (online data code: ilc_mdho06a)

Figure 9 - Severe housing deprivation, 2010 and 2011 (% of population) (Eurostat 2013)

- **Ownership and tenure**

The ownership of buildings plays a significant role on both the **rate and the depth of the refurbishment measures** that may be considered in the renovation projects. Arguably, the public sector should be leader in ‘deep renovations’ and its large portfolio of buildings should provide many opportunities for economies of scale. Private owners may be reluctant to act early and may require some kind of encouragement, incentives and regulations to stimulate reasonable rates and depths of renovation (BPIE, 2011).

In a BPIE survey, data considering residential and non-residential buildings of the EU27[3], together with Switzerland and Norway, were sorted based on their **ownership**, thus between public and private property buildings. The data shows that the largest portion of buildings can be classified as private ownership while 20% is allocated to ‘pure’ public property (BPIE, 2011). Figure 10 shows the country-by-country variations of private vs. public property. Only Austria reports more than 20% of residential dwellings held in public ownership. It should be noted that in many countries, social housing is fully owned by public bodies but there is an increasing trend toward private involvement. This trend is for instance found in Ireland, England, Austria, France, Denmark and The Netherlands. It is worth noting that in the latter case, the social housing is fully owned by private companies (housing association) (BPIE, 2011).

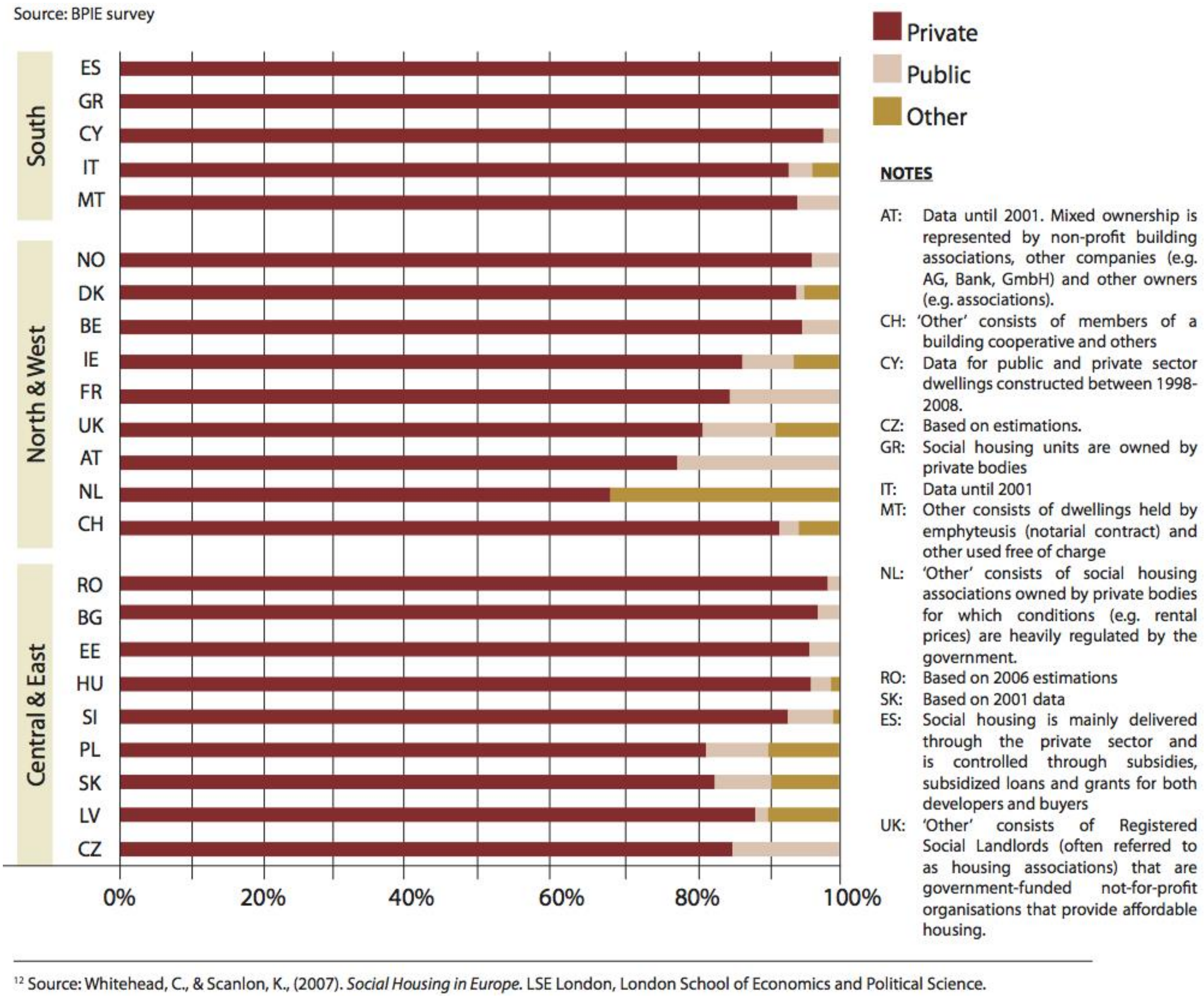
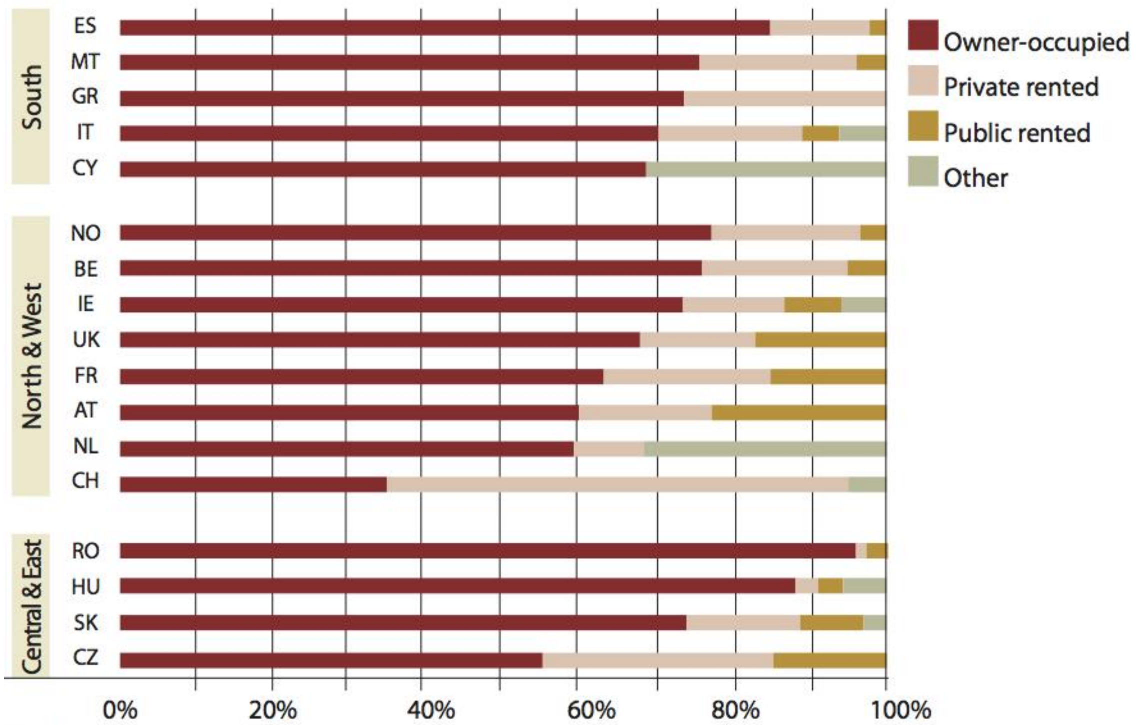


Figure 10 - Ownership of residential buildings in Europe by number of dwellings (except France which is in m^2) (BPIE 2011)

Another key factor, which undoubtedly influences the ability to take action on renovation measures to improve performances in the residential building stock, is the question of **tenure**. Figure 11 shows that at least 50% of residential buildings are occupied by the owner in all countries. Greece and Czech Republic were listed among the countries with the highest share of private tenants, while countries with significant portions of public rented dwellings (in most cases these are occupied by social tenants) are Austria, the UK, Czech Republic, The Netherlands and France (BPIE, 2011).

Source: BPIE survey



NOTES

AT: Data up to 2001.
CH: 'Other' consists of members of a building cooperative and others
CY: Data up to 2001. 'Other' consists of 13,9% of rented (mixed ownership) and 17,9 of other arrangements
CZ: Based on estimations.
HU: Data up to 2005. 'Other' includes public and private empty dwellings and other
IT: Data up to 2001
MT: Other consists of dwellings held by emphyteusis (notarial contract) and other used free of charge
NL: 'Other' consists of social housing associations owned by private bodies for which conditions (e.g. rental prices) are heavily regulated by the government.
RO: Data up to 2002
SK: Based on 2001 data
ES: Social housing is mainly delivered through the private sector and is controlled through subsidies, subsidized loans and grants for both developers and buyers
UK: 'Other' consists of Registered Social Landlords (often referred to as housing associations) which are government-funded not-for-profit organisations that provide affordable housing.

Figure 11 - Tenure of residential buildings in Europe by number of dwellings (except France which is in m^2) (BPIE 2011)

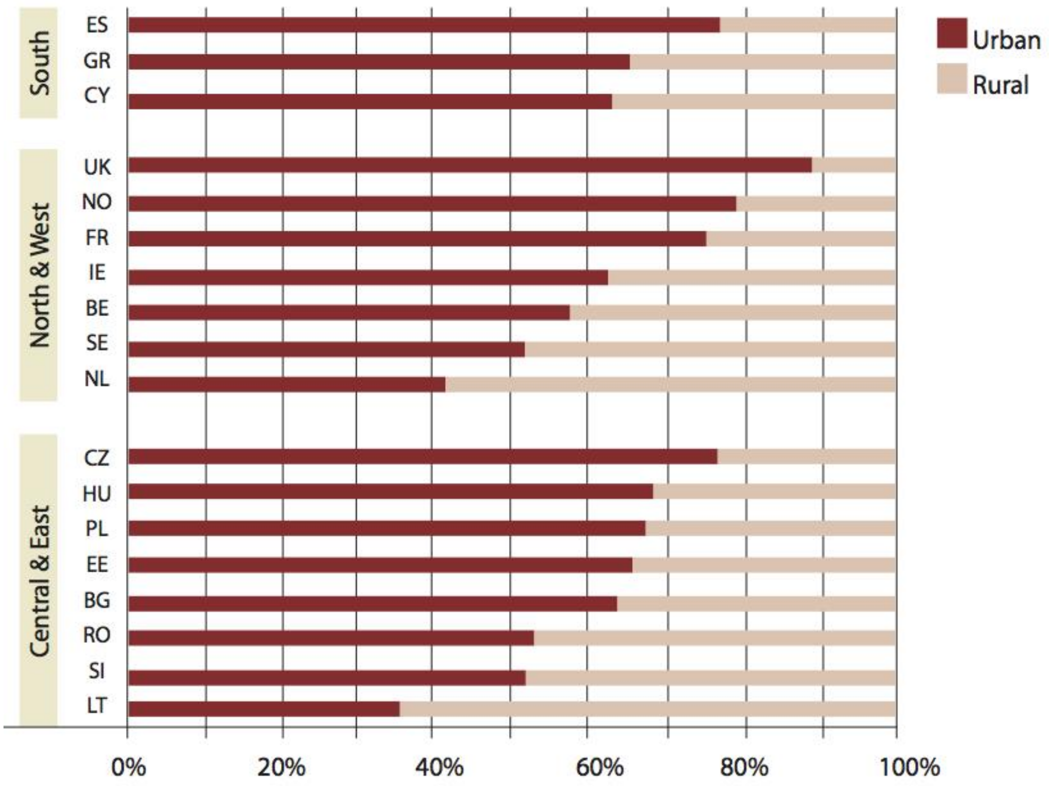
In the non-residential sector the ownership profile is more heterogeneous than that in the residential buildings, and private ownership can span from as low as 10% to nearly 90% depending on the country. The extent of public ownership of non-residential buildings suggests that this would be a good target for public policy to promote large-scale renovation (BPIE, 2011).

- **Location in the urban context**

The ability to adopt renovation measures to improve building performances can be affected by a number of factors including the location of a building. In the urban environment, economies of scale will come into play with large-scale renovation programs, enabling actions on streets and districts (BPIE, 2011).

Figure 12 shows that countries having the majority of residential buildings in rural locations include Lithuania, The Netherlands, Sweden, Romania and Slovenia, while countries having the highest level of urban residences include the UK, Norway, Spain, France and Czech Republic. These findings should be considered in conjunction with the relevant occupancy patterns for rural and urban areas, as rural areas are typically less populated meaning that the permanent occupancy rate in these areas is lower (BPIE, 2011).

Source: BPIE survey



NOTES

CY: Data concerns only built dwellings between 1980 and 2009

FR: Urban units are in territories of a minimum of 2000 inhabitants where the distance between buildings does not exceed 200 m.

LV: Data regards all buildings (residential and non-residential)

NO: Urban units are in territories of a minimum 200 persons (60 - 70 dwellings), where the distance between buildings normally does not exceed 50 metres.

NL: Urban units are located in territories with uninterrupted built-up area typified by the number of residents (more than 100 000), the number of jobs (more than 50 000) and the number of potential customers (more than 150 000)

SE: Data provided covers only existing buildings in 1990.

Figure 12 - Location of residential buildings (urban vs rural) by number of dwellings (BPIE 2011)

Construction technologies

To better understand the structural, seismic and energy performance of the European building stock, it is important to take a closer look at their structural typology and consistency, material characteristics and typology of secondary elements and components (such as infill walls, finishings and plant equipments).

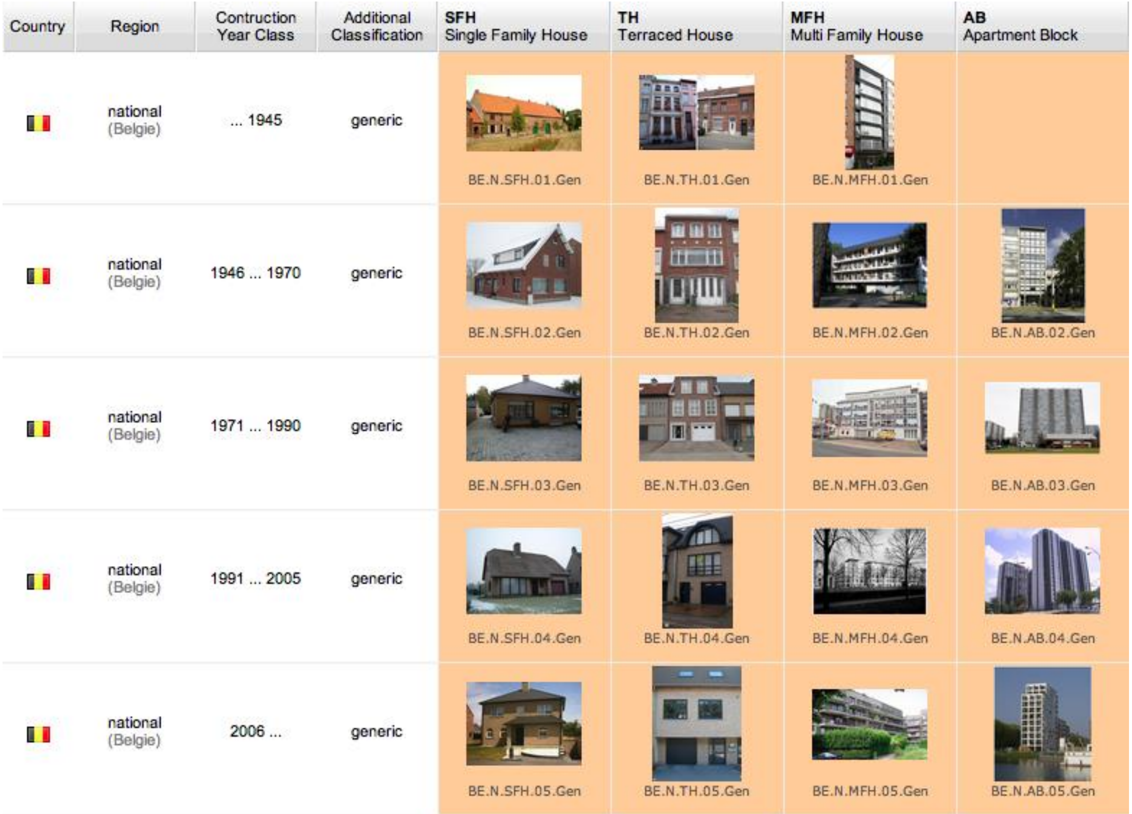
This kind of information can be found in many European research projects, mainly focused on the assessment of the energy performance of the buildings, which analyse a set of benchmark buildings to model and estimate their energy consumption. Two important EU projects are IMPRO-Building (JRC) and TABULA (IEE), both aimed at improving the environmental performance of residential buildings.

For instance, in the TABULA Project, the building stocks of 15 European countries were analysed (AT, BE, BG, CZ, DE, DK, FR, GR, IE, IT, PL, SE, SL, SP, RS). In this project an overview of the building typology is given by the "Building Type Matrix", which is reported in Figure 13. The columns of the matrix represent four building size classes (single-family houses, terraced houses, multi-family houses, apartment blocks), the rows a certain number of construction year classes. The single cells of the matrix form the generic "Building Types" of a country. To each generic building type of a country an exemplary building is assigned, which is represented by a photo, a description of the **typical materials** (wall, floor, roof cross sections) and the data about the **thermal envelope**. This exemplary building is supposed to be representative of the building type, meaning that its features can commonly be found in houses of the same age and size class (TABULA, 2012). These web tools are very useful to gather information about the typical materials used in the envelope of the European buildings of each construction period.

The analysis of the **seismic behaviour** of buildings also requires the knowledge of other characteristics, as the structure typology, the number of floors, the plan and vertical irregularities. Some European projects, like the RISK-EU and the ENSURE, studied the seismic vulnerability of some European cities. In particular, the RISK-EU project proposes a matrix of 23 building types, based on the Building Typology Matrix (BTM) of the European Macro-seismic Scale (EMS98). This matrix contains the most common building types of all European and Mediterranean countries (Figure 14).

In this scenario great relevance is acknowledged to the ongoing **GEM program** (www.globalquakemodel.org). GEM's effort is to build a heightened public understanding and awareness of seismic risk, leading to increased earthquake resilience worldwide. Through a collaborative effort, involving scientists and stakeholders, GEM is making a significant contribution toward advancing the science and technology needed for global state-of-the-art seismic hazard and risk modelling, data collection, and risk assessment at the global, regional, national and local scale.

Nowadays, none of the statistical offices of the European Union provides detailed information and statistical data about the European building **structural typology**; however, the impact of recent earthquakes on some European cities, has led the single nations to adequate their **National Building Census**. Therefore, information about building structures can be found in some recent national census and in some national projects. As an example, the statistical data of two nations located in seismic prone areas, Greece and Italy, are summarized in the following.



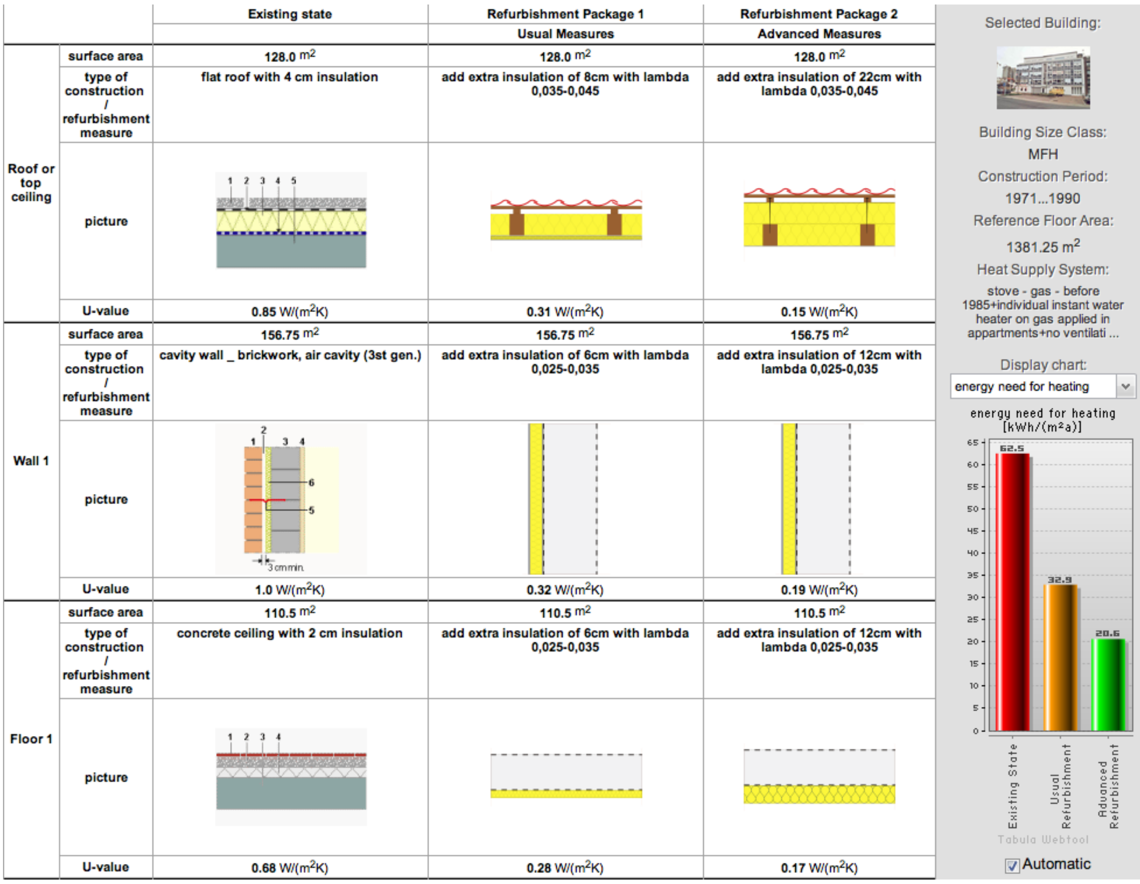


Figure 13 - Example of Building Type Matrix and building details - classification of the residential building stock of Belgium (TABULA WebTool 2012)

Label	Description of building type	Label	Description of building type
M	***Masonry structures***	***RC***	***Reinforced concrete structure***
M1	Load-bearing masonry walls composed of :	*RC1*	Support beams / columns
1.1	*Rubble*	*RC2*	Structural concrete wall
1.2	*Freestone*	*RC3*	Support beams / columns with unreinforced brick-lined wall:
1.3	*Ashlar*	*3.1*	*Even brick-lined structures*
M2	Crue	*3.2*	*Uneven structures (i.e., uneven support beams, uneven brick lining, flexible level)*
M3	Load-bearing unreinforced masonry walls:	*RC4*	Compound structure of reinforced concrete (portico and concrete walls)
3.1	Hardwood flooring	*RC5*	Prefabricated concrete walls
3.2	Masonry arches	*RC6*	Prefabricated concrete walls with structural concrete walls
3.3	Floors with metal and masonry joists	***S***	***Steel structures***
3.4	Reinforced concrete floors	*S1*	Steel Support beams / columns
M4	Load-bearing reinforced masonry walls	*S2*	Cross-braced steel structure
M5	Structures made completely of reinforced masonry	*S3*	Steel Support beams / columns with unreinforced brick-lined wall
		S4	Steel Support beams / columns with structural concrete wall cast in-situ
		S5	Steel and reinforced concrete components
		W	***Wooden structure***

Figure 14 - Building Typology Matrix of the most current building structures in Europe (RISK-UE Project, 2004).

- **Greece**

Thanks to the changes in the National Building Census, essential information such as the building structure, the infill material, the presence of pilotis and basement, the possible interaction of adjoining buildings were assessed and data are now available for all building stock in Greece.

The Hellenic Statistical Authority EL.STAT reports data from the building census of year 2001 (Figure 15). This survey shows that in Greece there are more buildings featuring a low number of floors rather than high rise constructions (57,9% of the building only shows the ground floor, 29,9% the first floor, 7,1% the second floor, and the remaining buildings are less than 5%), and there are more buildings without (90,8%) than building with basement (9,2%). The number of buildings with an open ground floor space in apartment block used as a parking lot is less than that of buildings with ground floor (respectively 2,7% and 97,3%), but it is important to recognize this type of buildings because they perform very poorly during seismic events.

Geographical Distribution of buildings	Number of floors						
	Ground floor	1st floor	2nd floor	3rd floor	4th floor	5th floor	6th floor and more
Y11,Anatoliki Makedonia, Thraki	180599	65336	11667	3230	1975	1180	485
Y12,Kentriki Makedonia	336790	165841	37601	19069	11450	6651	5762
Y13,Dytiki Makedonia	88647	44250	5906	2175	1030	371	114
Y14,Thessalia	247453	80419	14337	3097	2070	1540	739
Y21,Ipeiros	118246	41961	7210	2486	905	234	70
Y22,Ionia Nisia	76858	42776	7143	1489	469	122	19
Y23,Dytiki Ellada	187695	91463	15706	3797	1587	1027	1075
Y24,Sterea Ellada	189445	98495	17455	3037	1010	437	134
Y25,Peloponnisos	196684	136619	14835	3068	1311	685	183
Y31,Attiki	326329	204690	112222	46092	27646	24019	13730
Y41,Voreio Aigaio	78955	68656	7096	461	190	78	28
Y42,Notio Aigaio	114731	60026	11161	1728	244	63	37
Y43,Kriti	167589	93556	19705	4720	1260	332	106
Total	**2310021**	**1194088**	**282044**	**94449**	**51147**	**36739**	**22482**

Geographical Distribution of buildings	Indicator of Basement, Ground Floor, Pilotis			
	Basement and Ground floor	Basement and Open ground floor space in block of flats used as a parking lot	Ground floor	Open ground floor space in block of flats used as a parking lot
Y11,Anatoliki Makedonia, Thraki	13906	693	246139	3734
Y12,Kentriki Makedonia	53512	4392	512481	12779
Y13,Dytiki Makedonia	20065	322	121269	837
Y14,Thessalia	22316	1689	319739	5911
Y21,Ipeiros	14726	411	153364	2611
Y22,Ionia Nisia	2191	7	126261	417
Y23,Dytiki Ellada	16527	298	281282	4243
Y24,Sterea Ellada	21915	344	283087	4667
Y25,Peloponnisos	28344	686	318755	5600
Y31,Attiki	123208	14654	578600	38266
Y41,Voreio Aigaio	6234	21	148645	564
Y42,Notio Aigaio	7695	20	180005	270
Y43,Kriti	14543	381	269816	2528
Total	**345182**	**23918**	**3539443**	**82427**

Figure 15 - Number of floors and vertical irregularities of Greek buildings (EL.STAT, 2001).

- **Italy**

In Italy these data were collected by the national statistic centre ISTAT, during the building census carried out in 2001. Information about the building type (Figure 16), the contiguity and the number of floors (Figure 17), the age, the housing quality, the number of stairs and rooms was collected in the census of buildings and dwellings.

It emerged that 61,5% (6’903’982) of the residential buildings are load-bearing masonry structures, the 24,7% (2’768’205) are reinforce concrete (RC) structures and 13,8% (1’554’408) are other structures (wooden, steel or other structure).

Region	Building type		
	Load-bearing Masonry	Reinforced concrete	Other
Piemonte	544.031	224.879	108.234
Valle d'Aosta	18.663	9.217	11.181
Lombardia	705.827	406.222	227.409
Bolzano-Bozen	*42.483*	*16.936*	*10.674*
Trento	*64.710*	*33.572*	*17.585*
Trentino-Alto Adige	107.193	50.508	28.259
Veneto	667.712	146.887	145.657
Friuli-Venezia Giulia	143.241	66.777	70.296
Liguria	149.385	68.909	29.418
Emilia-Romagna	531.025	111.198	92.843
Toscana	499.276	100.027	68.419
Umbria	122.926	25.305	23.786
Marche	172.433	80.290	37.111
Lazio	443.705	175.016	113.846
Abruzzo	232.400	66.382	29.496
Molise	77.562	16.641	7.479
Campania	463.917	241.277	117.553
Puglia	533.227	216.300	144.337
Basilicata	99.753	33.049	15.170
Calabria	331.385	200.322	55.125
Sicilia	728.168	473.195	151.475
Sardegna	332.153	55.804	77.314
Nord-Ovest	**1.417.906**	**709.227**	**376.242**
Nord-Est	**1.449.171**	**375.370**	**337.055**
Centro	**1.238.340**	**380.638**	**243.162**
Sud	**1.738.244**	**773.971**	**369.160**
Isole	**1.060.321**	**528.999**	**228.789**
TOTALE ITALIA	**6.903.982**	**2.768.205**	**1.554.408**

Figure 16 - Different building types in Italian regions. Census 2001 (ISTAT, 2004).

Two important characteristics affecting the seismic behaviour of existing buildings are the contiguity to other buildings and the number of floors. The census data show that 53,0% (5’955’086) of buildings is isolated, whereas the remaining 47,0% is contiguous to other buildings on one or more sides (21,1% on one side, 25,9% on more sides). The number of buildings with first floor is higher than that with only ground floor (respectively 52,9% and 22,6%), the 17,3% of buildings has second floor and only the 7,2% has a third floor or more.

Region	Contiguity			Number of floors			
	No side	One side	Two sides or more	1	2	3	4 and more
Piemonte	464.426	235.184	177.534	108.396	537.364	165.772	65.612
Valle d'Aosta	24.122	10.228	4.711	4.865	18.627	11.794	3.775
Lombardia	856.670	265.661	217.127	205.016	773.416	248.941	112.085
Bolzano-Bozen	*53.672*	*11.957*	*4.464*	*5.678*	*31.284*	*25.678*	*7.453*
Trento	*74.352*	*23.179*	*18.336*	*12.908*	*57.532*	*33.389*	*12.038*
Trentino-Alto Adige	128.024	35.136	22.800	18.586	88.816	59.067	19.491
Veneto	687.756	181.819	90.681	141.205	619.077	153.967	46.007
Friuli-Venezia Giulia	185.854	59.509	34.951	55.906	155.819	52.315	16.274
Liguria	154.064	50.986	42.662	37.197	118.375	51.195	40.945
Emilia-Romagna	532.765	121.541	80.760	88.980	438.001	147.644	60.441
Toscana	368.559	150.901	148.262	114.096	377.570	129.527	46.529
Umbria	117.741	28.366	25.910	29.486	99.092	34.074	9.365
Marche	191.466	51.515	46.853	35.673	161.146	67.764	25.251
Lazio	488.620	126.754	117.193	180.803	351.089	118.619	82.056
Abruzzo	174.425	74.810	79.043	57.982	181.679	68.495	20.122
Molise	34.976	25.000	41.706	17.245	54.465	24.654	5.318
Campania	383.473	212.333	226.941	193.146	453.728	117.342	58.531
Puglia	250.242	169.004	474.618	461.097	322.445	67.434	42.888
Basilicata	61.871	37.903	48.198	47.100	71.881	20.933	8.058
Calabria	229.178	161.459	196.195	151.252	298.865	101.527	35.188
Sicilia	447.322	249.730	655.786	428.756	587.353	242.505	94.224
Sardegna	173.532	121.613	170.126	157.399	235.235	56.393	16.244
Nord-Ovest	**1.499.282**	**562.059**	**442.034**	**355.474**	**1.447.782**	**477.702**	**222.417**
Nord-Est	**1.534.399**	**398.005**	**229.192**	**304.677**	**1.301.713**	**412.993**	**142.213**
Centro	**1.166.386**	**357.536**	**338.218**	**360.058**	**988.897**	**349.984**	**163.201**
Sud	**1.134.165**	**680.509**	**1.066.701**	**927.822**	**1.383.063**	**400.385**	**170.105**
Isole	**620.854**	**371.343**	**825.912**	**586.155**	**822.588**	**298.898**	**110.468**
TOTALE ITALIA	**5.955.086**	**2.369.452**	**2.902.057**	**2.534.186**	**5.944.043**	**1.939.962**	**808.404**

Figure 17 - Contiguity and number of floors in Italian buildings. Census 2001 (ISTAT, 2004).

Projects about seismic risk assessment and researches collecting data on building materials and building types are available for other European and Mediterranean seismic prone area (Romania: Lungu et al., 2007; Algeria: Lazzali et al., 2012).

1A.2 BUILDINGS AND EARTHQUAKES

In order to analyse the issues connected to the seismic resilience of the existing building stock, it is important to take a closer look to the extent of the seismic activity in the European countries. The seismic activity can be classified as tectonic or non-tectonic and it involves, with different degrees of intensities, the majority of the European countries.

The Mediterranean area is a seismic prone area. Every year one or more intense earthquakes occur and cause destruction and a number of victims. Each of these seismic events demonstrates that the existing European building stock is not adequate from the seismic point of view and needs severe safety measures to be soon implemented.

Furthermore, relevance is nowadays acknowledged to non-tectonic seismicity (i.e. seismicity of volcanic origin or induced by the human activities, such as fracking induced by excavation or tunnelling operations), which has less devastating effects than an earthquake, but can affect countries with lower seismic hazard.

In this scenario, a general overview on the earthquake vulnerability of some European buildings typologies is reported. For single cases, the Eurocode 8 provides all the information needed to assess the seismic behaviour of buildings (Eurocode 8 - CEN 2005).

Stemming from this brief excursus, the main structural deficiencies of the European buildings and the research needs to reckon with such vulnerabilities can be drawn.

Seismic activity in Europe

Minimization of the loss of life, property damage, and social and economic disruption due to earthquakes depends on reliable estimates of seismic hazard. Seismic hazard is defined as the intrinsic natural occurrence of earthquakes and the resulting ground motion, with its effects. A relationship between hazards and their occurrence frequency can be derived through a process called seismic hazard analysis (Wang, 2005). This analysis is the first step in the evaluation of the seismic risk, obtained by combining the seismic hazard with local soil conditions and with building vulnerability factors (type, structural resistance, value and age of buildings and infrastructures, population density, land use). Frequent, large earthquakes in remote areas result in high seismic hazard but pose no risk; conversely, moderate earthquakes in densely populated areas entail small hazard but high risk (Giardini et al., 2003).

In Figure 18 the European-Mediterranean Seismic Hazard Map, edited in 2003 by Giardini, Jiménez and Grünthal for the ESC and the SESAME Project, is reported. This map depicts Peak Ground Acceleration (PGA) with a 10% chance of exceedance in 50 years for a firm soil condition. The map colours correspond to the actual level of the hazard: the cooler colours represent lower hazard while the warmer colours are associated with higher hazard (Giardini et al., 2003).

The map shows that the highest earthquake hazard is concentrated in Iceland and in the south-eastern areas of Europe. In particular the most hazardous countries are Italy, Greece, Turkey, Romania and the Balkan region, with PGA values exceeding the 0,4g. Whereas Spain, Portugal, France, Germany and Belgium are European countries with low/moderate hazard, although some of them (i.e. Portugal) have experienced devastating earthquakes through their distant and recent past.

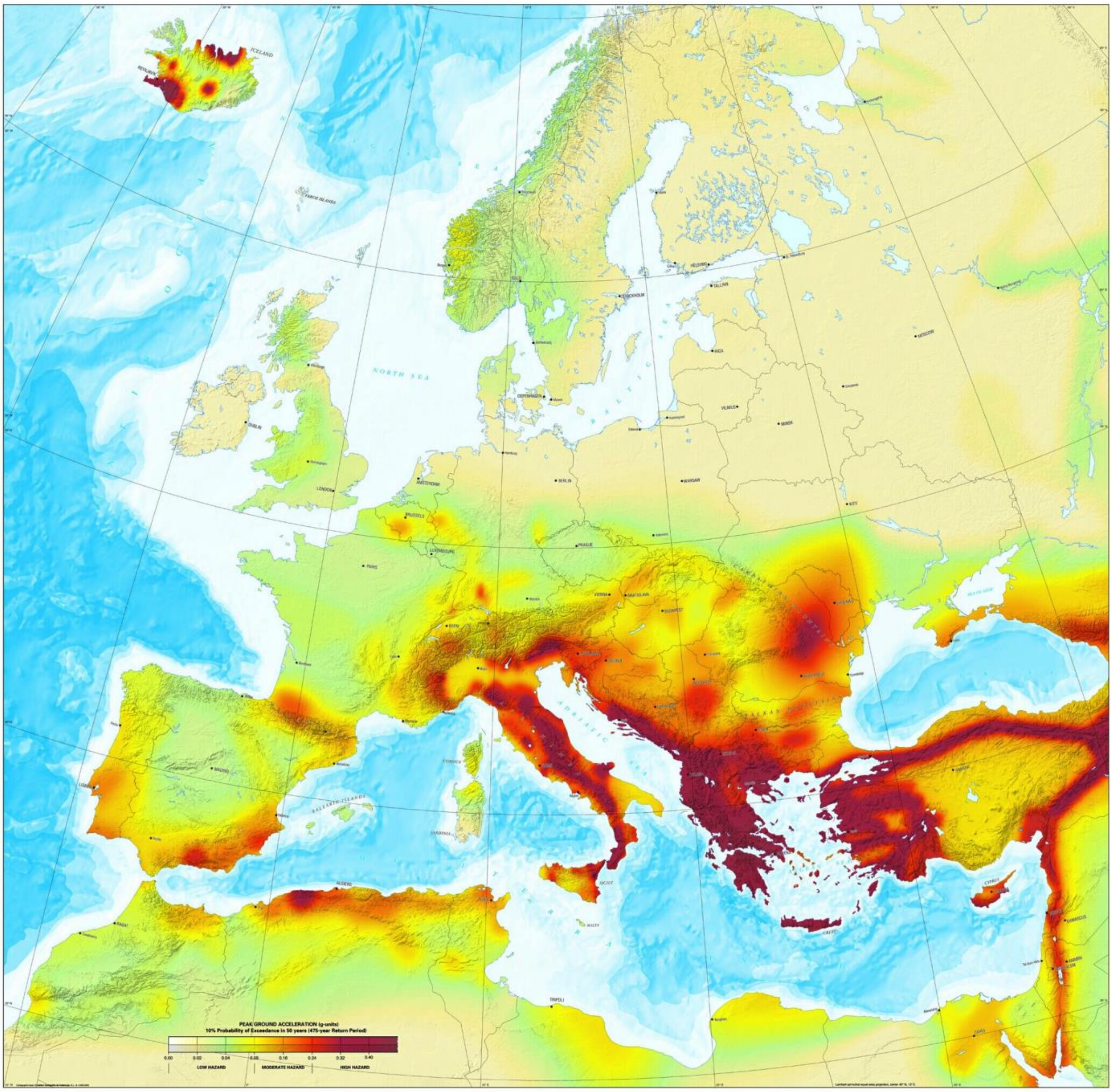


Figure 18 - European-Mediterranean Seismic Hazard Map (Giardini et al., 2003).

The European seismic activity is recorded on a real time basis in the whole European-Mediterranean region. Seismological data are collected from different institutes, notably the EMSC (www.emsc-csem.org) and ORFEUS (www.orfeus-eu.org). All these data access tools and sites are connected and integrated to the international net, thanks to projects like NERIES. With this project a single portal (www.seismicportal.eu) was created, which displays the seismological data available for the earth science research community.

The EMSC edits the Euro-Med bulletin. Figure 19 displays the information collected for the period 1998-2010. The distribution of the seismic events in the Euro-Med region for this time span reflects the situation expected from the Seismic Hazard Map, with a high number of earthquakes in Iceland and in the Mediterranean region (Greece, Italy, Portugal, Spain, the Balkan countries and Turkey). Noteworthy, some minor earthquakes of M4 and M3 are recorded also in France, Belgium, Germany, Switzerland, UK and Norway.

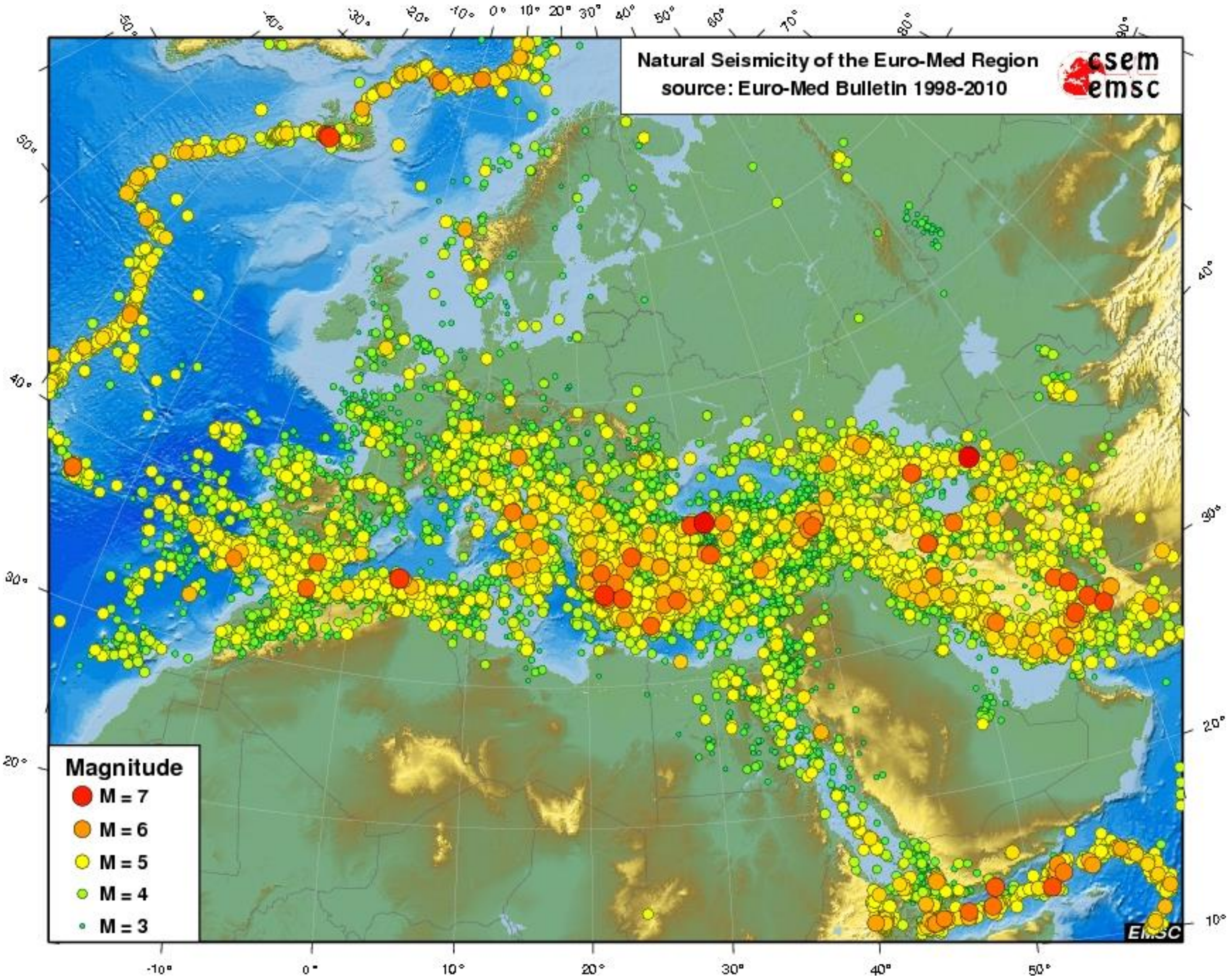


Figure 19 - Natural seismicity in the Euro-Med region for the period 1998-2010 as computed in the EMB for events of magnitude larger than 3. (csem-emsc, 2013).

The strongest earthquakes in the Euro-Med region in the last decade are reported in Figure 20. It could be seen that they are all located in the highest European hazard zones (Turkey, Greece, Italy, Spain, Iceland). In particular, the event with the highest magnitude (M7.2) recorded in Europe in this period has occurred in Eastern Turkey, in 2011.

As mentioned, another aspect to be taken into account is the non-tectonic seismicity. It is a phenomenon with no devastating effects, but that interests the entire European Countries. Figure 21 shows the distribution of non-tectonic events in the Euro-Med Bulletin. Patches of non-tectonic activity are observed, with clusters in Finland and Spain. Poland and Czech Republic, the Red Sea and Kazakhstan also present high activities, due to anthropogenic events (EMSC 2013).

REGION	LAT	LON	DATE	Km	MAGNITUDE
Eastern Turkey	38.78	43.40	2011-10-23	10	7.2 Mw
Southern Greece	36.50	21.63	2008-02-14	30	6.3 mb
Southern Greece	36.31	23.25	2006-01-08	60	6.7 Mw
Crete, Greece	34.13	25.42	2009-07-01	30	6.4 Mw
Dodecanese Islands, Greece	35.73	27.86	2008-07-15	58	6.4 Mw
Strait of Gubraltar	35.20	-3.96	2004-02-24	10	6.4 Ms
Eastern Turkey	39.00	40.53	2003-05-01	18	6.2 Ms
Southern Greece	37.99	21.49	2008-06-08	15	6.2 Ms
Central Italy	42.38	13.32	2009-04-06	2	6.3 Mw
Spain	37.07	-3.51	2010-04-11	623	6.3 Mw
Iceland	64.01	-21.02	2008-05-29	2	6.3 Mw
Southern Greece	36.33	21.81	2008-02-14	29	6.3 Mw
Azores Islands Region	37.39	-24.68	2007-04-05	13	6.3 Mw
Southern Greece	37.27	22.67	2008-01-06	83	6.2 Mw
Azores Islands Region	35.90	-10.31	2007-02-12	11	6.2 mb
Crete, Greece	34.23	25.00	2013-06-15	10	6.2 Mw
Southern Greece	27.99	21.49	2008-06-08	15	6.1 mb
Azores Islands Region	37.30	-24.70	2007-04-07	9	6.1 Mw
Eastern Mediterranean Sea	35.80	29.70	2005-01-23	30	6.1 Mw

Figure 20 - The strongest earthquakes in the Euro-Med zone for the period 2003-2013 (data source: www.seismicportal.eu)

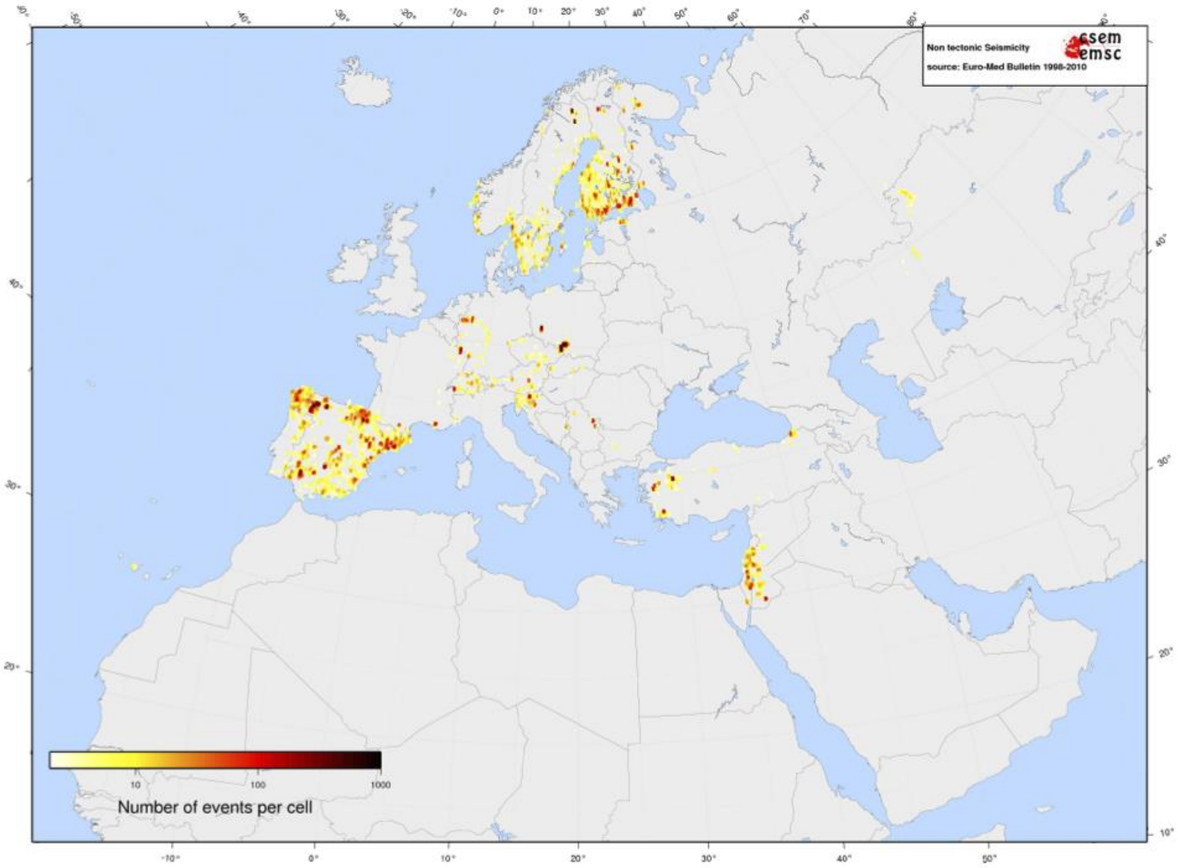


Figure 21 - Distribution of non-tectonic events in the Euro-Med Bulletin since 1998 (EMSC 2013)

Earthquake vulnerability of European buildings [4]

Seismic vulnerability assessment of the European building stock can be carried out, with different level of accuracy, by analysing the effects of the earthquakes on entire districts in a stricken areas (First level analysis), or by accurately evaluating the effect on single buildings (Second Level analysis). With a general, large scale approach, it is possible to recognize some recurring collapse mechanisms by assessing the main features of the building.

In order to evaluate the vulnerability of the existent European buildings it is important to survey some building's characteristics that can affect their seismic behaviour. The basic and most important information is about the building structural typology, either masonry-, reinforced concrete-, steel- or wood.

Some other important characteristics are: regularity both in elevation and in plan, number of stories, floor consistency and connection to the perimeter walls in masonry buildings, existence of possible earthquake resistance features, etc. The European Macro-seismic Scale (EMS98) classifies the buildings through a Building Typology Matrix (BTM) and for each type of structure provides a vulnerability class. Basically, six vulnerability classes (from A to F) of decreasing vulnerability are defined: A, B and C classes for ordinary buildings designed without explicit control of seismic resistance; D, E and F classes for buildings with levels of progressively increasing protection (Figure 22).

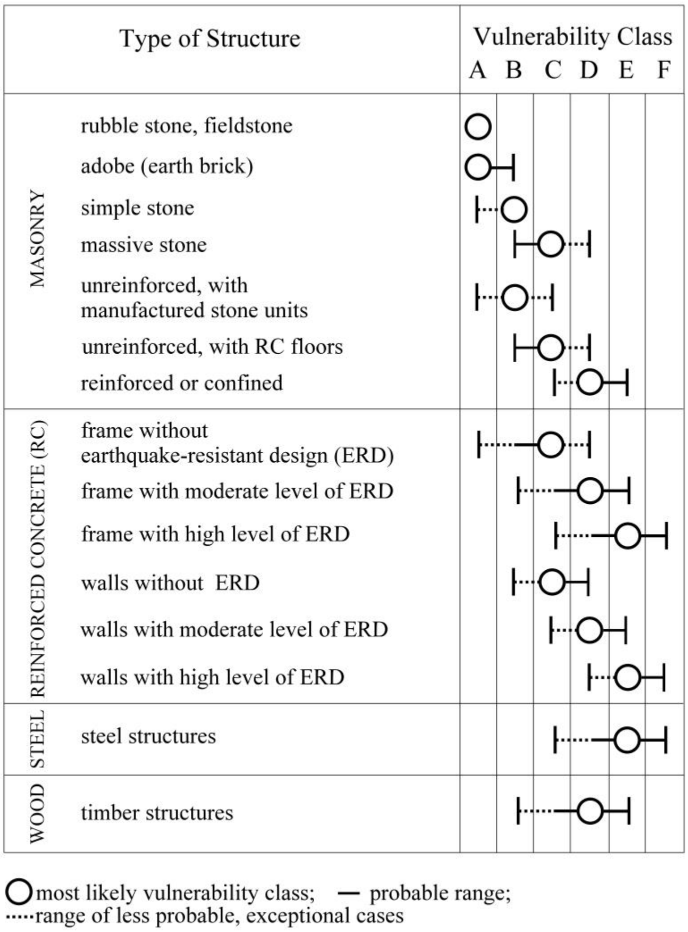


Figure 22 - Differentiation of structures into vulnerability classes - Vulnerability Table (EMS98 - Grünthal, 1998)

[4] Data and comments reported in this Chapter are mainly quoted from the EMS98 document (Grünthal, 1998).

Stemming from this classification, European building stock can be divided into six classes of decreasing vulnerability (A-F). The first three classes represent the strength of a "typical" adobe house, brick building and reinforced concrete (RC) structure; classes D and E are intended to represent approximately a linear decrease vulnerability as a result of improved level of earthquake resistant design (ERD) featured in recent well-engineered timber, reinforced or confined masonry and steel structures; class F is intended to represent the reduced vulnerability of a structure with a high level of earthquake resistant design.

In assessing the vulnerability of an ordinary existing structure, the first step is to assess the building type. Each building type has its own deficiencies. The EMS-98 summarizes the vulnerabilities that generally affect the seismic behaviour of the different types of structures. The following descriptions are mainly quoted from this document (Grünthal, 1998).

- **Masonry structures**

Ancient masonry structures, either made of bricks or stones, binded with poor quality mortar, were usually conceived to withstand the sole vertical loads. Typical wooden floors are loosely connected to the perimeter walls, and have neither in-plane stiffness nor strength. Possible perimeter wooden ties with steel anchorages are usually ineffective, due to the natural decay of the wood or for the failure of the anchorage-to-tie connection. Monumental buildings, for which massive stone, good materials and best available techniques were adopted, usually perform better than ordinary building with respect to vertical loads. Nevertheless, the resistance to earthquake depends on the structural three dimensional organization, which is often very poor, regardless of the relevance of the structure.

Adobe/earth brick buildings are also worth mentioning. This type of construction was typical in many regions, where suitable clays could be found. Adobe constructions vary widely, and this results in remarkable variations in the strength of adobe houses against both vertical loads and earthquake actions. Walls made of layers of adobe cast without the use of bricks are stiff and weak; adobe brick houses may perform better depending on the quality of the mortar, and, to a lesser extent, the quality of the brick. The weight of the roof is one of the most important factors affecting the performance of such houses, heavy roofs being a threat. Adobe houses incorporating wooden frames possess added strength and perform significantly better.

A very common type of construction in Europe is the **unreinforced masonry** structures made of brick or concrete blocks. These buildings have usually little horizontal resistance, which is mainly caused by the lack of efficient connection of the wooden floors to the perimeter walls, allowing the onset of out of plane mechanisms. Their vulnerability is affected by the number, size and position of openings. Large openings, small piers, as well as long masonry walls without transverse retaining walls or stiffening elements contribute to increase the vulnerability of these buildings. Cavity walls lacking the connections between the external leaves (i.e. lacking through stones) are acknowledged as a further source of vulnerability. Noteworthy, cavity walls have not only insufficient earthquake resistance, but can perform very poorly also with respect to vertical actions.

Possible **reinforced concrete floors** have a dual effect, as they can be either a source of vulnerability or entail a better performance of the building, depending on the consistency of the vertical masonry and the extension of the perimeter corbel within the masonry cross section. When the floor is properly connected to the outer walls and behaves like an in-plane diaphragm, gathering the seismic action (of both the floor and the pertaining walls subjected to out of plane seismic actions) to the resistant walls, the onset of out of plane mechanisms is inhibited and the global box structural behaviour can be exploited. Noteworthy, this improved performance can only be obtained if the RC floors are properly connected to the perimeter walls, which is rarely the case.

In the most frequent situation, the seismic vulnerability of masonry buildings is connected to the onset of **local collapse mechanisms** that jeopardize the global behaviour of the structure (Figure 23). The major vulnerability is the out-of-plane overturning of the perimeter walls and can lead to the collapse of the whole building. A second type of vulnerability is the in-plane collapse of walls, but these mechanisms are usually triggered by earthquakes of higher magnitude. Local mechanisms are classified into practical abaci for common structure typologies (INGV). In presence of thrusting elements, such as arches and vaults, the building vulnerability is often caused by insufficient confinement of the thrusting actions or even by the lack of tie elements, absorbing the horizontal forces.

Furthermore, the **restoration of masonry buildings** carried out in the recent past entails the inconvenient replacement of wooden floors with heavy R.C. slabs and curbs. Such an intervention is nowadays strongly discouraged. The considerable mass of the slabs, and its significant rigidity with respect to the stiffness of the existing structures, are recognized as the possible cause of several collapses after recent earthquakes, associated by either shear sliding or pounding effects, while the external curbs are observed to severely weaken the masonry and are often not able to counteract the tilting mechanisms.

Finally, decay of the material and repeated alterations and **rearrangements** of the walls made to adapt the structures to changing housing needs or usages over the years, usually entail impairing to the masonry structures (such as misalignment in the openings, partial demolition of the resisting piers, etc.), which may worsen the structural performance also with respect to vertical loads. In these cases, the survey of the building consistency and geometrical configuration is even more important than the material characteristic assessment.

For all these reasons, giving their vulnerability for granted, existing masonry construction safety assessment should be considered as necessary with respect to both horizontal and vertical loads.

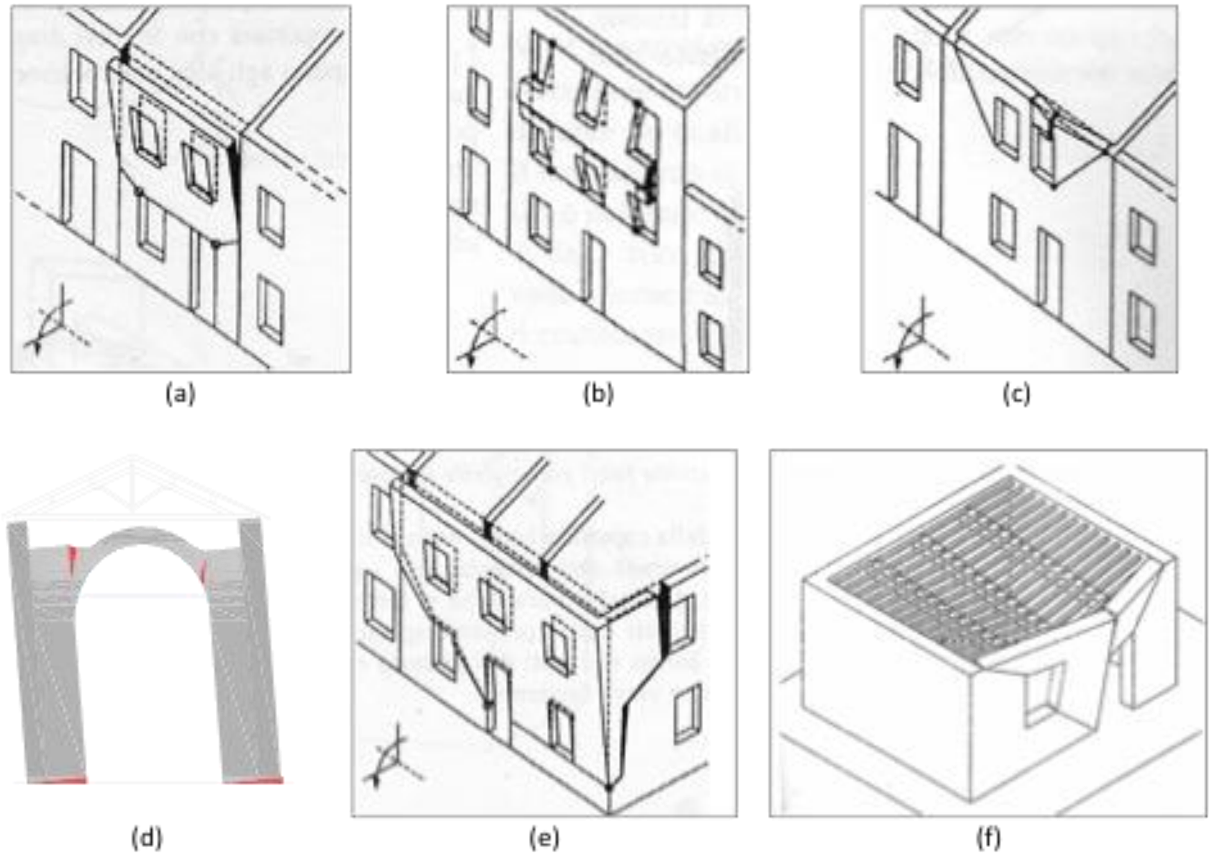


Figure 23 - Local collapse mechanisms (Beolchini et al., 2005)

- **Reinforced concrete structures**

This type of construction is widespread in modern cities and in city suburbs. RC building layout and structural performance are extremely variable, making it difficult to propose general and comprehensive guidelines for their seismic vulnerability assessment or for the prediction of their seismic behaviour.

There are two types of RC structures, either featuring frames or wall system. The older RC buildings implemented a resisting frame, usually conceived for the sole vertical loads. More recent structural frames are designed to resist to both vertical and horizontal loads. The newest structural conception is based on the superposition of a frame resisting vertical loads and a shear wall and floor diaphragm system to withstand the horizontal seismic actions.

The structural system of reinforced concrete frame consists of beams and columns coupled by moment- and shear resistant joints. The structural behaviour of RC frames is determined by the ratio between the column’s height and beam’s length and by the resistance (cross-sections and reinforcement detailing) of columns and beams. Weak columns and strong beams are indicators of seismic vulnerability.

A major distinction can be done based on the date of construction: the late nineties, when the seismic building codes were licensed, serves as a dividing line between the buildings which are likely to be well-designed and those that do not feature any anti seismic characteristics.

The larger portion of the European RC building stock was built between 1950-90, as shown in the previous chapters. Most of these buildings have already exhausted their design service life (50 years) and often exhibit significant structural deficiencies with respect to both static and seismic actions. In seismic prone areas, such as in the southern Mediterranean European countries (Italy, southern France and Spain, Portugal, Greece, Turkey), the serious structural deficiencies of older RC structures have been highlighted by recent earthquakes. As a matter of fact, these buildings were designed and erected without any seismic safety standard (which first appeared after 1970) or any reference to good anti-seismic reinforced concrete construction practice, and accounting for static loads lower than those currently recommended. Finally, durability concepts were not yet brought into focus and durability issues were not carefully addressed at the time of construction, thus many buildings show today significant signs of decay.

For all these reasons, existing RC buildings require structural safety assessment and possible strengthening interventions to maintain their service functionality and to pursuit a good performance against earthquake loading.

Typical RC structures, built right after the II World War until the late 80’s, are made of reinforced concrete frames with masonry infill walls. A “pilotis” floor is frequently present at the building basement level. Existing RC frames are often oriented in a single direction (one-way frames). Structural elements and joints are characterized by poor structural detailing, which result in limited ductility of the structure. Floors are generally excessively deformable and often lack a RC topping slab. Possible RC walls, designed to withstand the sole vertical actions, are typically located at the stairwells or at the elevator.

The high seismic vulnerability of these structures is usually bound to the collapse due to the pilotis floor, to one-way frames, to poor detailing of the structural joints, to plan and elevation regularity, cast quality and ability of the workmanship. RC frames are particular vulnerable against abrupt discontinuity in the lateral stiffness over the building height: either the pilotis floor or the irregular distribution of the infill walls in elevation can trigger a soft storey mechanism and cause the collapse of the entire building. Such building types are very vulnerable against lateral loads. In the case of buildings showing remarkable irregularities in the ground-plan, torsional effects might overload the outer columns, and increase the vulnerability of the frame.

The seismic vulnerability is also affected by the frame and the masonry infill interaction. The **frame-infill interaction** may have positive effects in the case of regular infill distribution and for buildings located in low seismicity areas. In this case the infill provides the seismic strength required to counteract the modest seismic actions and the building can be more effectively modelled with respect to the horizontal forces as a ribbed-masonry structure rather than a RC frame. On the other hand, the frame-infill interaction is often negative in highly seismic prone areas, where the collapse of the infill often causes the early collapse of the frame. If the infill has openings or the infill does not extend in elevation up to the top beam intrados, a "short-column" effect might increase the seismic vulnerability by resulting in anticipated shear failure of the frame columns.

As far as the structural retrofit techniques is concerned, two main approaches are followed today: the "local approach", consisting of the local retrofit of the frame joints and members for the strengthened frame to resist the seismic actions; and the "global approach", where the building is provided with a brand new structure designed to resist the horizontal loads. These interventions are discussed in chapter 2A.1.

- **Steel and wooden structures**

The diffusion of steel and wooden constructions is modest in the European seismic prone areas (i.e. Mediterranean areas), with respect to masonry or RC structures and only few data about their performance, observed after recent earthquakes, is available. The assessment of their seismic vulnerability is beyond the scope of this paper.

However, it is worth underlining that efficient and safe anti seismic structures can be obtained by adopting every material (either steel, wood, masonry or reinforced concrete), as long as the structures are correctly conceived and organized with respect to both static and seismic loads.

The EMS-98 (Grünthal, 1998) also provides a list of aspects, which affects the global seismic vulnerability of a structure, regardless of the construction type. These vulnerability indicators are common to all types of structures, both engineered and non-engineered, as well as structures with and without ERD.

- **Regularity**

As stated in EMS-98, from the earthquake resistance point of view, "the ideal building would be a cube in which all internal variations in stiffness (like stairwells) were symmetrically arranged". Far from this ideal layout, it is well acknowledged that for existing buildings the more regular and symmetrical the layout, the less significant the vulnerability to earthquake shaking.

With respect to current anti-seismic codes (i.e. Eurocode 8) engineered buildings must be classified according to their structural regularity on the basis of both global parameters (such as main plan and elevation dimensions) and global and local deviations from a regular ground plan and vertical shape. Regularity should be considered in a global sense, being more than just external symmetry in plan and elevation; regularity should imply uniform variation of the stiffness of the seismic resisting elements in elevation and comply with a predictable structural behaviour under seismic action, characterised by principal translational vibration mode shapes. For engineered structures it is expected that measures taken to ensure regularity corresponds to rules of earthquake resistant design.

Gross irregularity is easy to identify; for example, buildings with L-shaped ground plans are often subject to significant torsional effects, which may greatly increase the structural damage in existing buildings without any ERD. It would be unwise to assume that a building meets standards of regularity solely on the base of the symmetry of the external profile of the ground plan. Even if the ground plan is regular, problems may arise in buildings having significant asymmetry in the arrangement of internal components of varying stiffness. In this respect, the position of lift shafts and stairwells is often crucial in determining structural irregularity. Figure 24 shows an example of the effects of in-plane irregularities.

Figure 24 - Damage for torsional effects caused by in plan irregularities

Another case is represented by buildings in which one storey (usually the ground floor) is significantly weaker than the others, such in the case of pilotis floor, with bare columns supporting the upper stories (Figure 25). Such layouts are acknowledged for triggering possible **soft storey mechanism**, leading to the building global collapse. Continuous strip windows extending over the frame bay length may introduce similar effects.

Figure 25 - Collapse of the first story due to a soft story mechanism

In some cases, buildings which had previously a good level of regularity may have been adversely affected by subsequent modifications. For example, the conversion of the building ground floor into a garage obtained by demolishing the infill walls may weaken the structure by creating a soft storey. Possible extension to a building is likely to make the ground plan layout more irregular, and introduce significant irregularities of resisting element stiffness. Finally, structural resistance might have been impaired or reduced by previous earthquakes damaging the structures.

- **Ductility**

Ductility is a measure of a building's ability to withstand lateral loading in a post elastic range, i.e. by dissipating earthquake energy and creating damage in a controlled wide spread or locally concentrated manner, depending on the structural system and detailing. Ductility can be as well a function of construction type: ERD steel houses have high ductility, compared to more brittle lower-ductility buildings such as brick houses. In the case of existing RC building, erected prior to the licensing of anti-seismic code, the poor detailing of the structural elements and beam-column joints determine a very low ductility, thus a low energy dissipation capacity.

- **Position**

The position of a building with respect to the neighbouring constructions can significantly affect its behaviour during an earthquake and its damage level after the seismic event. In the case of a row of houses in an urban block, those houses located at the end of the row or in a corner position are the most affected by the earthquake; one side of the house is anchored to the adjoining building, while the other side is not, causing an irregularity in the global stiffness of the structure which leads to increased damage. In the case of masonry structures, the presence of either facades misaligned from the main prospect, volumes protruding from the skyline, or misaligned of the neighbouring buildings floors are recognized as a major source of vulnerability of the building aggregate.

Severe damage can be the consequence of the proximity of two tall buildings having different natural periods, and located too close to one another. During an earthquake they may sway at different frequencies and smash into each other, causing an effect known as **pounding** (Figure 26). Such damage is not a measure of the strength of the earthquake shaking but an indicator of the lack of structural joints between the buildings.

Figure 26 - Pounding effect due to the proximity of two buildings with different heights

- **Quality and workmanship**

As stated in EMS98, workmanship ability affects the structure quality and obviously, a building that is better built will be stronger than one that is badly built. This aspect has been neglected in the past but is now gaining more and more attention. The use of good quality materials and good construction techniques result in a building having better chances to withstand earthquake shaking than the use of poor materials and slipshod workmanship (Dimova and Negro, 2005). In the case of materials, the quality of the mortar is particularly important, and even rubble masonry can exhibit a reasonable strength if the mortar is of high quality.

- **State of preservation**

Ordinary and extraordinary maintenance are other key factors in the seismic vulnerability assessment. A building which has been well-maintained will perform in accordance with its expected strength. A building which has either experienced significant decay, or might have been damaged by previous earthquakes may reduce its seismic performance to such an extent that a relatively weak aftershock can cause disproportionate amounts of damage (including collapse).

Noteworthy, a structure may appear to be in good condition because the aesthetic appearance of the building has been recently renewed, but neither fresh plaster, unless appositely designed as a strengthening system, nor nice paint necessarily mean that the structural system of the building is also in good shape.

1A.3 BUILDINGS AND ENERGY

The European Union is the largest regional energy market, the largest energy importer and the world's largest economy in terms of combined GDP (Gross Domestic Product) (BIO service, 2013). Indeed, Europe consumes one fifth of the energy produced in the world even if its reserves are limited, so one of its main characteristic is the energy dependence from foreign countries. In details, Member States are obligated to import over half of the needed energy, buying petrol from OPEC and Russia and importing gas from Norway, Russia and Algeria (EC, 2013).

The building sector is one of the key consumers of energy in Europe. Buildings demand energy during their whole life cycle both directly and indirectly. Direct energy demand is necessary for their construction, operation and eventually dismission and demolition; but energy is required and consumed also indirectly for the possible mining, processing and production of the construction materials (Sartori and Hestnes, 2007).

Understanding building energy consumption requires an insight into the energy levels consumed over the years and the mix of used fuels. The final building energy consumption history recorded for EU27, Norway and Switzerland since the 1990s shows that consumption is characterized by two main trends: a 50% increase in electricity and gas usage, and a decrease in use of oil and solid fuels by 27% and 75%, respectively (Figure 27) (BPIE, 2011).

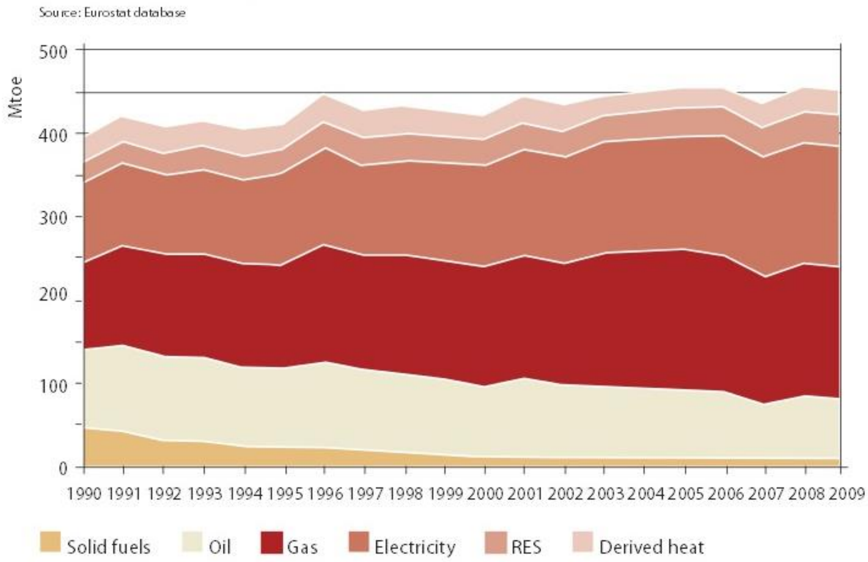


Figure 27 - Historical final energy consumption in tons of equivalent oil the building sector since 1990s for the EU27, Switzerland and Norway (BPIE, 2011)

The **utilisation phase** of a building is the longest stage of its life cycle, usually lasting many decades and producing significant environmental impacts, accounting for the greatest part of a building's energy use. The main building processes demanding energy are living environment heating, heating of drinking water, electricity for lighting, ventilation cooling, as well as air conditioning systems, so the building operation requires the consumption of a huge amount of energy. Besides, a great number of pollutants are emitted, a large volume of natural resources is consumed and a huge amount of wastes are produced in building facilities.

The main environmental impact of building operation is from electricity generation, as buildings are great consumers of electrical energy. A great amount of fossil resources are therefore consumed, emitting a large volume of greenhouse gases and other pollutants such as sulphur dioxide and nitrogen oxide. A significant share of electricity comes from nuclear energy, so the production of radioactive waste is also a significant environmental pressure from energy consumption in buildings (JRC, 2012).

In short, energy consumption in buildings - for space heating, water heating and use of electric appliances - is a key cause of environmental impacts, considering that energy use in buildings - including commercial and public buildings - represents approximately 40% of total final energy consumption and 36% of CO_2 emissions in Europe.

In order to define energy performance of buildings in details, a main subdivision between residential and non-residential buildings has been made in the following sections.

Residential building energy performance

Residential buildings comprise the biggest segment of the EU's building stock and are responsible for the majority of the sector's energy consumption.

Energy in households is mainly consumed by heating, cooling, hot water, cooking and electric appliances. In 2009, European households were responsible for 68% of the total final energy use in buildings.

Final energy consumption per person in the European Environment Agency (EEA) member countries (EU-27, EFTA and Turkey) increased by 3% between 1990 and 2007. The trend was reversed between 2005 and 2007 when energy consumption per person decreased by 9% in the EU-27, partly driven by rapidly increasing energy prices, although energy efficiency policies might also have contributed to this effect. Household electricity consumption per person increased more rapidly: on average by more than 30% between 1990 and 2007 in the EEA member countries, in spite of increasing prices in many countries (EEA, 2008).

Living space heating accounts for 70% of household energy consumption in the EU-27, followed by water heating and appliances/lighting (Odyssee database, 2010).
Rising energy consumption for space heating is mainly driven by an increase in housing space per person. The average area of a dwelling unit rose from 86 to 92 m^2 in the EU-15 between 1990 and 2007 (EEA energy indicator ENER22, 2010), while the number of people per household decreased from 2.8 to 2.4 (Odyssee database, 2010), giving a 20% rise in floor space per person and an increase in the number of households.
In additions, the strong correlation between heating degree-days and fuel consumption emphasises the link between climatic conditions and use for heating as the year-to-year fluctuations in heating consumption largely depend on the climate of a particular year (Figure 28).

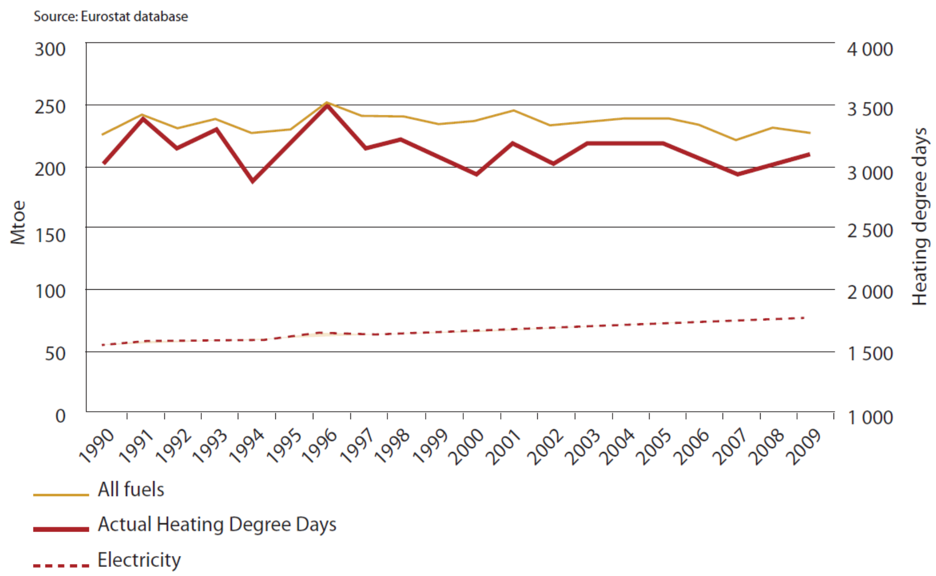


Figure 28 - Historical final energy use in tons of equivalent oil in the residential sector in EU27, Norway and Switzerland (BPIE, 2011)

On the other hand, the main reasons behind the significant increase in electricity consumption (38% over the last 20 years) (Figure 28) are the steady increases in the numbers of appliances and a rising demand for air conditioning and cooling technologies, especially in the Mediterranean countries (JRC/IE, 2009).

With regard to the energy product per region in 2009 (Figure 29), gas turns out to be the most common fuel used in buildings in all regions, with a share of 41%, 39% and 26% on total consumption in North & West, South and Central & East regions, respectively. Oil use, instead, is highest in North & West Europe where Germany and France are the biggest consumers. The highest use of coal in the residential sector is in Central & Eastern Europe where also district heating has the highest share of all regions. Renewable energy sources (solar heat, biomass, geothermal and wastes) have a share of 21%, 12% and 9% in total final consumption in Central & Eastern, South and North & West regions, respectively (BPIE, 2011).

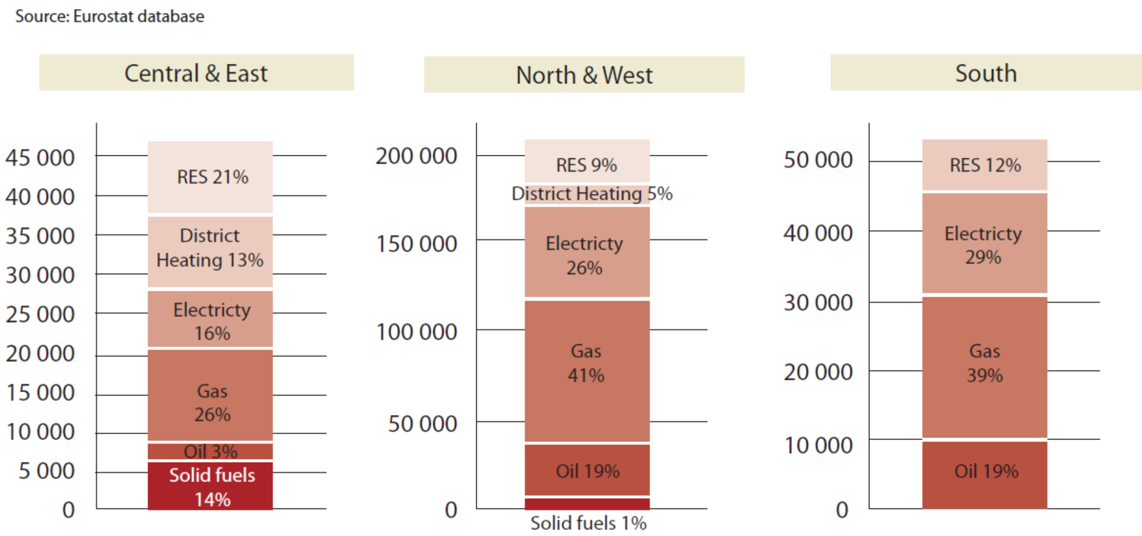


Figure 29 - Final energy mix in residential buildings (thousand toe) by region (BPIE, 2011)

A wide variation in energy and electricity consumption per dwelling for different European countries in 2010 can be observed. Figure 30 shows that per capita energy and electricity consumption is substantially higher in Northern and Western Europe than in Southern and Eastern Europe. These geographical differences are important to keep in mind when designing measures to increase energy efficiency (BIO service, 2013).

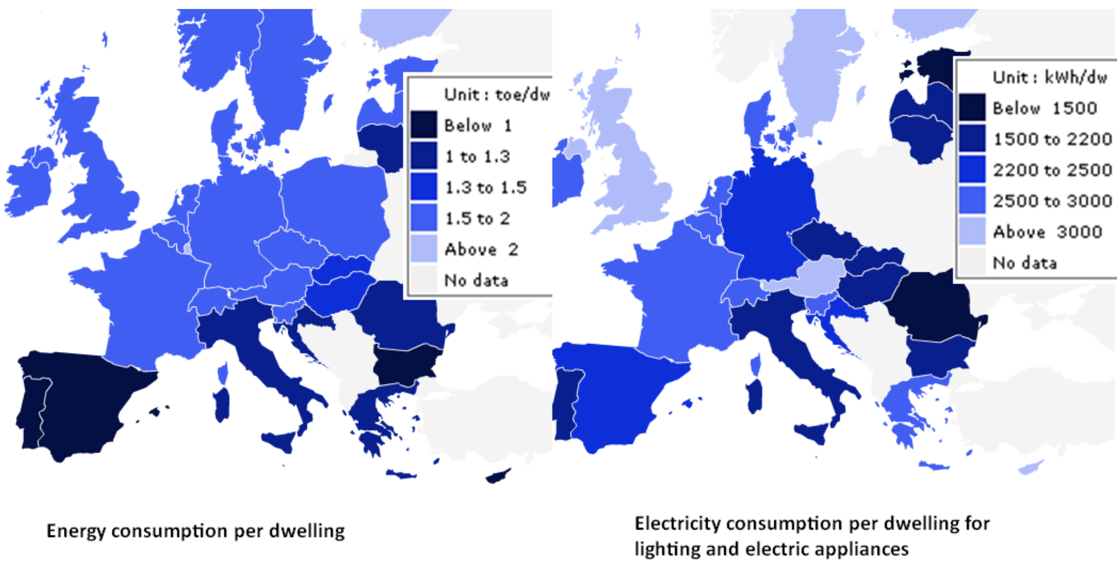


Figure 30 - Energy and electricity consumption per dwelling in Europe (Odyssee database, 2010)

On those basis, the energy performance of households depends on a number of factors such as the performance of the installed heating system and building envelope, climatic conditions, behavioural characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty meaning that not all buildings are used at maximum capacity).

Within the existing European building stock, a large share (more than 40%) was built before 1960s where there were only few or no requirements for energy efficiency and only a small part of these buildings have undergone major energy retrofits. This means that most of the existing buildings have low insulation levels and their plant systems are old and inefficient.
The oldest part of the European building stock, characterized by very low energy efficiency, greatly contributes to the high energy consumption in the building sector.
This is clearly demonstrated in Figure 31, which shows data on typical heating consumption levels of the existing stock by age, for several countries analysed through the BPIE survey (BPIE, 2011).

By this analysis, it is worth noting that the largest energy saving potential is associated with the older building stock. This is a trend observed in all countries. In some cases buildings from the 1960s perform even worse than buildings constructed in the years before (c.f. Bulgaria and Germany). It is interesting to note the large consumption levels for heating in the UK, highlighting the very poor performance of UK buildings.
Moreover, although heating needs in Southern countries such as Portugal and Italy are lower due to milder winters, the energy use in these countries is relatively high, which can be an indication of insufficient envelope thermal insulation in their building stocks. For those countries, cooling becomes an important contributor to the overall consumption, where homes are, in many cases, equipped with air-conditioning systems.

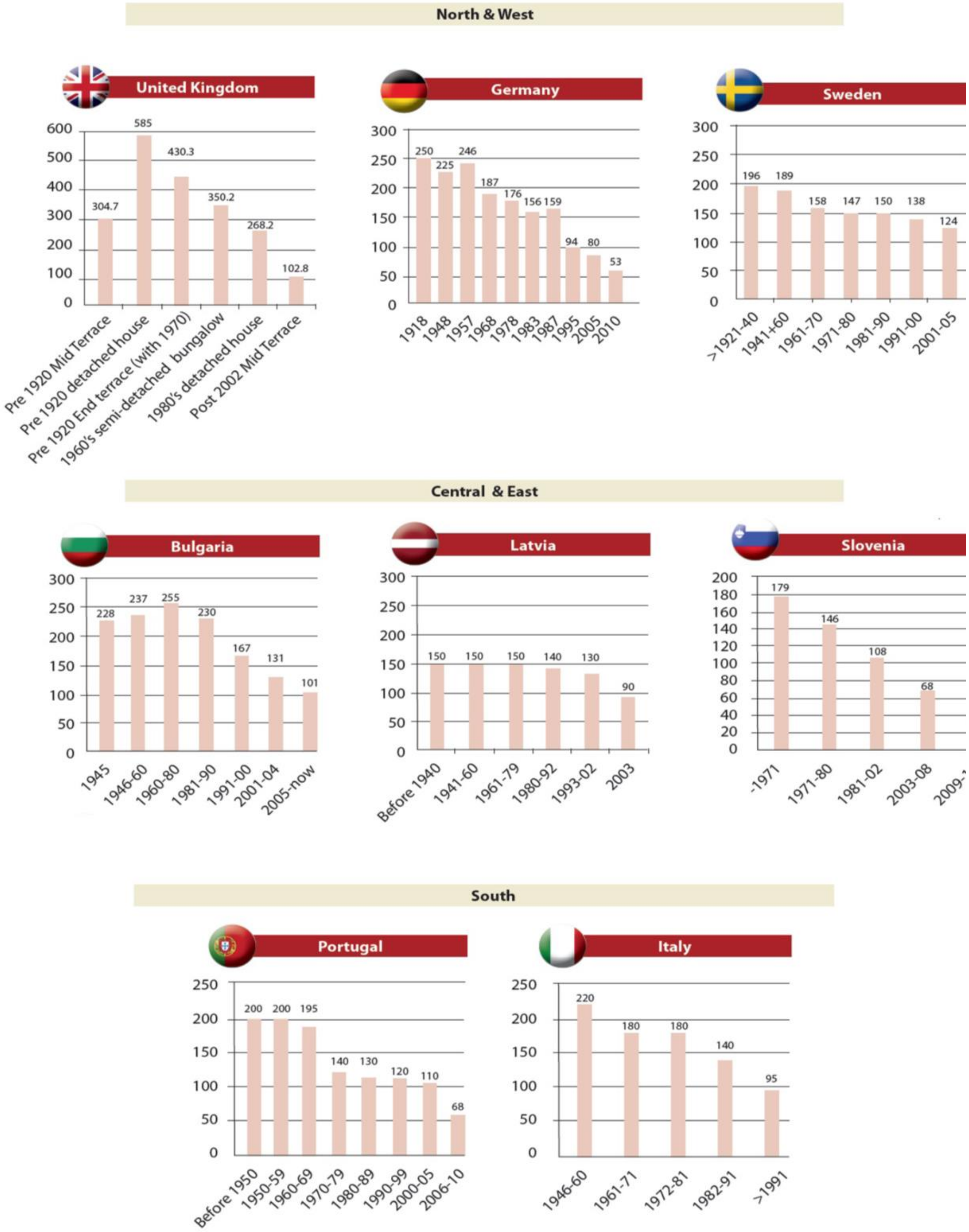


Figure 31 - Average heating consumption levels in terms of final energy use (kwh/(m^{2}a) of single family homes by construction year (BPIE, 2011)

Non-Residential building energy performance

Understanding energy use in the non-residential sector is complex as end-uses such as lighting, ventilation, heating, cooling, refrigeration, IT equipment and appliances vary greatly from one building category to another within this sector.

According to BPIE study, it is estimated that the average specific energy consumption in the non-residential sector is 280kWh/m^2 (covering all end-uses). This is at least 40% larger than the equivalent value for the residential sector. Within the non-residential sector, variations are expected from country to country and also from one building type to another.

These variations are clearly illustrated in Figure 32 where the specific energy use in offices, educational buildings, hospitals, hotel & restaurants and sports facilities are presented for a number of countries. While hospitals are, on average, at the top of the scale with continuous occupancy and high-energy intensity levels, their overall non-residential consumption is small. This is also the case with hotels and restaurants, which are equally energy intensive. While these two categories represent the highest energy intensive type in specific terms, offices, wholesale & retail trade buildings, on the other hand, represent more than 50% of energy use, being much larger in number. Education and sports facilities account for a further 18% of the energy use while other buildings account for some 6%.

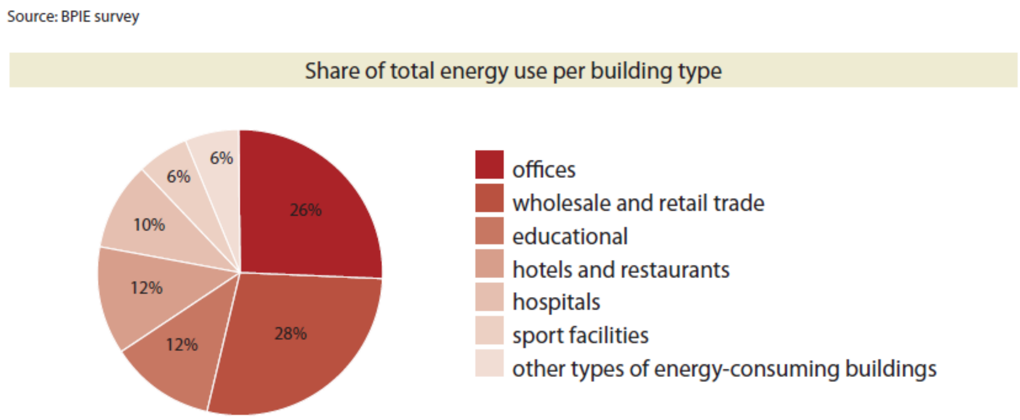


Figure 32 - Final energy use in non-residential building types for different countries across Europe (BPIE, 2011)

The energy performance discussion illustrated for the residential buildings in the previous chapter, also applies to the non-residential sector (hence similar renovation measures should be considered), while the installation of smart energy management systems in non-residential buildings becomes more important due to their high share of electricity use.

Indeed over the last 20 years electricity consumption in European non-residential buildings has increased by a remarkable 74% (Figure 33). This is compatible with technological advances over the decades, where an increasing penetration of IT equipment, air conditioning systems etc. means that electricity demand within this sector is on a continuously increasing trajectory (BPIE, 2011).

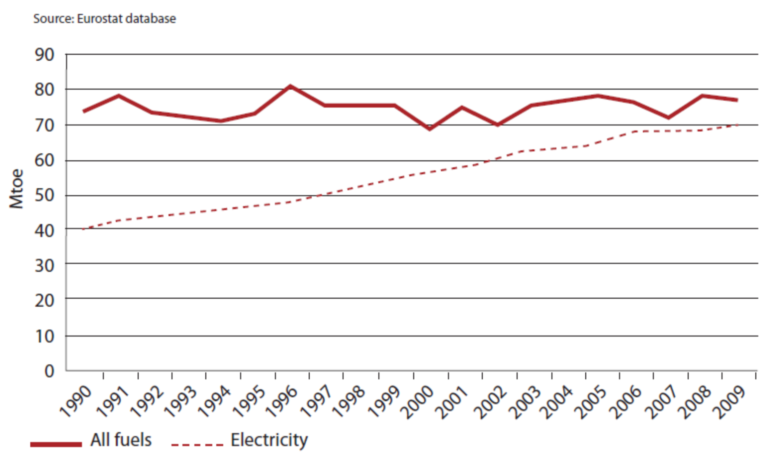


Figure 33 - Historical final energy use in the non-residential sector in the EU27, Norway and Switzerland (BPIE, 2011)

For example, the deployment of efficient lighting control systems has substantial potential in the non-residential sector as electricity consumption for office lighting, which has been estimated to be 164 TWh in 2007 in the EU27, is among the highest end-use in this sector.

1A.4 BUILDINGS AND ENVIRONMENT

In European Union, the construction of buildings uses 50% of materials, generates 30% of waste and consumes 40% of the total EU energy. This data reveals a sector that has a huge impact on the economic, ecological and social environment.

The building sector has great effects on the environment in each phase of the construction, from early planning to building end-of-life. The main impacts are land use, consumption of raw materials, energy and water, production of waste, as well as noise and air emissions and impacts on biodiversity. The Reference Document on Best Environmental Management Practice in the Building and Construction Sector (JRC, 2012) points out the environmental aspects of construction sector and gives the characteristics that a building needs to be environmentally friendly. This document explains the strategy to select best environmental management practice based on the overall environmental impact during construction or refurbishment, use phase and deconstruction activities (Figure 34).

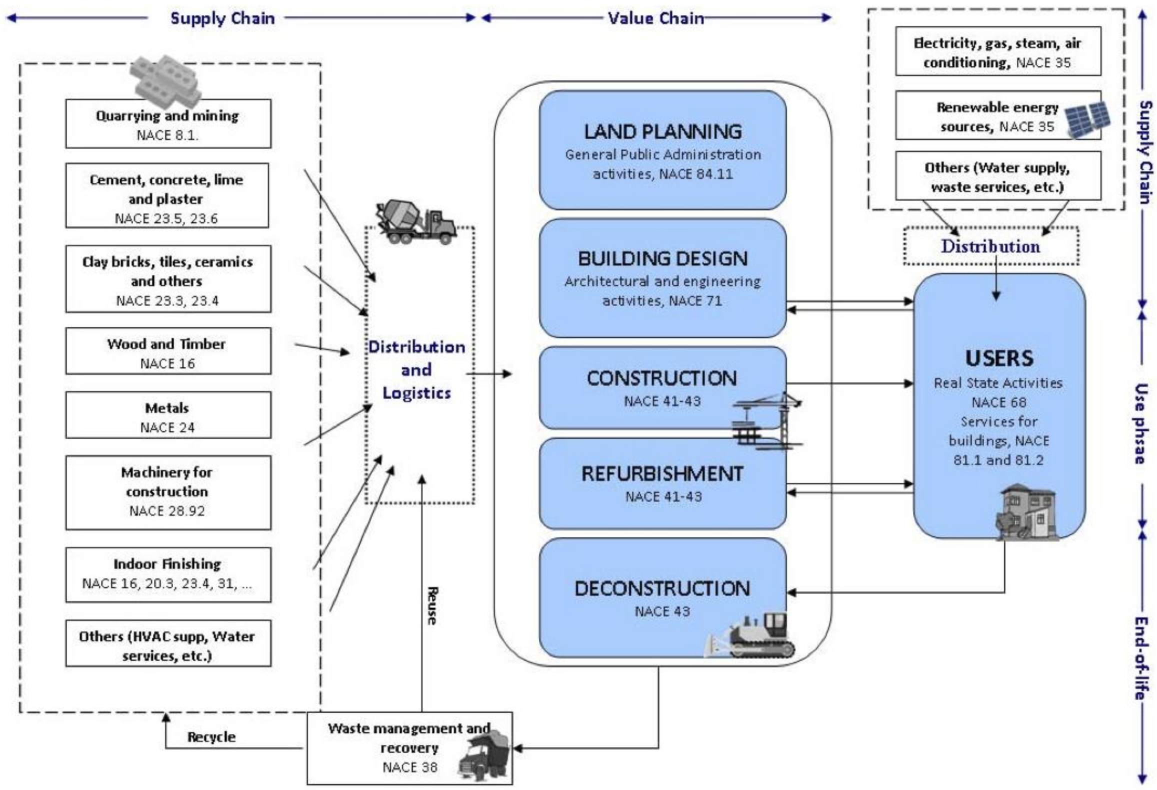


Figure 34 - Construction chain flowchart and relation to the other economic activities (JRC, 2012)

A short description on the impacts for each building phase is explained below, as reported in the Reference Document on BEMP (JRC, 2012):

- Land planning: it introduces the land use question and generates impact on biodiversity, resources consumption and on the urban environment.
- Building design: best design practices to minimize the impact of the use phase, especially regarding energy consumption and waste management must be considered. In this initial phase the construction products must be selected, minimizing the life cycle environmental impact of products and their performance during the use phase.
- Construction and refurbishment: the management and size organizational practices must

contemplate waste management, reuse schemes, recycling flows and materials efficiency.

- Building use: it is the most important phase, as it is the phase where the most important impacts are produced over the long lifetimes of buildings. Nevertheless, the most important best practices regarding the use phase may be taken during planning and design stages.
- Deconstruction or demolition: this phase produces the highest quantities of waste that could be recovered applying the principle of selected demolition.

Below, a summary list of the relevance of environmental aspects in the construction sector is shown (mainly quoted from JRC, 2012):

- Use of raw materials: the use of raw materials for construction works is regarded in a closed loop system (i.e. construction wastes can be used as raw materials after an appropriate treatment, avoiding the use of natural resources). So, environmentally friendly sourcing should be integrated in the management system, which should accomplish objectives for the use of recycled materials, the reuse of materials and the improvement of materials efficiency. In a closed loop system, the role of deconstruction activities and recycling plants is also very relevant. Avoidance of hazardous substances is taken into account in the environmentally friendly sourcing of materials.
- Waste: this issue is directly linked to the closed loop view for raw materials. The designing out waste approach can avoid the generation of waste during construction or during deconstruction. The waste balance of the sector as a whole can be improved through responsible sourcing of recycled products. For hazardous waste strict controls and regulations must be taken into account.
- Use of energy: it is one of the most important aspects regarding the life cycle environmental impact of buildings. Reducing the energy demand of buildings might be accomplished by enforcing several measures: improving the performance of the envelope through better insulation; applying integrative design concepts and adopting some design premises for heating, lighting, ventilation and air conditioning systems. Moreover, the use of efficient building management systems and the use of better energy sources can lead to reduced energy consumption. Energy efficiency during construction activities is less relevant, but not negligible and must be considered in the building design.
- Use of land: the urban sprawl, use of land and the heat island effect of built environments is another important issue connected with the building construction, in which the public administration has a great role.
- Biodiversity: construction projects have the potential to impact on species and natural habitats. Habitat fragmentation occurs as the natural landscape is gradually developed and subdivided. The remaining patches of original habitat are often too small and too far apart to support the survival and reproductive needs of certain species. Other types of landscape disturbance with potential consequences on biodiversity include alterations in soil structure through compaction and changes in a site's hydrology. Moreover, the noise and light generated during the construction phase may affect feeding and breeding behaviours, which could have a negative impact on long-term population levels. Landscape disturbance caused by development can also contribute to the introduction of invasive alien species into natural habitats.
- Air emissions: the majority of CO_2 emissions of the construction sector as a whole comes directly from energy consumption during the use phase. The main emissions to the

environment from construction works come from dust, which can be very relevant in dry climates. Other relevant emissions originate from the use of machinery (particulate materials, NOx, noise and vibrations).

- Emissions to water: water pollution is not a major concern for building construction sites, except for those projects affecting natural waterways or where the groundwater table is high enough to require specific protective measures, usually coordinated by public bodies. Run-off water pollution should also be controlled through appropriate measures and the impact on soil should also be considered.

It could be seen that the most important environmental effects of the construction sector are the use of raw materials, the construction and demolition (C&D) waste and the use of energy.

The European Construction Technology Platform in its Vision 2030 & Strategic Research Agenda about the building materials (ECTP, 2005) has as target for 2030 to reduce the environmental impact of building material production and demolition and, in particular:

- 30% specific reduction of the natural raw materials needed for building materials production;
- 100% re-utilization of construction and demolition waste;
- 30% specific reduction in CO_2 emission of building materials production.

In the next sections these three important impacts of the building sector on the environment are further analysed.

Construction Industry Natural Resource Consumption

As emphasized in the Environmental statistics and accounts in Europe (Eurostat, 2010), one of the main objectives of the EU sustainable development strategy is the improving of the resource efficiency, to reduce the overall use of non-renewable natural resources and the related environmental impacts of raw materials use. A good indicator to assess the resource efficiency is the domestic material consumption (DMC), that measures the total amount of materials directly used by an economy and is defined as the annual quantity of raw materials extracted from the domestic territory (domestic extraction used DEU), plus all physical imports minus all physical exports (physical trade balance PTB).

Figure 35 (Eurostat, 2012) shows the major components of the domestic extraction; in 2009, about half of the 14.6 tonnes per capita of DMC of the EU27 are made up by sand and gravel (4.6 tonnes per capita - 32%) and other non-metallic minerals such as natural stones, clay etc. (2.7 tonnes per capita - 18%), with 3.5 tonnes per capita fossil energy materials make up around one fourth (24%); crop residues & grazed biomass (1.5 tonnes per capita) and other biomass (1.9 tonnes per capita) together contribute another fourth (23%) and metal ores constitute the smallest category with 0.4 tonnes per capita (3%).

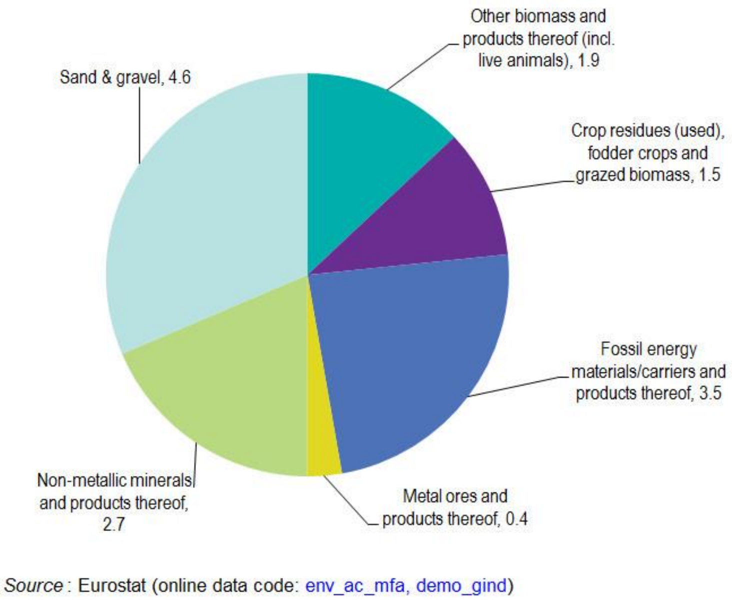


Figure 35 - Domestic Material Consumption (DMC) by major components, EU-27, 2009 (tonnes per capita) (Eurostat, 2012)

From this breakdown, the importance of the construction industry — which uses much of the sand, gravel and other non-metallic minerals — can be seen (50%). In fact, while a small proportion of these minerals may not be used in the construction sector, the overwhelming majority are, making it a rough proxy for the material consumption of the construction sector.

The composition of DMC by main material categories varies considerably across countries (Figure 36). Obviously, the composition is influenced by domestic extraction and hence depending on the natural endowment with material resources. In particular, the outliers Cyprus, Finland, and Ireland show extraordinarily high consumption of sand and gravel and other non-metallic minerals suggesting high construction activity (Eurostat, 2012).

The single material categories of DMC have been developing differently (Figure 37). Most pronounced has been the development of non-metallic minerals and products thereof, which is quantitatively important with around 3 tonnes per capita and assumingly closely related to construction activities. It increased by more than 35% between 2000 and 2008 and shows a sharp decline in 2009. Sand and gravel decreased to 4.7 tonnes per capita in 2002/2003, increased to 3.3 tonnes per capita in 2007/2008 to drop again in 2009 to 2.7 tonnes per capita (Eurostat, 2012). These trends reflect very well the global recession that began in 2008. Due to the significant time lag in the availability of data on material flows, it is not possible to estimate in a timely fashion the decline in Europe's use of resources that resulted from the economic crisis (EEA, 2012).

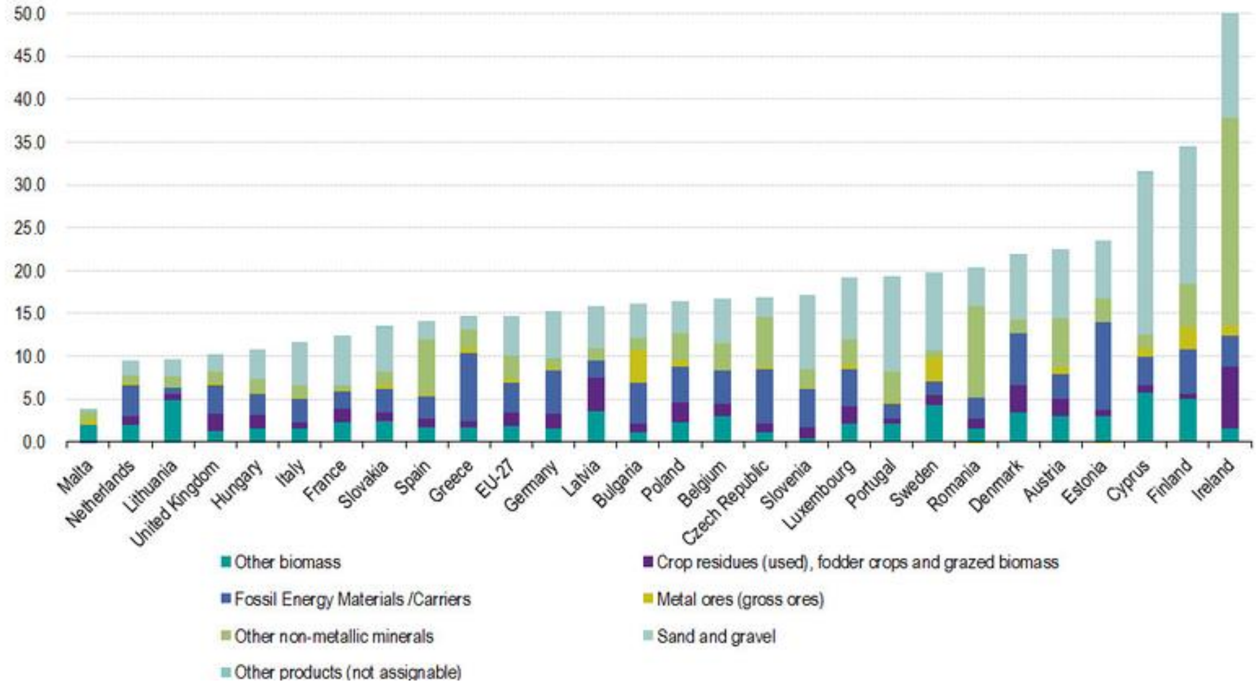


Figure 36 - DMC by country and main material category, 2009 (tonnes per capita) (Eurostat, 2012)

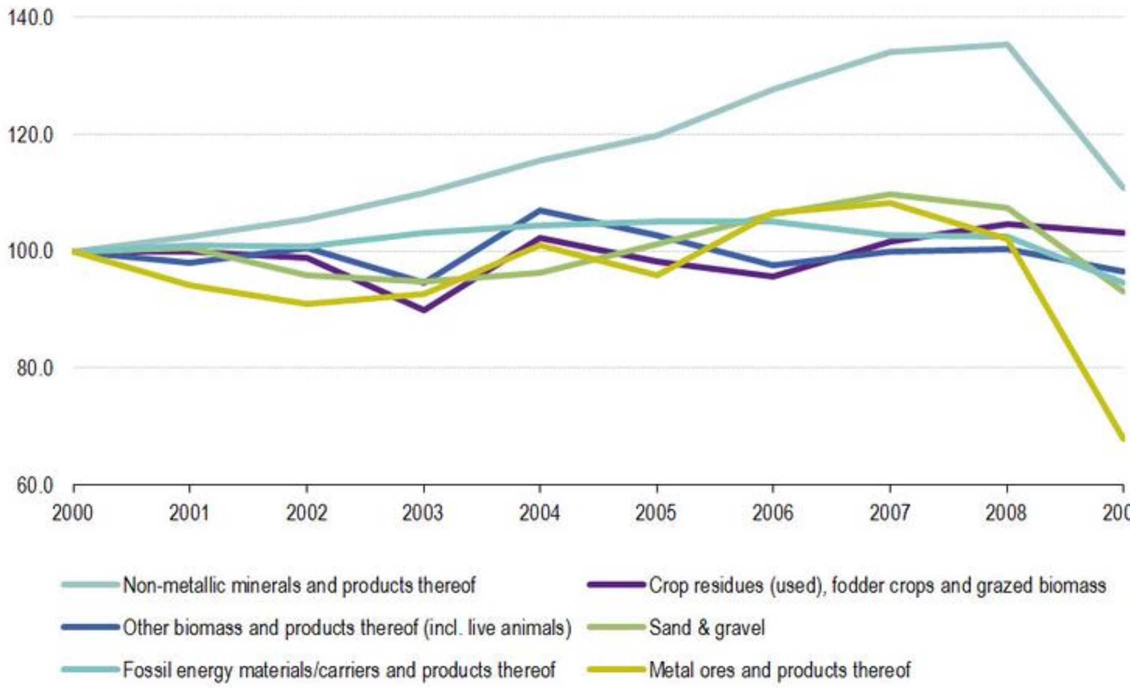


Figure 37 - DMC by main material category, EU-27 2000-2009 (Index 2000=100) (Eurostat, 2012)

The environmental impacts associated with this great extraction and production of material resources are well described by the EEA SOER report (EEA, 2012). They include impacts on land, water, and air, the movement of massive amounts of materials and related high use of energy, as well as toxic emissions and generation of waste on a large scale. High use of natural resources increases pressures on both the source function of ecosystems — for example maintaining the availability of supplies and ensuring sustainable yields — and on their role as sinks — absorbing pollution or neutralizing discharges. All in all, it is generally accepted that there are physical limits to continuing global economic growth based on the current patterns of resource use.

Construction and Demolition Waste (quantities, nature, recovery and recycling)

In the context of the Framework Contract on the Sustainable Management of Resources, Construction and Demolition (C&D) waste has been identified by the European Commission as a priority stream because of the large amounts generated and the high potential for re-use and recycling embodied in these materials. Indeed, a proper management would lead to an effective and efficient use of natural resources and the mitigation of the environmental impacts to the planet. For this reason, the Waste Framework Directive (WFD) requires Member States to take any necessary measures to achieve a minimum target of 70% (by weight) of C&D waste by 2020 for preparation for re-use, recycling and other material recovery, including backfilling operations using non hazardous C&D waste to substitute other materials (BIO Intelligence Service, 2011).

- **Quantities**

The Eurostat statistics show that in 2010, the total generation of waste from economic activities and households in the EU-27 amounted up to 2502 million tonnes; this value was slightly higher than in 2008 but lower than in 2004 and 2006; the relatively low figures for 2008 and 2010 may, at least in part, reflect the downturn in economic activity as a result of the financial and economic crisis. Among the waste generated in the EU-27 in 2010, some 101.3 million tonnes (4.0 % of the total) were classified as hazardous waste. As such, inhabitants in the EU-27 generated on average about 5.0 tonnes of waste each, of which 202 kg were hazardous waste (Eurostat, 2013).

The Eurostat analysis of the total waste generated by main economic activity shows two activities that generated particularly high levels of waste across the EU-27 in 2010, namely: the construction sector accounting for 860 million tonnes (34.4 % of the total), and mining and quarrying activities, contributing to generate 672 million tonnes of waste (28.3 % of the total, similar to the 2008 analysis, Figure 38). The vast majority of the waste that was generated within these activities was composed of mineral waste or soils (excavated earth, road construction waste, demolition waste, dredging spoil, waste rocks, tailings and so on) (Eurostat, 2013). This explains the high share of mineral waste and soils, 65% in relation to total waste produced.

There was a considerable variation in the amount of waste generated in 2010 across European countries; the highest share of the EU-27 total being accounted for by Germany (14.5 %), just ahead of France and the United Kingdom. Some of the large variations between countries may be linked to the differences in economic structures. For example, the high level of waste generated in Bulgaria, Finland, Estonia, Sweden and Romania was strongly influenced by large quantities of mineral wastes from mining and quarrying activities, whereas in Luxembourg, mineral waste from construction was largely responsible for the high amount of waste generated (Eurostat 2013).

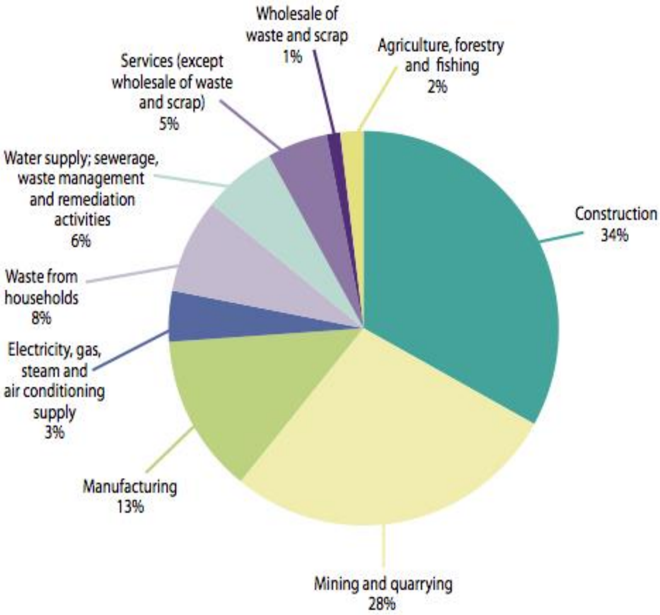


Figure 38 - Total waste generation in the EU-27 by economic activity, 2008 (%) (Eurostat, 2012)

Construction and Demolition (C&D) wastes are generated from the construction and demolition or deconstruction of buildings and other infrastructures and account for around one third of the controlled waste within the European Union. C&D waste materials typically include soils, concrete, bricks, glass, wood, plasterboard, asbestos, metals and plastics. The Waste Framework Directive (WFD) excludes uncontaminated soil and other naturally occurring material excavated in the course of construction activities, when the material is used, and remains, on site (JRC - IES, 2011).

Some caution is always needed when reviewing statistics on C&D waste generation and composition. Different methods and waste definitions are sometimes used in compiling surveys, which makes them incomparable.

The ETC/SCP working paper EU as a Recycling Society shows the development of C&D waste generation per capita in the EU Member States and Norway since 1995. The generation per capita in the old EU Member States and Norway, France and Luxembourg generate 7 and 15 tonnes per year respectively. Germany and Ireland generate between 2 to 4 tonnes, whereas the rest of the countries generate between 0.2 tonnes (Norway) and 2 tonnes (United Kingdom) per capita. Among the new EU Member States the differences are also large in generation per capita but, with the exception of Malta, the level is lower than 2 tonnes per capita (ETC/SCP, 2009).

Figure 39 presents the spread of C&D waste across European countries in generated tonnes. These values vary significantly among the Member States. These high geographical variations cannot be assumed to reflect actual arising of C&D waste; the main reasons for these discrepancies are the unequal levels of control and reporting of C&D waste in Member States, as well as differences in definitions and reporting mechanisms. The quality of the available data is therefore the main issue in estimating the quantities of C&D generated waste. Other explanations for geographical variation include economic reasons (the quantities of C&D generated waste is highly dependent on the rate of new constructions, and the economic growth of the country), architectural habits (the types of materials used in construction shows great regional variation, e.g. in some regions brick is the main construction material, whereas in others concrete represents the majority; wood is a major construction material in northern countries like Finland or Sweden, etc.), cultural issues (e.g. demolition is seen as a failure in countries such as France, whereas it is regarded in a more positive way in other countries), or technical issues (the quality of the materials used in old construction influences the rate of demolition, e.g. more demolition is expected in new

Member States because of the low quality of the concrete used in old constructions). However, an accurate analysis of geographical variations would require reliable data, which is not the case with the current reporting system (BIO Intelligence Service, 2011).

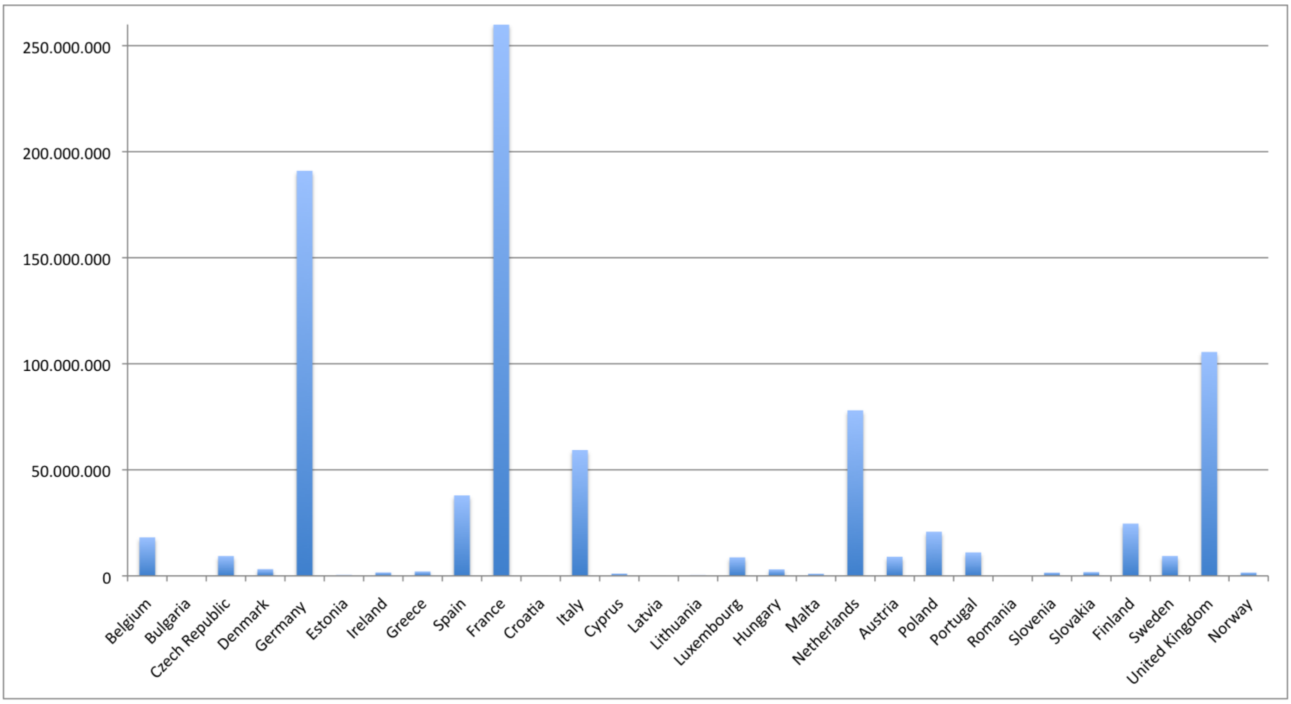


Figure 39 - Generation of C&D waste EU Member States - source: Eurostat database, 2013 (tonnes)

The BIO Intelligence Service estimated in the Service Contract on Management of C&D Waste that the C&D waste quantities are likely to range between a total of 310 and 700 million tonnes per year in the EU-27 (0.63 to 1.42 tonnes per capita per year). The systematic inclusion of excavation waste would significantly increase these amounts, ranging from a total of 1350 to 2900 million tonnes of waste per year (2.74 to 5.9 tonnes per capita per year).

- **Composition**

It is difficult to define a specific composition for C&D wastes (in percentage terms) as it vary between sites, regions and countries. Considerable differences might as well be surveyed between the composition of construction wastes and of demolition wastes. Data sources are limited, as detailed surveys and analyses can be costly.

A BIO Intelligence Service survey presents the available characterization data in 9 Member States (Netherlands, Flanders, Denmark, Estonia, Finland, Czech Republic, Ireland, Spain and Germany) and the results, excluding the excavated material in order to obtain more comparable data, are reported in Figure 40.

Ranges	% - Min	% - Max	Million tonnes - Min	Million tonnes - max
Concrete and Masonry - total	**40,0%**	**84,0%**	**184**	**387**
Concrete	12,0%	40,0%	55	184
Masonry	8,0%	54,0%	37	249
Asphalt	**4,0%**	**26,0%**	**18**	**120**
Other mineral waste	**2,0%**	**9,0%**	**9**	**41**
Wood	**2,0%**	**4,0%**	**9**	**18**
Metal	**0,2%**	**4,0%**	**1**	**18**
Gypsum	**0,2%**	**0,4%**	**1**	**2**
Plastics	**0,1%**	**2,0%**	**0**	**9**
Miscellaneous	**2,0%**	**36,0%**	**9**	**166**

Figure 40 - Ranges of composition of C&D waste in some European Countries (%, tonnes) (BIO Intelligence Service, 2011)

A Construction Resources and Waste Platform survey, 2009, shows waste generation performance of construction sites for different building types. From Figure 41 it could be observed that average values are around 15-20 m^3 of waste per 100 m^2 (around 100-150 kg/m^2). Lower waste generation is observed for industrial buildings, where, usually, more prefabricated elements are used and, therefore, less waste is generated at site (JRC, 2012).

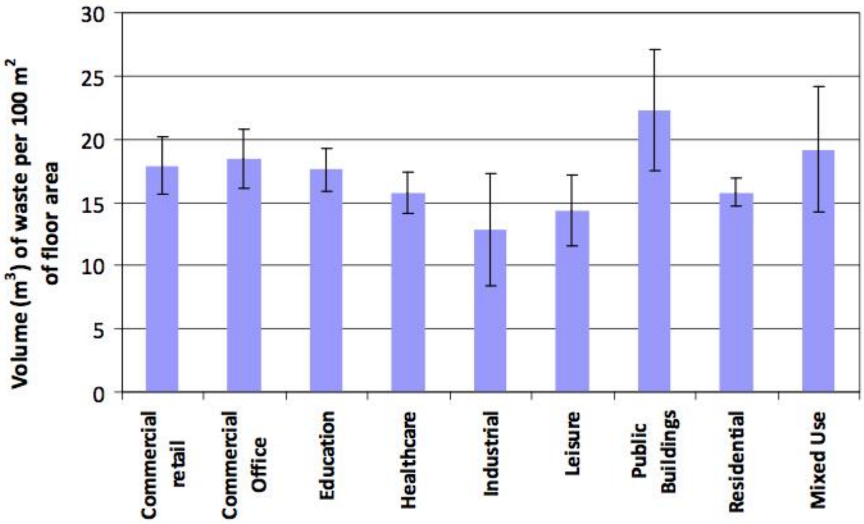


Figure 41 - Waste generation during construction for different types of buildings (JRC, 2012)

Figure 42 shows waste typologies for different types of buildings. As observed, there are four main fractions of waste: bricks, concrete, mixed waste and inert fraction. Hazardous waste is a very small fraction. The rest is composed of timber, packaging waste, metals, etc. The composition of wastes is quite similar for all building types, except for public and industrial buildings. The supposed simplicity for industrial buildings in their composition, make the generation of waste concrete higher than for other buildings. Public buildings construction generates a significant amount of inert waste, which may be a consequence of bad accounting or a measurement methodology for inert and concrete wastes (JRC, 2012).

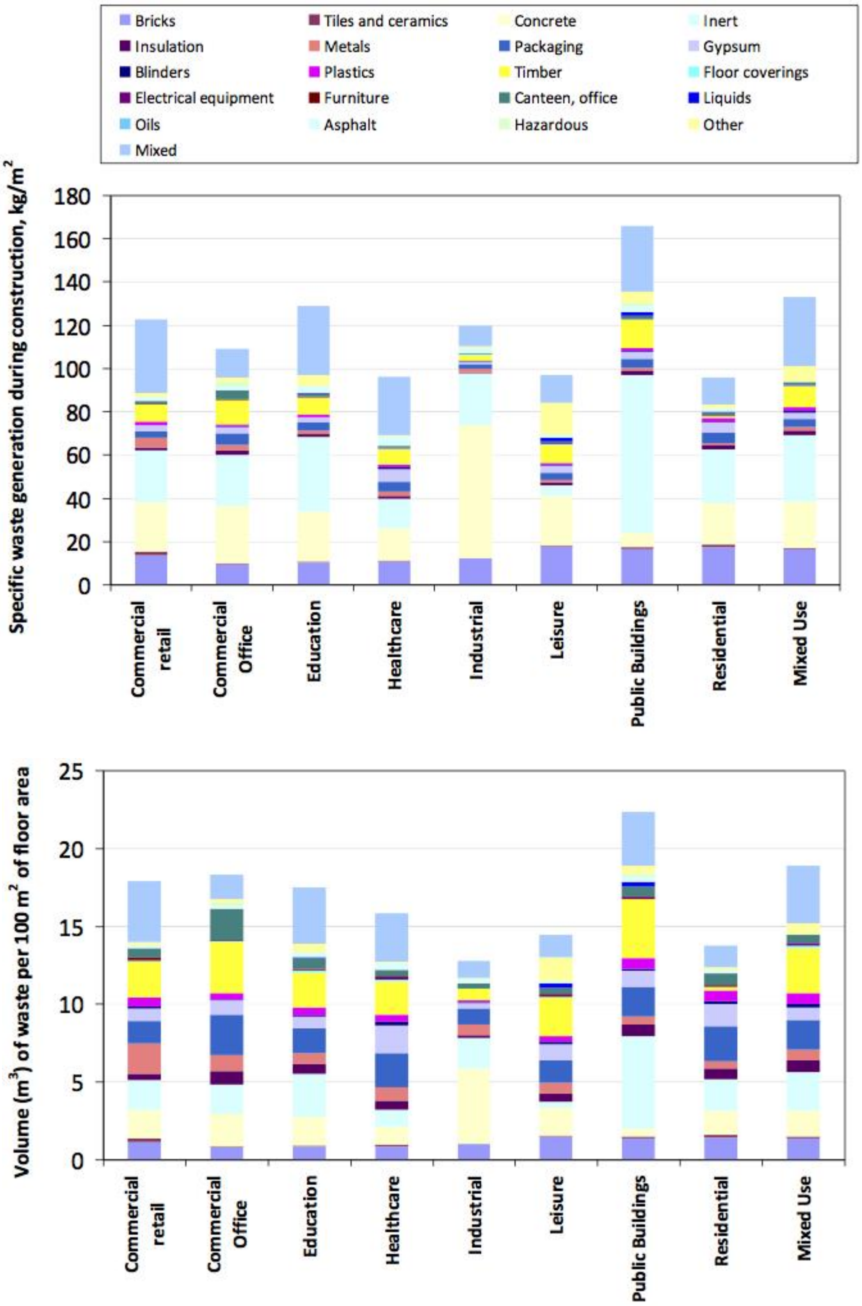


Figure 42 - Waste generation during construction for different types of buildings in volume and mass units (JRC, 2012)

It is important to note that **hazardous substances** may be contained in any building components or materials and require special consideration. The main hazardous components in C&D waste are: asbestos (found in insulation, roofs and tiles and fire-resistant sealing), lead based paints (found on roofs, tiles and electrical cables), phenols (found in resin-based coatings, adhesives, and other materials), polychlorinated biphenyls (PCBs) (found frequently in joint sealing and flame-retardant paints / coats, as well as electrical items) and polycyclic aromatic hydrocarbons (PAHs) (frequently found in roofing felt and floorings, amongst other items present in a wide array of products) (JRC, 2012).

Llatas, 2011, elaborated a model to estimate total wastes arising from construction projects. A full list of results can be found in the literature (Llatas, 2011). The most interesting point on the publication is the estimation of wastes generated per construction process, calculated in a chronological way. Figure 43 shows a summary of these results. As shown, large amount of materials are produced at the beginning because of the need for site clearing and excavation needs. Then, packaging and construction and demolition waste are produced. Waste generation rate is lower at the final stages (JRC, 2012).

Sitework process	Packaging waste [m^3]	Mineral C&D waste [m^3]	Excavated materials [m^3]	Total [m^3]
Site clearing	0	0	180.00	180.00
Earthworks	0	0	569.20	569.20
Installation of mechanical utilities	3.21	1.51	51.64	56.36
Foundations	10.15	24.33	1.50	35.98
Structure	21.14	40.81	0	61.95
Masonry	118.32	52.27	3.30	173.89
Roofing	18.10	7.76	1.20	27.06
Services	18.00	18.70	0	36.70
Coatings	31.71	16.93	1.50	50.14
Carpentry	0.36	1.59	0	1.95
Glass	6.80	0.14	0	6.94
Paintings	8.30	0.07	0	8.37
Total	**236.09**	**164.11**	**808.34**	**1208.54**

Figure 43 - Waste generation per category and per process (example)
(JRC, 2012; adapted from Llatas, 2011)

The composition of wastes generated at construction sites mainly depends on the building typology, local conditions, design and prevention measures, thorough designing of wastes and other prevention practices on site. For construction of new buildings, earthworks will generate the most important fraction of wastes (from 60 to 90 % in some cases), while packaging will be important in volume but not in weight. In the example of Figure 43, the volume of packaging materials is presumed to be higher than the volume of mineral construction wastes. Nevertheless, this would depend on the final design and on the construction practice. According to the example, packaging waste is composed of wood (70%), plastic (13%), cardboard (11%), metal (5%) and mixed packaging materials (1%). Mineral construction wastes are composed by concrete (49%), bricks (30%), mixed fraction (14%), municipal solid waste (2.1%), mixed wastes (1%) and limestone (0.5%). Hazardous waste would be about 5% of total construction and demolition waste, mainly consisting of gypsum and wood, containing losses of releasing agents and other chemicals (JRC, 2012).

- **Recovery and Recycling**

The EU has only recently introduced recycling targets for construction and demolition waste. A 70% recycling target was introduced in the new EU Waste Framework Directive 2008/98/EC to be achieved by 2020. It includes only recycling of non-hazardous construction and demolition waste and excludes soil and stone.

Data on total recycling of construction and demolition waste is available from 18 EEA countries and are reported in the ETC/SCP working paper Europe as a Recycling Society (ETC/SCP, 2009 and 2011). The composition of the recycled construction and demolition waste is available from only 11 countries. Figure 44 shows that the total recycling rates vary significantly among the countries, but in general, the rate is quite reasonable (>50%) for 11 countries. Five countries have very high recycling percentages (> 70%), already in excess of the 2020 target. Six countries have recycling rates between 50% and 70%, one country between 30 and 50% and six countries below 30% (ETC/SCP 2011).

For different waste materials within the construction and demolition waste stream, recycling data is only available in tonnes per capita and not in percentage of the generated waste stream. Therefore, in Figure 45 the recycled amount of a specific waste stream is related to the total amount of construction and demolition waste recycled.

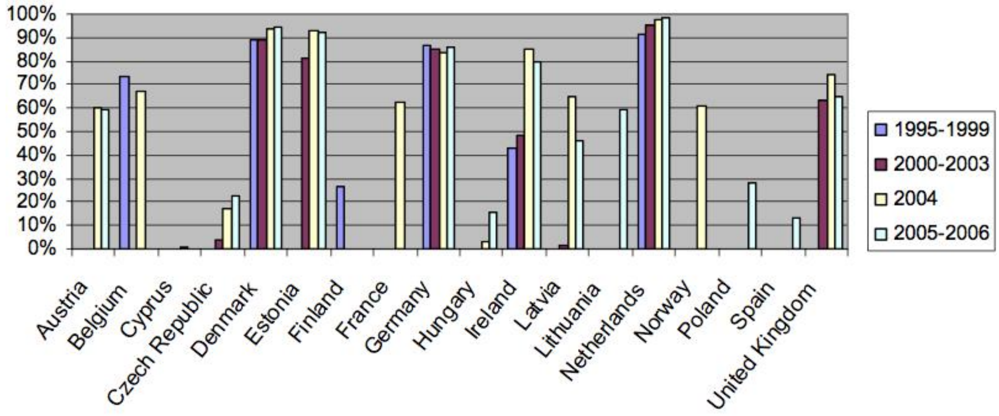


Figure 44 - Recycling of construction and demolition waste in percentage of generated amount in the EU and Norway - Source: Eurostat and ETC/RWM, 2008 based on national reports and statistics (ETC/SCP, 2009)

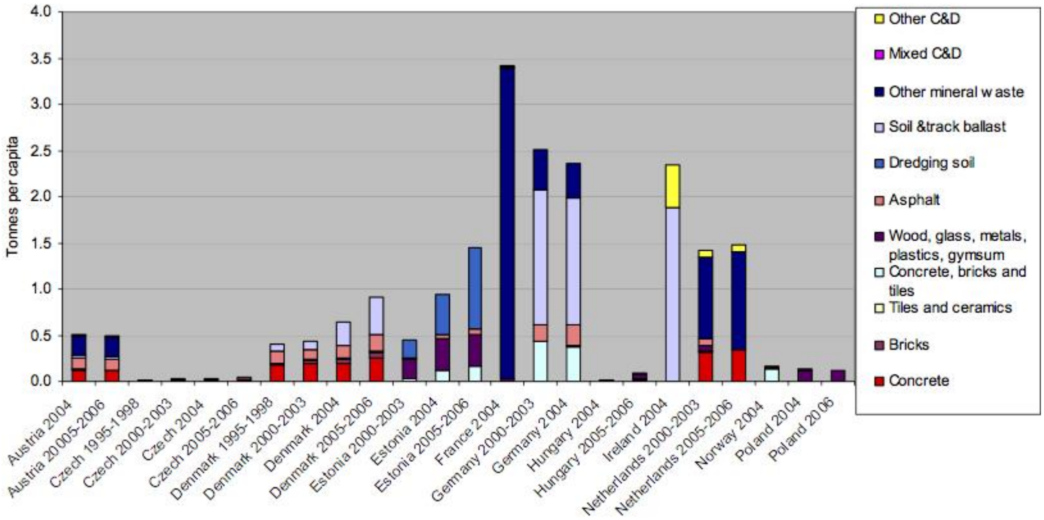


Figure 45 - Development in tonnes in the composition of recycled construction and demolition waste in the EU and Norway - Source: Eurostat and ETC/RWM, 2008 based on national reports and statistics (ETC/SCP, 2009)

Some countries like the Denmark, Germany and the Netherlands have high recycling amounts per capita of concrete, bricks, tiles and asphalt. This can be explained by the use of source separation mandates, reuse and recycling targets combined with landfill taxes in Denmark and the Netherlands. Furthermore, the relatively high costs of raw materials for primary construction material in these countries can be considered.

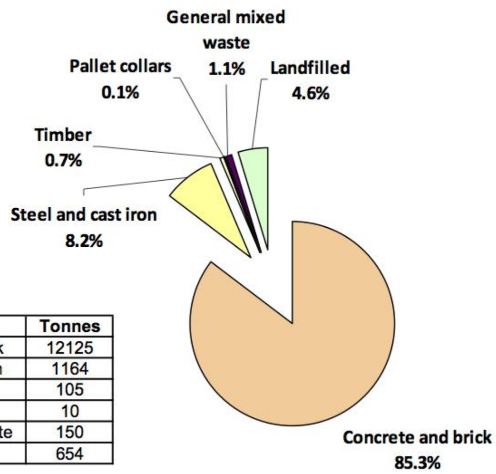
The very high recycling levels in some countries such as the Netherlands, Denmark, Estonia, Germany, France and Ireland can possibly be explained by the composition of the recycled waste. These countries all have a very high rate of stone and soil in the recycled amounts, since dredging soil, soil and track ballast as well as other mineral waste accounts for between 39% and 74% of the total recycled amounts.

However, recycling of soil and stone is not included in the 70% recycling target set by the EU. Therefore it is also relevant to underline that the four countries with the highest total recycling rate have also per capita higher recycling of concrete, bricks and tiles and asphalt. In contrast the Eastern European countries have much more metal included in their recycled amounts, which is documented in ETC/SCP (ETC/SCP 2011).

Recycling is difficult when materials are mixed, when composite materials occur or when pollutants like hydrocarbons or asbestos are present, e.g. in chimneys. In order to obtain materials in an optimal composition for recycling facilities, the available recycling techniques, as well as the location of processing facilities, have to be considered during dismantling planning. The demolition of buildings, as it was traditionally performed, produces large amounts of debris that often results in a significant portion of the total waste stream. **Selective deconstruction** as an alternative to demolition means the systematic disassembly (‘construction in reverse’) of buildings in order to maximize the reuse and recycling of recovered materials. One of the main obstacles to the use of recycled construction materials in high-grade applications is the heterogeneity of the composition and the contamination of construction and demolition waste (C&D waste) resulting from demolition of buildings (JRC, 2012).

Whereas the demolition of a building often leads to the mixing of various materials and contamination of non-hazardous components, **deconstruction** aims at separating materials at source. Complete selective dismantling is currently often not the preferred technique, mainly due to the higher cost, at least when a high purity of waste streams is not required. The separation of building materials for recycling can alternatively be achieved by sorting techniques at recycling facilities, but the most efficient way to produce mono-fractional material streams is the selective dismantling of buildings. Due to the fact that, in theory, every single building element can be separated, the achievable separation of the building materials is extremely high. On the other hand, extensive dismantling leads to high operating costs, especially labour costs. Depending on the prices for disposal and recycling, labour costs may offset savings caused by less expensive disposal. A strategy in-between conventional demolishing and selective deconstruction is also possible, aiming at separating material flows and removing contaminants to a large extent with limited effort (JRC, 2012).

In the UK, a demolition case study from WRAP (WRAP, 2007) showed a recovery rate higher than 95% in the Bryan Donkin Valves manufacturing site in Chesterfield. 43 buildings were demolished (48 500 m^2 of floor area), and the project took 18 weeks total. Except for several asbestos contamination cases, all the materials produced on site were recycled or reused. As a result of these activities, recycling and reuse rates in the Bryan Donkin site reached those shown in Figure 46. Out of the 14 200 tonnes of generated waste 13 550 (95.4%) were reclaimed (JRC, 2012).



Material	Tonnes
Concrete and brick	12125
Steel and cast iron	1164
Timber	105
Pallet collars	10
General mixed waste	150
Landfilled	654

Figure 46 - Materials reused, recycled and landfilled in the Bryan Donkin site (JRC, 2012; adapted from WRAP, 2007)

Construction Industry Environmental impacts in terms of CO_2 emissions

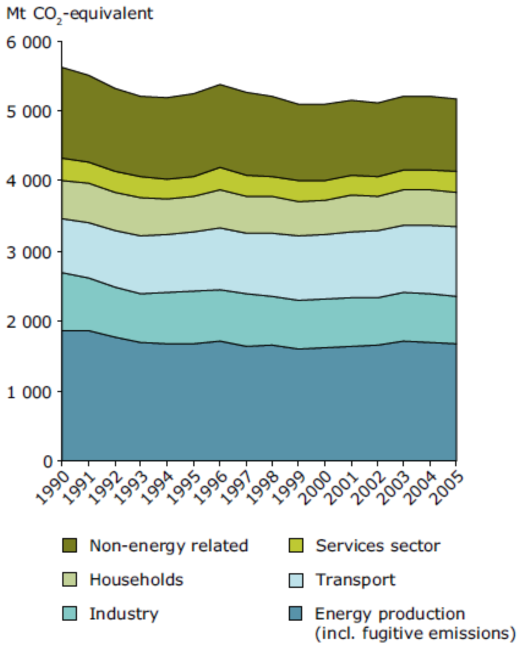
Global climate change roots in the enhanced **greenhouse effect** caused by human activity. Human activities, in particular the development of industry over the last 200 years, have caused an increase in the emission and atmospheric concentration of certain gases, called "greenhouse gases" - primarily carbon dioxide - CO_2 - and methane - CH_4. These gases intensify the natural greenhouse effect that occurs on Earth, leading to an increase in the average temperature of the planet that, if left unchecked, would potentially cause severe and perhaps even catastrophic disruptions to the Earth's climate (http://www.orbeo.com/-Market-overview-.html).

Construction sector is one of the main contributor to GHG emissions with about 36% of the EU's total CO_2 emissions, due to the high-energy consumption during the whole building life (construction, use-phase and end of life). Therefore, an adaptation action for example in terms of innovative energy technologies is needed.

The European Commission has taken many **climate-related initiatives** since 1991, when it issued the first Community strategy to limit carbon dioxide (CO_2) emissions and improve energy efficiency. It is clear that action by both Member States and the European Community needed to be reinforced if the EU was to succeed in cutting its greenhouse gas emissions to 8% below 1990 levels by 2008-2012, as required by the Kyoto protocol (ECCP, 2006).
At European level a comprehensive package of policy measures to reduce greenhouse gas emissions has been initiated through the European Climate Change Programme (ECCP) in 2000. It examined a range of policy sectors and instruments with potential for reducing GHG emissions, focusing to eleven areas. One of the most important initiatives was the EU Emissions Trading Scheme (EU-ETS), which covers CO_2 emissions from some 11550 emitters in the power generation and manufacturing sectors (ECCP, 2006).

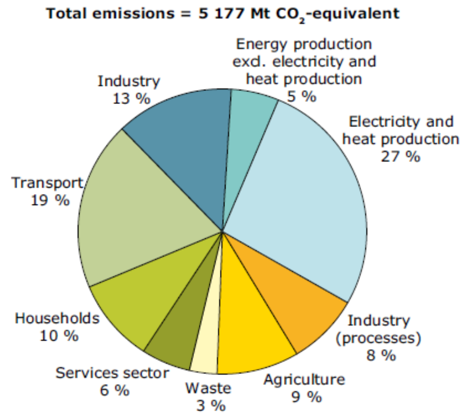
Between 1990 - 2005, thanks to the adoption of these several European initiatives and the Kyoto protocol, sectors showing the largest decreases in greenhouse gas emissions are industry and non‑energy related (e.g. industrial processes). Since 1999, GHG emissions started to rise again, with some fluctuation over the period of 2004 - 2005 (Figure 47a).

All that considered, in 2005 the total greenhouse gas emissions in the EU‑27 was 5177 Mt CO_2‑equivalent comprising 82.5% CO_2, 8.1% CH_4, 8.0% N_2O, while the remaining 1.4% corresponded to the fluorinated gases. Energy‑related emissions continued to be dominant, representing approximately 80% of the total emissions with the largest emitting sector being the production of electricity and heat, followed by transport (Figure 47b).



Note: See Figure 48 b

Source: EEA, 2007a, as reported by countries to UNFCCC and under the EU GHG Monitoring Mechanism Decision.



Note: (i) Greenhouse gas emissions are those covered by the Kyoto Protocol and include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and three fluorinated gases, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

(ii) Greenhouse gas emissions have been calculated in t CO_2-equivalent using the following global warming potentials (GWP) as specified in the Kyoto Protocol: 1 t CH_4 = 21 t CO_2-equivalent; 1 t N_2O = 310 t CO_2-equivalent; 1 t SF_6 = 23 900 t CO_2-equivalent. HFCs and PFCs have a wide range of GWPs depending on the gas, and emissions are already reported in t CO_2-equivalent.

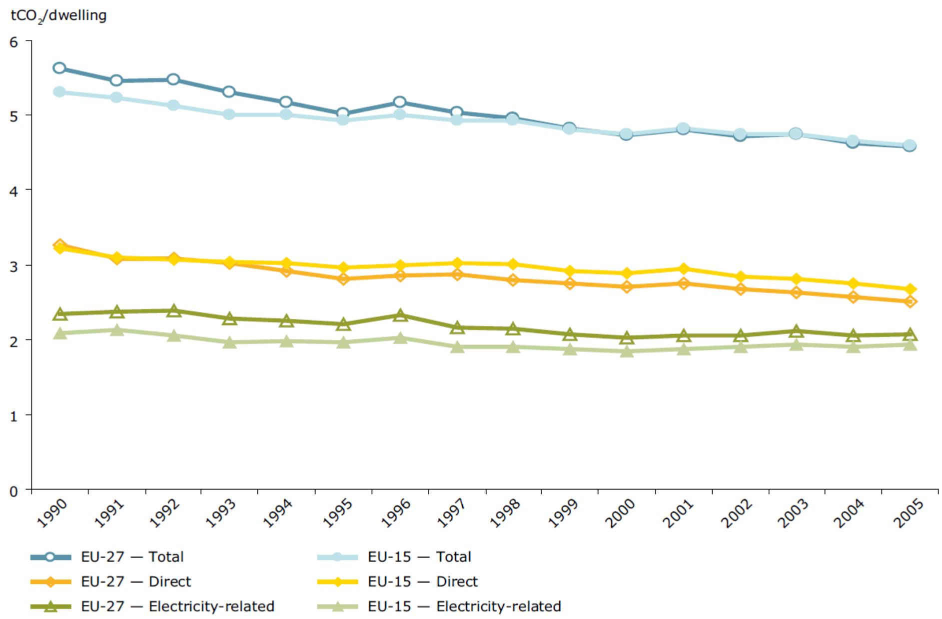
Source: EEA, 2007a, as reported by countries to UNFCCC and under the EU GHG Monitoring Mechanism Decision.

Figure 47 a

Figure 47 b

Figure 47 - a: Trends in greenhouse gas emissions by sector between 1990 - 2005, EU-27 – b: Structure of total greenhouse gases emissions by sector, EU-27, 2005 (EEA, 2008)

Focusing on construction sector, CO_2 emissions per dwelling from the direct use of fuels in households slowly decreased in both the EU-15 and EU-27 over the period (by 17% and 23% respectively) (Figure 48).



Source: Odyssee.

Figure 48 - Household CO_2 emissions per dwelling, climate corrected (EEA, 2008)

This is largely due to improvements in the thermal efficiency of buildings, as well as to the increased efficiency of energy supply systems (primarily boilers) in households. Electricity related emissions also slightly decreased despite a rise in the electricity consumption of households by almost 19% per dwelling in the EU-27 due, in part, to a more widespread ownership of appliances. The decrease in CO_2 emissions resulted from improvements in the carbon intensity of electricity generation, although the decrease in overall emissions has been lessened by the increase in the number of dwellings in Europe (EEA, 2008).

The most recent data available show that the total GHG emissions, without LULUCF (land use, land-use change and forestry), in the EU-27 decreased by 18.4% between 1990 and 2011 (-1024 million tonnes CO_2 equivalents). Emissions decreased by 3.3% (155.0 million tonnes CO_2 equivalents) between 2010 and 2011 (Figure 49) (EEA, 2013).

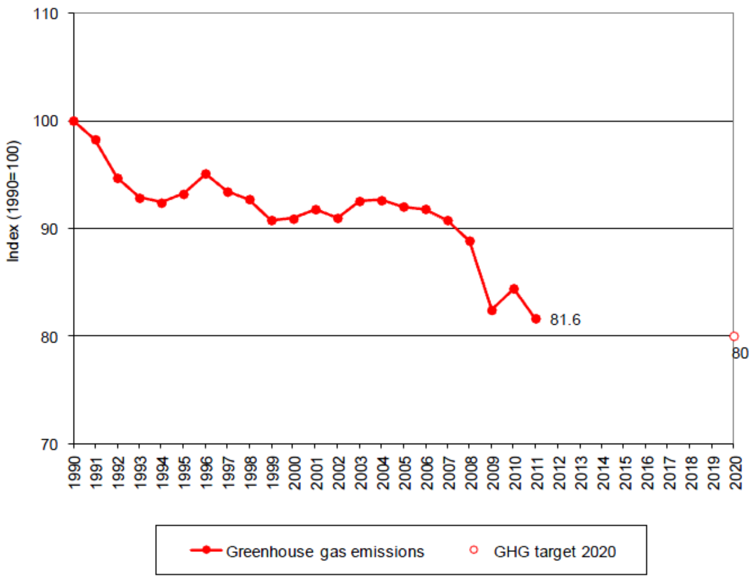


Figure 49 – EU-27 GHG emissions 1990 - 2011 (EEA, 2013)

In general, GHG emissions decreased in the majority of key sectors in 2011, particularly those relying on fossil fuel combustion (Figure 50).

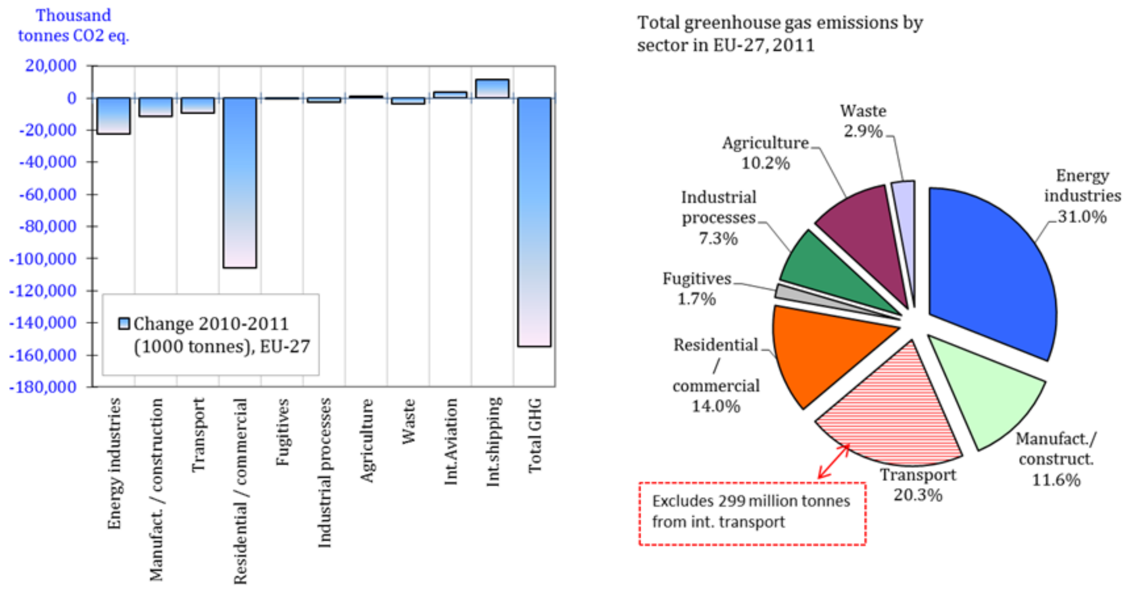


Figure 50 – greenhouse gas emissions by main sector in the EU-27, 2011 (EEA, 2013)

The residential and commercial sector contributed to lower emissions in the EU-27 in 2011. This sector broadly falls outside the scope of the EU ETS. The milder winter conditions and the lower demand for heating were the principle reason for the 104 million tonnes decrease in emissions in 2011, particularly from households. Around 70% of the decrease in emissions from households and services in 2011 was accounted by lower use of natural gas.
The second largest decrease stemmed from energy industries, sector including emissions from heat and electricity production and refineries, with a net reduction in emissions of 47 million tonnes in 2011. The combined effect of these two sectors (residential/commercial and energy industries) contributed to about 90% of the total reduction in GHG emissions in the EU in 2011 (EEA, 2012/EEA, 2013).

Figure 51 presents the most influential key emission sources (excluding bunkers) in the EU in the periods 1990 - 2011, showing the change in emissions in the period 2009 - 2010 and in the period 2010 - 2011 and underlining increases of 2010 and the decreases of 2011.

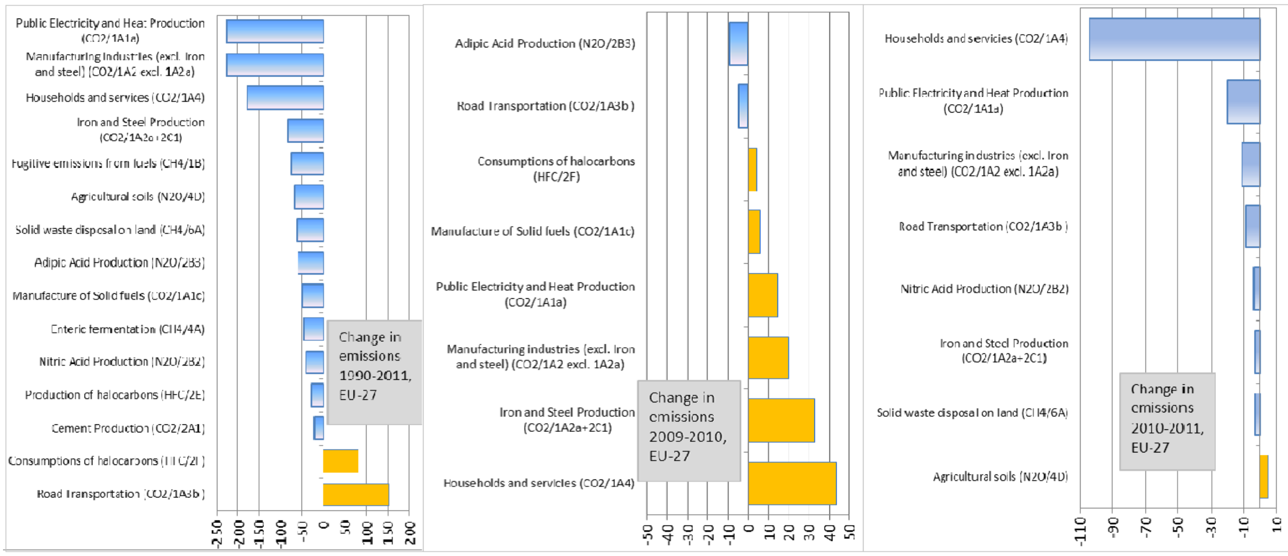


Figure 51 – Overview of the EU-27 source categories recording the largest increases and decreases in the periods 1990 - 2011, 2009 - 2010 and 2010 - 2011 (EEA, 2013)

Focusing on residential sector (EEA, 2012/EEA, 2013) CO_2 building-emissions were the fourth largest key category of GHG emissions in the EU-15 and accounted for 10.4% of total GHG emissions in 2010. In 2011 this sector became the third largest key category of GHG emissions in the EU-15, accounting for 8.9% of total GHG emissions.
The emission trend within this category is mainly dominated by CO_2 emissions from liquid and gaseous fuels. Total GHG emissions decreased by 4% since 1990 in 2010 and by 21% in 2011, although CO_2 emissions from gaseous fuels increased strongly (+46% in 2010 and +26% in 2011), which was counterbalanced by decreasing emissions from other fossil fuels (Figure 52).

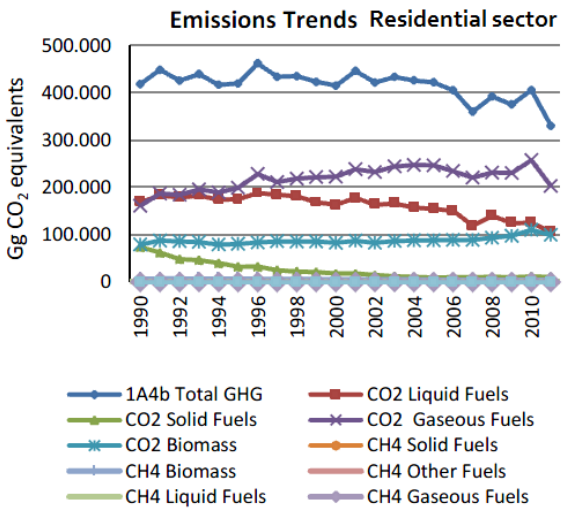


Figure 52 – Residential: Total, CO_2 and CH_4 emission (EEA, 2013)

Fossil fuel consumption in households increased by 6% between 1990 and 2010, with a fuel shift from coal and oil to gas, instead it decreased by 13% between 1990 and 2011.
The largest reduction in absolute terms was reported by Germany reducing emissions by 27.5 million tonnes and by 47.6 million tonnes between 1990-2010 and 1990-2011, respectively. Austria, Denmark, Finland and Sweden also showed reductions of emissions between 1.3 to 5 million tonnes. In absolute terms Belgium, France, Greece, Spain and the United Kingdom had the largest emission increases between 1990 and 2010. Instead only four member states (Greece, Luxembourg, Portugal and Spain) show increases in their emission between 2010 and 2011. One reason for the performance of the Nordic countries and Austria is the increased use of district heating. As district heating replaces heating boilers in households, an increase in the share of district heating reduces CO_2 emissions from households (but increases emissions from energy industries if fossil fuels are used). In Germany, efficiency improvements and the fuel switch in eastern German households are two reasons for the emission reductions.
In particular, between 2010 and 2011 all Member States except Greece show a decrease in emissions (EEA, 2012 – EEA, 2013). In general, this reduction can be attributed to these factors influencing CO_2 emissions:

1. outdoor temperature,
2. number and size of dwellings,
3. building codes,
4. thermal properties of building stock,
5. fuel split for heating and warm water,
6. use of renewable energy sources, e.g. biomass or solar panels,
7. use of district heating.

The 2012 EEA estimates indicate that EU greenhouse gas emissions continued to decrease slightly between 2011 and 2012, although by less than the decrease in emissions between 2010 and 2011. For the EU-28, total GHG emissions in 2012 are estimated to be 19% below 1990 emissions.
On a sectorial basis, the greatest absolute reduction in emissions in the EU occurred in the energy sector and this reduction was largely made in the new Member States. Within the energy sector, emissions decreased mostly in manufacturing industries, construction and transportation. However, emissions from the residential and commercial parts of the energy sector increased significantly because of larger heat consumption.
Indeed the winter in Europe was generally colder in 2012 than it was in 2011. This led to higher

heating demand and higher emissions from the residential and commercial sectors. However, higher residential emissions did not offset much lower emissions in other combustion sectors, and as a result, total fossil fuel emissions decreased for the EU as a whole (EEA, 2013).

Emissions related to buildings use phase have been largely explained, but it is worth to note that CO_2 emissions are generated during all the stages of the building process, from activities (sub-processes) related to construction (production, assembly), to their use (use-phase and maintenance) and to their dismantlement (end of life) - *from cradle to grave*.

With regard to the **production phase**, significant CO_2 emission sources include mining and processing of raw materials. In details, 85-95% of all embodied CO_2 emissions associated to supplied construction materials accumulates prior to leaving factory gates, instead the remaining 5-15% relates to the construction, maintenance and demolition of the building (E2B, 2012).

In the case of cement clinker production, more than 60% of the released CO_2 is due to the decarbonisation of raw materials and is responsible for more than 500 kg CO_2/t of the cement clinker. It is reported (Dimoudi & Tomba, 2008) that for some examined office buildings, embodied CO_2 of the structure‘s building materials (concrete and reinforcement steel) represent the largest part of the building total embodied CO_2, varying from 68% to 70% (typically concrete accounts for two thirds of this amount and reinforcement steel for a third).

Cement production accounts for an estimated 5% of the world's CO_2 emissions. Although concrete has relatively low embodied carbon content, it is massively used worldwide, therefore has the highest total GHG emissions. Indeed, cement is manufactured at the annual rate of more than 3 billion tons per year, enough to produce more than 10 billion cubic meters (around 25 billion tons) of concrete (E2B, 2012).

1B Requalification needs

Assessment of the technology options for earthquake resistant, eco-efficient buildings, requires in-depth knowledge of the consistency of the existing building stock, in terms of main characteristics, state of preservation and possible deficiencies. The analysis carried out in this section has highlighted how Europe's building stock is mostly antiquated, obsolete from the technological point of viewand structurally unsafe with respect to seismic actions.

30-40% of the European buildings were constructed before the 1960s, thus they have exhausted their design life, and the possibility of their further usage should be determined based on the result of a thorough structural assessment analysis.

In the previous sections the seismic performance, the energy consumption and the environmental impact of existing buildings have been analysed. Accordingly, the major requalification needs can be listed:

- The largest percentage of the existing European buildings, both in reinforced concrete or masonry, because of their age and their structural design, are characterized by **high seismic vulnerability**. These buildings must be retrofitted to comply with current seismic legislation, or must be improved to such an extent as to guarantee an acceptable safety level. The climatic upheavals and the environmental disasters lead to the development of new advanced technologies for new buildings, but the existing building stock still represents the most important challenge.

- The building’s **energy consumption** is very high, technologies are often obsolete, building envelopes are made with old and inadequate materials. As a consequence their energy performances are very poor. From the energy point of view it is very important not only to build new low-emission buildings, but most of all to improve the energy performances of the existent building stock, that consumes 40% of the total EU energy and emits 36% of the EU’s total CO_2 emissions.

- 30% of the **generated waste** and the 50% of the extracted raw materials in the EU is attributable to the construction sector. These data trigger two main considerations:
  (1) in order to reduce waste, **requalification of existing buildings** should always be preferred to demolition and reconstruction. The re-use of materials and the reduction of waste in landfills is one of the main objectives of the EU for the next decades;
  (2) the **use of high-efficiency materials** in the construction and renovation of buildings must become mandatory. These materials must not only have better environmental performance during their service life, but must be guaranteed as efficient throughout their whole life-cycle (e.g. with sustainable extraction and production, optimized transportation logistics, enhanced re-use and recycling, and increased lifetime and durability).

2. TECHNOLOGY OPTIONS FOR EARTHQUAKE RESISTANT, ECO-EFFICIENT BUILDINGS

Nowadays a great number of technologies, either traditional or innovative, for earthquake-resistant, eco-efficient buildings are available, and much research is being carried out in the field of the seismic risk mitigation and in the reduction of the environmental impact of the construction sector.

The selection of the adequate type of technology depends on the specific characteristics and renovation targets of each single building being examined. Technology options, implying both materials and techniques, can be selected based on the desired performances, the available budget, the type of man labour, and the aesthetic expected result.

This section provides examples of leading edge technologies and good practices that are currently used to improve the seismic and environmental performance of existing buildings. Among the great number of existing highly innovative technologies, only a selection of the most relevant and more frequently adopted is summarized in the following.

2A State of the art

2A.1 EARTHQUAKE RESISTANT BUILDINGS

Technologies to be adopted in the construction of new earthquake resistant buildings are well described in the newest European and National Codes (Eurocode 8 - CEN 2005), for this reason in the following part of the document only a selection of available requalification technologies for existent buildings are reported.

In order to select the appropriate anti seismic intervention criteria on existing buildings, the site seismic hazard, the structural vulnerability, the building exposition, the typology and the building structural deficiencies should be attentively assessed. Vulnerability and main structural deficiencies of the existent structures depend on their structural typology (Masonry, RC, Steel or Wooden structures), their main characteristics (e.g. stone, adobe or reinforced masonry; frame or wall RC structure), the vulnerability sources (e.g. irregularities in plan or in elevation, previously damaged elements, insufficient confinement of horizontal thrusts in masonry structures, and so on and so forth).

Some most frequent strengthening options are summarized in the following for the main structural typologies, namely: reinforced concrete and masonry structures.

RC structures

Among the **strategies** aimed at the static and seismic retrofit of RC framed structures, local or global interventions can be carried out.

Local interventions consist of beam-to-column joint strengthening. This solution is often proposed in the rehabilitation practice. However, the result of local joint strengthening is both uncertain and very expensive, since it requires major demolitions and reconstruction of the finishing, which are acknowledged to affect up to 70-75% of the total construction costs in a new building. These solutions also involve the temporary downtime of the building.

Alternatively, in order to increase seismic resilience, **global solutions** can be proposed, which are aimed at complementing the existing structures with brand new earthquake resistant systems. The effectiveness of complementing existing buildings with dampers or dissipative bracing systems to enhance their seismic performance and reduce damage was proved in past years with many numerical and experimental studies. Global interventions include, among others: a) external new shear walls, either over-resistant or dissipative, b) strengthening of the existing walls formerly reinforced to withstand vertical loads only (stairwell or elevator shaft walls, or perimeter walls), c) strengthening of the infill walls, etc. Base isolation can be regarded as a special global intervention.

Among all possible global interventions, **external interventions** are very promising. These interventions do not necessarily require the relocation of the inhabitants during the works; the appropriate use of dampers allows concentrating the damage into limited zone and reducing the repair costs after an earthquake to the sole substitution of few elements. The cost effectiveness of this solution, its structural reliability, the chance of lowering repair costs and shortening the building downtime after an earthquake, foster an opportunity for a more widespread application of the technique.

The use of external earthquake-resistant structures entail the increase of the global dimensions of the existing building; when the urban restrictions do not allow any enlargement of the original building footprint, additional external shear walls can be concealed in the perimeter infill walls. The footprint increase facilitates interventions in very high seismic prone areas but may imply partial derogation from the urban planning parameters.

The descriptions of the techniques illustrated in the following are mainly quoted from Earthquake Design Practice for Buildings (Booth, Key, 2006).

- **Addition of shear walls**

Additional shear walls have been widely used to strengthen and stiffen reinforced concrete moment frame structures. They can be built either within the existing concrete frame or outside the perimeter of the existing building. Shear walls reduce the ductility demand on the frame beams and columns during the ground motion, which in turn are likely to be able to continue supporting the pertaining gravity loads after the earthquake. When properly designed, shear walls inhibit the onset of a weak or soft storey mechanism, and their remarkable stiffness provides protection to non-structural elements, particularly cladding. The method is particularly suitable for low-rise construction (up to five stories).

The strengthening shear walls can be obtained by strengthening existing infill wall or by building new infill masonry panel in the case of bare frame bay. This solution is particularly suitable if the strength shortfall is low, and the main objective is to remove eccentricities in plan or/and elevation.

The RC shear walls can be formed within an existing concrete frame, by dismantling the infill walls and by casting a new RC panel. The panel must be connected to the surrounding beams and columns by means of either steel dowels or any kind of connection preventing shear sliding between the perimeter chords and the inner panel.

Among the existing infill wall strengthening methods, the use of carbon X-shaped fibre reinforced bands glued with epoxy and connecting the panel corners, or the use of high performance concrete or fiber concrete based plasters have been proposed. These methods are comparable in construction cost to additional internal concrete shear walls, but are more impairing of the continuing operation of the building.

As a major drawback, by concentrating the seismic actions into few elements, the additional shear walls need to be provided with foundations that are stiff and strong enough to resist the design moments and shears at their bases. This can give rise to requirements for substantial new footings, particularly where poor ground characteristics are observed.

- **Cross-bracing**

Adding steel cross-bracing to RC or steel moment frame buildings is an alternative technique, which relieves ductility demand on the existing frame, and protect the non-structural elements. Noteworthy, additional steel cross-bracings can be relatively quickly assembled and connected to the existing building frame, thus minimizing disruption and downtime of the building use.

The bracing members may be directly attached to the existing frame, which in turn must support additional axial forces during an earthquake. This solution can be regarded as the least disruptive, but its efficiency depends on the adequacy of the existing beams and columns. Alternatively, a complete new braced frame can be added, leaving the existing frame to carry only the gravity loads (Booth, Key, 2006).

- **Passive dampers**

Cross-bracings can be connected to existing moment-resisting frames through passive dampers, which allow limiting the additional forces on the existing frame, while dissipating energy (Figure 53). Viscous, hysteretic, frictional, or piezoelectric frictional devices can be used. Further information is given in the NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA 450).

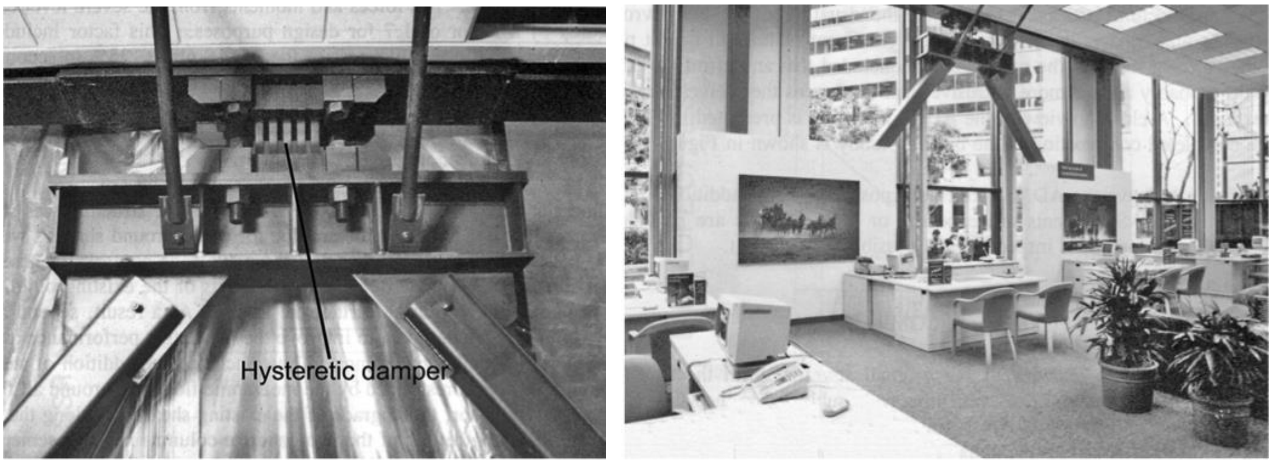


Figure 53 - Hysteretic steel dampers added as retrofit: detail of damper and general view (Booth, Key, 2006)

- **Jacketing of concrete frame elements**

Existing frames can be strengthened by means of jackets, either made of steel plates, high performance reinforced concrete or composite materials. To quantifying the improvement obtained from the different jacketing methods, reference to Annex A of Eurocode 8 Part 3 (CEN 2005) can be made.

While column jackets can be assembled quite easily, the presence of a horizontal slabs often makes the intervention difficult or impossible for beams. Accordingly, beam jacketing is mainly used for increasing shear strength, with little effect on the flexural ductility. As a major shortcoming, it is worth noting that this technique does not allow for strengthening the inner beam–column joints.

- **Strengthening of floors**

Floors are fundamental in the seismic performance of structures. By behaving like in-plane diaphragms they gather the inertial forces to the lateral resisting elements, and tie the entire structure together.

The in-plane strength and stiffness of concrete floors may be improved by overlaying a thin RC slab. High performance concrete can be used to reduce the thickness of the additional slab and to halve the additional gravity loads. Alternatively, steel bracing can be fixed at the existing floor intrados (Zanotti et al. 2013).

Recent studies show that traditional RC floors can perform like in-plane diaphragms and withstand the seismic load for moderate hazard seismic areas, regardless of the presence of a RC topping (Zanotti et al. 2013). The result is interesting given that the expensive and impairing structural works required to form a new floor diaphragm are often the biggest obstacle to the execution of the anti-seismic intervention.

- **Seismic base isolation**

Base isolation is one of the most effective means of protecting existing and new buildings against earthquake actions. Base isolation aims at substantially decoupling the building super-structure from its sub-structure resting on the shaking ground, thus protecting both structural and non-structural elements. Base isolation can considerably enhance both seismic performance and seismic resilience.

Noteworthy, this technique localizes the intervention to a single storey (Figure 54). It is therefore particularly suitable anytime preservation of the existing architecture and shortening the building downtime after an earthquake are important issues.

Figure 54 - Retrofitting of an existing reinforced concrete building with seismic isolation (Booth, Key, 2006)

Masonry structures

In the most frequent situation, the seismic vulnerability of masonry buildings is connected to the onset of local collapse mechanisms that jeopardize the global behaviour of the structure. The major vulnerability is the out-of-plane overturning of the perimeter walls, which can lead to the collapse of the whole building. A second type of vulnerability is the in-plane collapse of walls, but these mechanisms are usually triggered by earthquakes of higher magnitude.

Masonry structures main consolidation works are usually aimed at inhibiting the activation of out of plane mechanisms and at improving the wall in plane strength. This goal can be pursuit through the introduction of perimeter ties, and/or floor or roof diaphragms.

- **Tie system**

The adoption of perimeter ties embedded within the wall thickness, is a traditional technique, which was effectively adopted to secure the structure against wall overturning (Figure 55). Effective tie systems inhibit the onset of local out-of-plane mechanisms and favour a building box structure behaviour. Tie systems also increase the in-plane strength of the walls resisting the seismic actions.

When the tie confining effect is insufficient the tie system must be strengthened or replaced. This operation is usually done by complementing the existing tie system with new ties, either placed in the internal or external surface of the wall (provided that the embedment of the ties within the wall would require expensive and difficult drilling works).

For the solution to be effective, the perimeter ties must allow triggering a resisting arch mechanism within the masonry wall width, by confining the horizontal thrust at the springing. The same confining action can be effectively obtained by adopting an internal tie system. This solution has the obvious advantage of being hidden from the sight, but it may also serve in case of irregular or preciously decorated external walls.

The introduction of new ties is probably the less invasive intervention; however, its effectiveness is not always guaranteed. Perimeter horizontal steel ties are inadequate any time the resisting arch and tie system is ineffective. Steel ties are ineffective in the case of long-span buildings lacking strong transverse walls, as the wall span-to-thickness ratio is unfavourable and little constraint is provided to the toppling masonry walls. In this case, regardless of the positioning of the perimeter ties, the resisting arch is excessively low-raised and its resistance is negligible. Furthermore, in the case of walls of poor quality, discontinuity in the wall leaves caused by chimney within the wall thickness, or structural weakening induced by porches and by particular geometric configurations, the resisting arch mechanism effectiveness is jeopardized and the structural global behaviour cannot be restored. In all these cases, either floor or roof diaphragms are preferable.

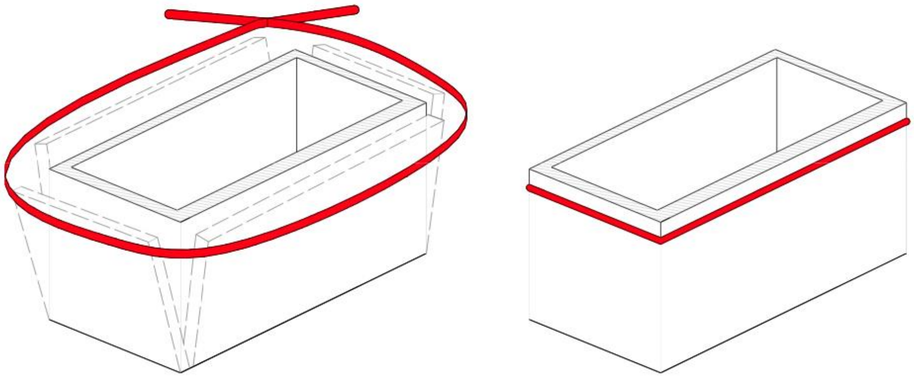


Figure 55 - Perimeter tie system

- **Floor and roof diaphragms**

Among the techniques aimed at increasing the existing building earthquake resistance, floor and/or roof diaphragms are probably the most effective ones (Figure 56, Giuriani and Marini 2008a and b among others). Floor and roof diaphragms introduce additional horizontal elastic constraints along the masonry height, whose stiffness depends on their horizontal flexural deformability. Floor or roof diaphragms gather and transfer the horizontal seismic actions of the lateral walls, thus inhibiting the perimeter wall overturning and favouring a global behaviour of the structure. Like perimeter ties, diaphragms also increase the in-plane strength of the walls resisting the seismic actions.

The effectiveness of the technique mainly depends on the correct connection of the diaphragm to the perimeter walls. Dowels are used to transfer the seismic action gathered by the diaphragm to the shear resisting walls, whereas ties are used to collect the seismic action of the walls loaded out-of plane. For the sole roof diaphragms, deep vertical anchorages might be necessary to secure the roof against the up-lifting actions induced by the diaphragm folded shape and thin lime mortar layers (reinforced with glass fiber mesh) might be necessary to improve the shear strength along the crowning masonry walls (Giuriani and Marini 2008a).

In order to form floor diaphragms a few techniques are available in the construction practice. The use of a thin ordinary reinforced concrete slab, cast overlaying the floor extrados, connected to the floor wooden joists and to the perimeter walls, is one of the most common techniques; this solution is suitable for reinforcing floors with an irregular shape and does not require any specialized man labour. As a shortcoming, this is not a “dry technique” that is usually preferred in the restoration of ancient buildings. Furthermore, concrete might increase structural weight and seismic actions; and possible leaching might damage any decorations on the floor intrados.

The use of high performance concrete is a recent improvement of this technique and allows the concrete slab thickness to be significantly reduced (20 mm), thus halving the additional loads.

The use of concrete slab might be unsuitable for the construction of roof diaphragms due to the significant weight increase. For roof diaphragms, lighter solutions using wooden panels are usually preferred. Roof diaphragms can be formed by placing overlaying plywood panels on the existing wooden planks, which are connected to each other by means of nailed steel flanges. The whole pitch diaphragms are nailed to the perimeter steel chords, and to both roof joists and masonry walls by means of steel studs and vertical anchored bars.

A common alternative solution suitable for both roof and floor diaphragms lies in overlaying a new thick plank on the existing floor extrados. In plane shear resistance is obtained by nailing the new plank to the existing one laying underneath.

In the case of forming diaphragms on the extrados of existing concrete floors the thin concrete slab solution is usually addressed.

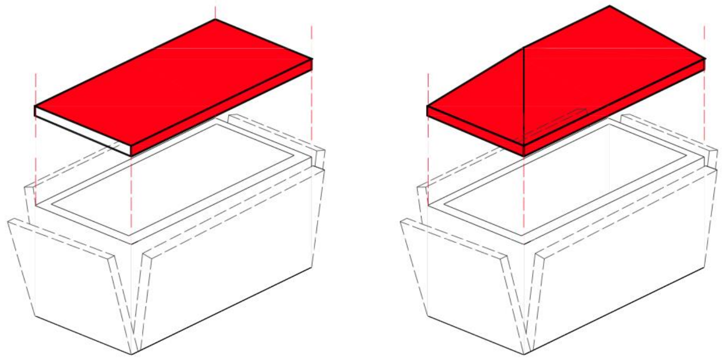


Figure 56 - Retrofitting with the realization of a floor or roof diaphragm

- **Bars injection**

Significant effort can be made to improve the performance and ductility of masonry constructions.

In the case of ancient masonry, ductility at the pier base can be enhanced by adopting special strengthening systems increasing the lateral confinement action at the wall base. To this end, thin steel rebars can be introduced within the wall thickness at its base.

- **Guniting of masonry walls**

Masonry walls can be strengthened by adding a thin layer of mortar to one or both lateral faces. These additional layers are reinforced with plaster light mesh. The mortar is usually applied at high pressure to improve compaction of the additional layer and bonding to the masonry. The effectiveness of this solution depends on the correct bond of the strengthening layer to the existing masonry. Provided that friction or chemical adhesion are insufficient, thin through ties are usually adopted to secure the reinforcement against early detachment and failure.

- **Seismic isolation**

Also in the masonry buildings the seismic isolation can be applied in some specific cases.

2A.2 ECO - EFFICIENT BUILDINGS

Energy renovation of the European building stock turns out to be not only the key to reach the European climate targets, but it becomes also a way to satisfy needed economic and social benefits.

There are 25 billion m^2 of buildings in the EU27 together with Switzerland and Norway ranging from homes, offices and commercial spaces, hospitals and leisure centres. This building stock exhibits a variety of different shapes, orientations, sizes, styles, ages, used fuels, occupancy and location. Each of these factors has an impact on the achievable energy and cost savings. Furthermore a further issue of the building renovation problem is the decision-making process (BPIE, 2011).

In this scenario, there is a very wide range of possible costs and savings for an almost endless permutation of the improvement measures to be applied to the European building stock. Moreover, the renovation costs vary greatly among EU regions and countries, being influenced by many factors such as: market development, prices of materials, financing cost, labour market costs and the existence of specific support programmes and policies.

Although the difficulty of collating these data is recognized, adopting energy savings measures to improve the performance of the existing building stock is more and more essential to satisfy European environmental and economic goals and to meet the EU's climate and energy security targets. Indeed, improving the buildings energy performance represents the most environmentally benign way to address building impacts positively.
Energy efficiency is a key factor in securing the transition to a 'green' resource efficient economy and to achieving the EU Climate and Energy objectives, namely a 20% reduction in the GHG emissions by 2020 and a 20% energy savings by 2020. By reducing the buildings' energy consumption, a direct reduction of the associated GHG emissions will be obtained and a fast and cheaper implementation of renewable energy sources will be triggered.

The 2006 Energy Efficiency Action Plan identified residential and commercial buildings as being the sector with the largest cost-effective savings potential by 2020, estimated at around 27% and 30% of energy use, respectively. In addition, the Action Plan indicates that, in residential buildings, retrofitting walls and roofs insulation offer the greatest saving opportunities, while in commercial buildings, improving energy management systems is more important (EEAP, 2006).

The main legislative instrument in Europe to regulate energy performance in buildings is the 2002 Energy Performance Buildings Directive (EPBD). Despite the already undertaken actions, a large cost-effective energy savings potential was not exploited. As a result, many of the social, economic and environmental potential benefits at EU and national level are still not fully neither experienced nor explored. An important tentative to tackle these challenges has been made with the recast of EPBD in 2010. In particular savings in tons of equivalent oil per year and impacts in tons of CO_2 per year, predicted to be achieved through the new or reinforcement provisions of the EPBD recast, are shown in Figure 57 (BPIE, 2011).

In short, the energy performance of the European building stock should be significantly improved in order to comply with the ambitious targets for improving energy efficiency by 2020 and the even more ambitious targets for GHG emissions reductions by 2050.
The most effective way of achieving those targets is a combination of cutting energy demand in buildings through increased energy efficiency, a wider deployment of renewable technologies in buildings, together with decarbonising energy supplies. Reducing energy consumption has another particular importance in improving security of supply and reducing import dependency.

Source: Proposal for a recast of the EPBD (2002/91/CE) – Impact assessment

	Final energy savings in 2020 (Mtoe/a)	CO_2 emission reductions in 2020 (Mt/a)	Job creation in 2020
Abolition of the 1 000 m² threshold for major renovations	20	51	75 000
Setting up energy performance requirements at cost-optimal levels	5 (up to 10 in 2030)	13 (up to 24 in 2030)	Up to 82 000
Setting up EU-wide nearly Zero Energy Buildings requirements and development of national plans	>15	>41	+++
Independent control systems for EPCs	21	57	60 000
Requiring an inspection report for heating and air conditioning systems	5	15-20	46 000

Figure 57 - Calculated impacts and benefits to be achieved with the EPBD recast reinforcements (BPIE, 2011)

According to BPIE, the average energy intensity of residential buildings in the EU was around 200 kWh/m² in 2011; therefore in order to reduce the average energy consumption from the building sector to 50 kWh/m² in OECD countries, a large-scale upgrade of the existing building stock would be needed and 60% of buildings would require retrofits by 2050 (BIO service, 2013).

In spite of that there are still too few renovated buildings, so that Commission's estimations, which take into account the National Energy efficiency targets for 2020 in the context of 2020 Europe Strategy, suggested that only half of the EU 20% target will be achieved in 2020. Most **estimates of renovation rates** (other than those relating to single energy saving measures) are mainly between around 0.5% and 2.5% of the building stock per year (Figure 58).

Source: BPIE survey

Country	Residential	Non-residential	Unspecified	Comment
AT			1.20%	
CY			0.9%	Average rate 1980-2009
CZ	2.4% (single family); 3.6% (multi-family)			Estimated by SEVEn
FI			1-1.5%	
DE			0.7%	
HU	1.30%			
IT			1.20%	
LT	0.36%	2.75%		Average rate for 2005-10
NL	3.5%	1.6% (offices)		
NO	1.5%	1.5%		
PL	2.5% (multi-family buildings)			
PO			1.5%	
SL			2%	
CH			0.8-1%	

Figure 58 - Renovation rates across different member states (annual % of building stock renovated) (BPIE, 2011)

These rates typically reflect the activity of the past few years, which in some cases are linked to special circumstances during those years (e.g. the existence of a renovation programme) and therefore may not be of normal practice. In any case it could be assumed that the current prevailing renovation rate across Europe is 1% (BPIE, 2011).

According to 2011 BPIE report, a renovation intervention of a building facade (i.e. walls and windows) will qualitatively provide a different level of energy saving than one extended to all of the building envelope and its energy systems (HVAC, lighting etc.) and to the installation of renewable technologies. There is therefore a need to categorise different **levels of renovation**.

At its most basic, the energy performance of a building can be improved by the implementation of a single measure, such as a new boiler plant or the insulation of the roof space. Normally, these types of measures might be termed "energy efficiency retrofit", that means a "minor renovation". Typically, energy savings of up to 30% might be expected by the application of one to three low cost/easy to implement measures.

At the other end of the scale, renovation might involve the whole replacement or upgrade of all elements which have an impact on energy use, as well as the installation of renewable energy technologies in order to reduce energy consumption and carbon emission levels to nearly zero or, in the case of an "energy positive" building, to less than zero (i.e. a building that produces more energy from renewable sources than it consumes over an annual cycle). The reduction of energy needs towards very low energy levels (i.e. passive house standards, below 15kWh/m^2 per year) will lead to the avoidance of a traditional heating system. This is considered to be a break point where the ratio of the benefits (i.e. energy cost savings) to investment costs reaches a maximum. These renovations could be called nearly Zero Energy Building (nZEB).

Between these two extremes (Minor and nZEB renovation type), other renovation types can involve a number of upgrade measures. These interventions can be subdivided into "Moderate", involving 3-5 improvements and resulting in energy reductions ranging between 30-60%, and "Deep" (60-90%). A deep renovation typically adopts a holistic approach, considering the renovation as a package of measures synergistically working together.

The four categories of renovation are summarised in Figure 59.

Source: BPIE model

Description (renovation type)	Final energy saving (% reduction)	Indicative saving (for modelling purposes)	Average total project cost (€/m²)
Minor	0-30%	15%	60
Moderate	30-60%	45%	140
Deep	60-90%	75%	330
nZEB	90% +	95%	580

Figure 59 - Renovation type and cost estimates (BPIE, 2011)

Finally improving energy efficiency of buildings has important macro-economic benefits and can substantially contribute to all three priorities of the Europe 2020 Strategy, namely: (i) greenhouse gas emissions 20% (or even 30%, if the conditions are right) lower than 1990; (ii) 20% of energy from renewables; (iii) 20% increase in energy efficiency. Improving energy efficiency of buildings can as well contribute to the EU 2050 roadmap target of reducing CO_2 emissions by 80-95% by 2050, thus pursuing near total decarbonisation of the energy system by 2050.

Technologies for improving energy efficiency [5]

Eco-efficient building characteristics can be achieved thanks to the application of a number of available technologies. The most used technologies are briefly described in the following.
Despite different improvements, for instance in heating systems, there is still a large saving potential associated with the adoptions of innovative technologies in residential buildings, which has not been exploited. These technologies are easily implemented in new buildings but the challenge is mostly linked to finding ways to improve the performance of our existing stock, which forms the vast majority of our buildings. For new buildings, materials and energy equipment integration based on high heat resistance and integrated ventilation systems allow constructions to reach very low energy demand. For refurbishment, instead, the diversity of the building typologies requires an innovation process where refurbishment design, technology options and construction systems are more challenging (E2B, 2012).

Opportunities to improve the energy performance of buildings include (JRC, 2012):

1. Improving the thermal performance of the building fabric through insulation of walls, floors and roofs, and replacement and tightening of windows and doors.
2. Improving the energy performance of heating, ventilation, air conditioning (HVAC) and lighting systems.
3. Installation of renewable technologies such as photovoltaic panels, solar thermal collectors, biomass boilers, or heat pumps.
4. Installation of building elements to manage solar heat gains.

In the following section these opportunities are exposed in details.

1. Thermal performance

With regard to the thermal performance, this report is focused on envelope insulation and on windows replacement:

1.1_Envelope insulation

Limiting the thermal conductivity of major construction elements is the most common thermal performance requirement for buildings. These are based upon thermal transmittance (U value) requirements (expressed in W/m^2K) for the main building envelope construction elements. In particular the envelope becomes the most critical part in relation to energy efficient buildings considering that its impact is 57% of the building thermal loads.
Sufficient thermal insulation of the building envelope is essential for shielding the interior of the building from the exterior environment and minimising thermal transfer (heat losses or gains) through the envelope during the winter and summer periods.
The main building elements involved in the envelope insulation are:

- **a.** Walls
- **b.** Roofs

a. Walls

According to 2011 BPIE study, Figure 60 compares typical U values of exterior walls in a number of countries for different construction periods and compares these with the respective requirements

[5] Data and comments reported in this Section are mainly quoted from the JRC Reference Document on Best Environmental Management Practice in the Building and Construction Sector (JRC, 2012)

for today's new buildings. The lack of proper insulation in older buildings is clear in all countries due to the lack of insulation standards in those years (BPIE, 2011).

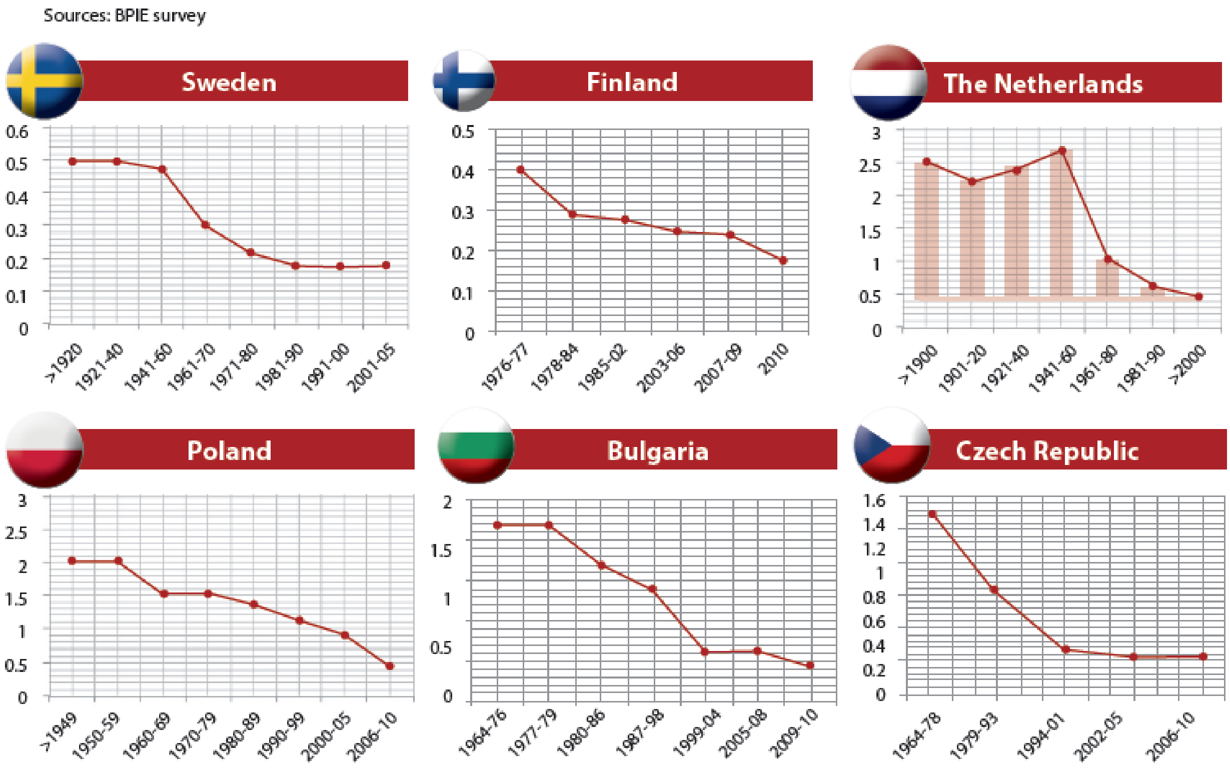


Figure 60 - U values (W/(m²K) for external walls in different countries for different construction periods. (BPIE, 2011)

The effect of the Energy Performance Buildings Directive (EPBD) implementation can also be demonstrated especially in those countries with no previous enforced regulations for insulation such as Portugal, where thanks to EPBD a 50% reduction in the U values has been applied over the past five years. This is in contrast with Northern and Western countries where long traditions of thermal insulation requirements existed prior to the EPBD with stringent requirements being implemented around the 1970s after the oil crisis (c.f. sharp decrease in 1960-1970s in The Netherlands). In Sweden, national requirements concerning energy performance of buildings were in place as early as 1948.

There are two main ways of obtaining improved thermal insulation:

- Increasing the thickness of the insulation, a method which has been used for the last 20 years but which has various disadvantages, for example, the cost of construction and the loss of space.
- Improving the thermal insulation properties by reducing the thermal conductivity of the insulation material.

For a long time, in those regions with an extended annual heating period, 100 mm of standard insulation such as expanded or extruded polystyrene, foamed polyurethane (PU), fibreglass, etc, were considered as good insulation. Nevertheless energy specialists recently calculated that the economically optimised thickness should be 300-500 mm, depending on the specific climatic conditions. Nowadays, many existing building regulations and standards demand U-value that is approximately equal to 0.2 W/(m^{2}K) for roofs and walls, which means about 200 mm thick insulation layers (IEA/ECBCS, 2005).

The problem of thick insulation layers is especially critical in the case of renovation of buildings, where there are severe limitations on space and also many other technical and urban planning constraints, so the second approach could be probably preferable and enable easier application in the case of building retrofit.

Insulating materials may be classified according to their composition/production into inorganic, organic and synthetic materials. Each of them has its application areas and its function as part of the building envelope, e.g. heat protection, moisture proofing, noise protection (impact sound insulation, airborne sound insulation) and fire protection.
Technically, the best way to insulate a building component is on the external side, as this increases internal comfort, reduces problems with thermal bridges and does not lessen the useful floor area. If it is not possible to use external insulation, i.e. because of exceeding the building footprint dimensions or entailing poor aesthetic (Thunshelle et al., 2005), internal insulation is used (JRC, 2012).

A part from the above mentioned common insulation techniques, several outstanding and innovative techniques, that may be used to improve the performance of walls, could be described such as vacuum insulation and transparent insulation.

- *Vacuum insulation*

The reason for examining the applicability of high performance thermal insulation in buildings (e.g. evacuated insulation in the form of vacuum insulation panels) came from the aforementioned difficulties involved in renovation projects.

Nowadays the most innovative insulation application in energy renovation could be the use of **Vacuum Insulation Panels** (VIP) (Figure 61). According to the 39th research program of IEA/ECBCS the thermal resistance of evacuated insulation is a factor of five to ten better than conventional insulation of the same thickness. VIP in general are flat elements consisting of an open porous (and therefore evacuation-capable) core material which has to withstand the external load caused by atmospheric pressure, as well as a sufficiently gas-tight envelope to maintain the required quality of the vacuum.
Vacuum insulated panels, compared to conventional insulation materials of the same thickness, save about 26 kWh per m² component area and about 7.3 kWh per m² useful building floor area.
The main drawback of these systems is that gas leakage causes an increase of the thermal conductivity of 0.0015 W/mK in 20 – 30 years.

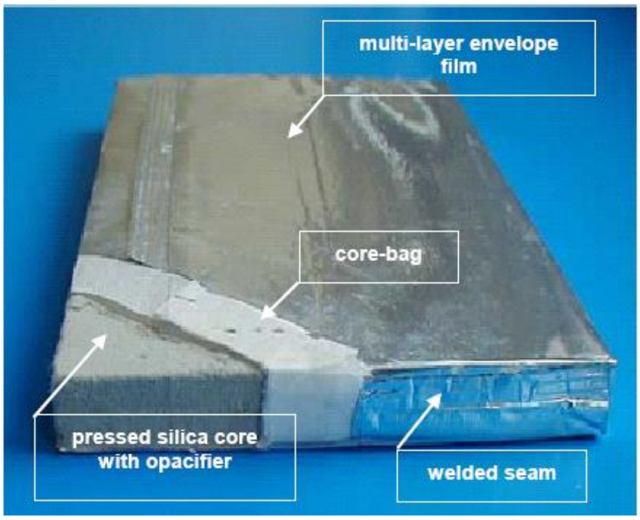


Figure 61 - Components of a VIP (IEA/ECBCS, 2005)

- *Transparent insulation*

Transparent insulation, instead, reduces heat losses and increases solar gains in comparison with opaque insulation (Figure 62). With this system, the solar radiation passes the transparent insulation layer and is converted into heat at the dark coloured exterior surface of the wall. Therefore, the insulation reduces the heat losses, entailing significant solar heat gains, and a large part of the gained heat is transferred to the inside of the building (JRC, 2012).

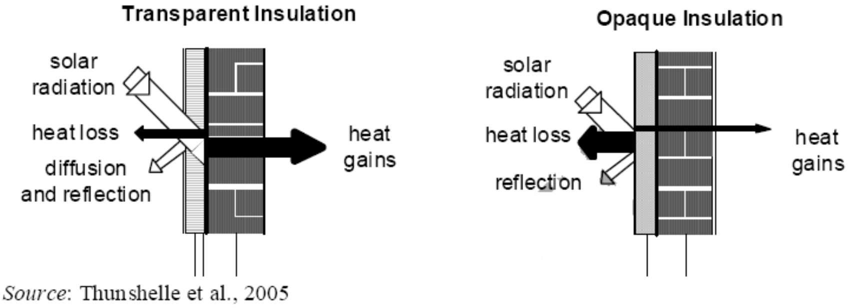


Figure 62 - Functional principle of transparent insulation in comparison with opaque insulation (JRC, 2012)

These techniques aimed at improving the performance of walls, through warmer inner surfaces of walls.
The useful energy saving potential of transparent thermal insulation materials compared to conventional insulation materials of the same thickness ranges from 13 to 71 kWh per m² component area (envelope) and up to 21 kWh per m² useful building floor area (Reiss et al., 2005; Thunshelle et al., 2005).

b. Roofs insulation

The thermal behaviour of roofs can be improved by increasing the thickness of insulation materials, considering the same techniques used for walls. Nevertheless, some outstanding techniques are designed to enhance the environmental performance, such as cool, brown and green roofs (JRC, 2012).

- *Cool roofs*

A cool roof is a roofing system able to reject solar heat and keep roof surfaces cooler under the sun, in the same way as white houses in Mediterranean countries do. This ability to stay rather cool in direct sunlight is due to the properties of materials, which reflect the solar radiation (solar reflectance or albedo) and release the heat they have absorbed (infrared emissivity).
A cool roof reflects and emits the sun's energy back to the sky instead of allowing it to enter the building as heat. In many climate zones, a cool roof can substantially reduce the cooling load of the building.

The benefit of cool roofs is to reduce cooling demand and to reflect solar radiation, thus directly reducing global warming potential and avoiding environment damages caused by the urban heat island effect.
Because cool roofs reduce air-conditioning used during the hottest periods, the associated energy savings occur when the demand for electricity is at its peak. Therefore, use of cool roofs reduces the stress on the energy grid during hot summer months and helps avoid shortages that can cause blackouts or brownouts.

The cool roof concept can provide several direct benefits to the building owner and occupants:

- reduced air conditioning use, resulting in energy savings typically ranging between 10 – 30%

- decreased roof maintenance due to longer roof life
- increased occupant comfort, especially during hot summer months

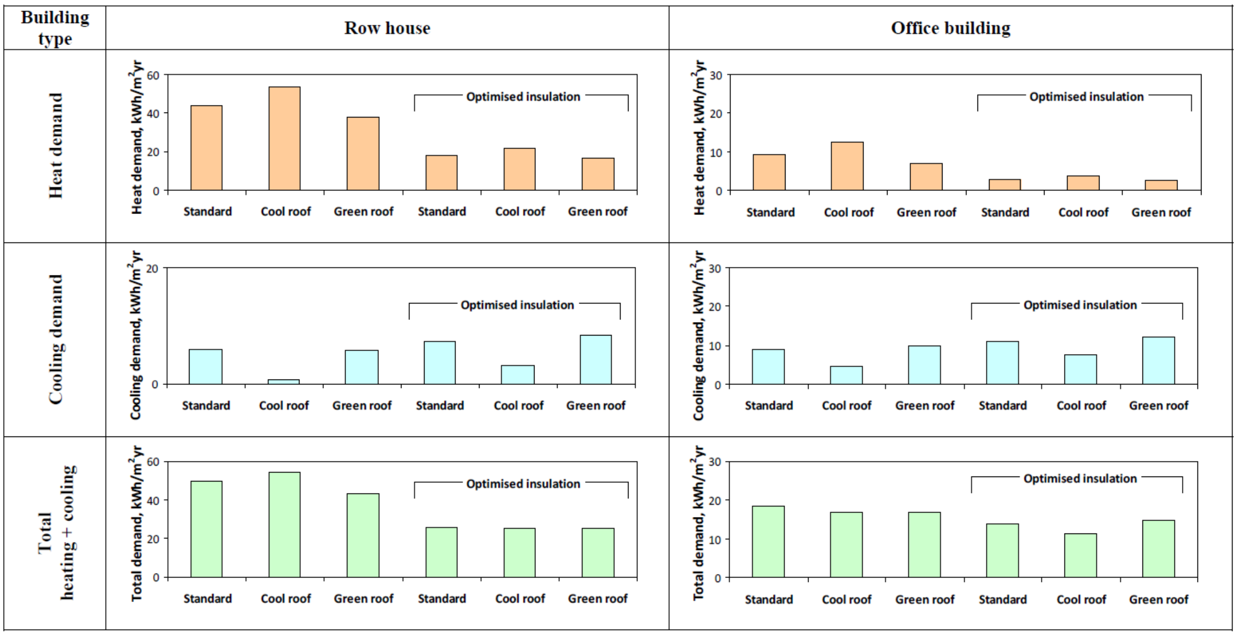
Cool roofs can be applied to most types of roofs, including single homes, apartment blocks, industrial structures, commercial buildings and offices. However, the benefit of the reduced solar heating of buildings is limited to hot climate zones.
At high latitudes in winter, the increase in roof albedo is less effective in reducing the heat island due to low incoming solar radiation, and even a need for increased heating that compensates for reduced solar heating (JRC, 2012).

- *Green roofs*

Pitched green roofs and flat green roofs act as insulation layer: they stabilise temperatures during summer and winter and provide urban heat island mitigation benefits. The latter ones differ between extensive roofs, which have a thin layer of growing material, and intensive roofs, which have a greater soil depth.

Green and brown roofs are identified as good practices to conserve biodiversity. From the thermal balance point of view, the additional layer of green and brown roofs adds insulation to the building, helping to reduce temperature fluctuations, not only because of insulation but also due to the evapotranspiration processes. In addition, the contribution of green roofs to albedo is relevant and they can act also as a cool roof. For green roofs, the benefits go beyond the thermal balance: biodiversity, urban heat island benefits, reduction of water run-off, etc. are several environmental benefits derived from their application.
The concept of green roofs is applicable on flat roofs and on steep roofs with low pitches. Steep roofs need special consideration for the selection of plants. Resistance is a key factor, as water is less available in this type of roof. Moreover, mechanical aspects when designing a green roof should be taken into account (JRC, 2012).

A 2010 study called COOLROOFS show the results of the comparison of green roofs and cool roofs for a Mediterranean city (Barcelona) in a row house and office buildings (Figure 63).



N.B. Adapted from Cool Roofs, 2010

Figure 63 - Heat, cooling and total energy demand of a row house and an office building with different types of roofs (Cool Roofs, 2010)

Cool roofs are able to reduce the energy demand for cooling but with significant drawbacks on the energy demand for heating, as solar gains are reduced.
Green roofs have an insulation capacity, so the effect may not be good for cooling, but they reduce heating demand. In conclusion, total energy demand does not vary much from the 'standard practice' building compared to cool and green roofs, for row houses and for office buildings.
Nevertheless, when applying an optimal insulation level, the overall energy demand is significantly reduced, even though energy demand is increased because of the higher influence of internal gains. Integrative approaches are needed when applying cool or green roofs.

1.2_Windows replacement

Windows are responsible for heat loss in cold climates during winter and are a source of heat gain in warm climates during summer. They provide natural light, ventilation and increase the comfort of occupants by providing a view of the outdoors.

The total energy flow for a window consists of three major components (Figure 64) (JRC, 2012):

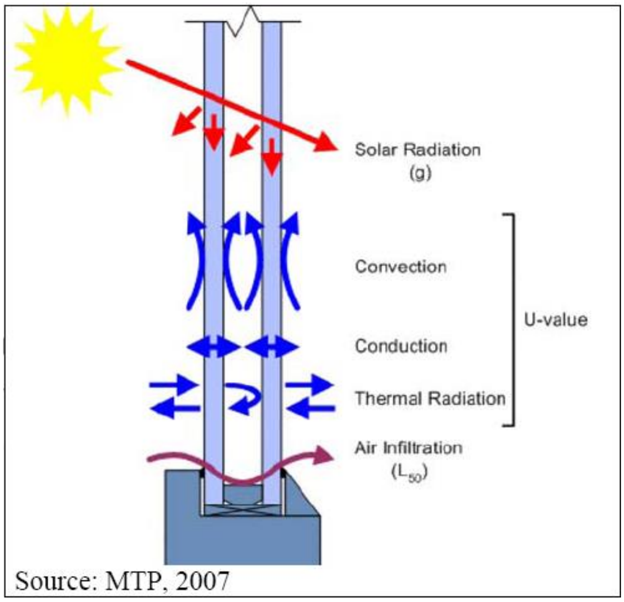


Figure 64 - Energy flow through a window (JRC, 2012)

- Solar heat gain from *solar radiation.* This is measured by the solar factor (g), which measures energy gains from solar radiation. The value of g is given as a number between 0 and 1 and a higher g means more solar heat gain.

- Heat losses and gains from *conduction*, *convection* and *radiation* arising from all the components of the window. This is measured by the U-value and a window with a lower U-value loses less energy through heat losses.

- Heat losses from *air infiltration* through the window. This is measured by the L_{50} value, which measures uncontrolled air leakage through a window. Air leakage through the windows is considered to be part of the performance of the frame.

Windows, exterior walls and the **connection joints** constitute the main components to be checked with respect to heat protection requirements. The weakness of one of these components produces inefficiency in the whole system. Therefore glazing, frame, jointing and connections have to provide low heat transfer coefficients and air-tightness (JRC, 2012).

Indeed 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 wastage. This highlights the importance of appropriate air tightness levels in a building. A building with high air tightness levels typically suffers from high energy consumption levels, while a building with very high air tightness levels can cause unhealthy conditions for its occupants, especially if there is inadequate ventilation. The latter is typically linked to poor indoor air quality and the so-called sick building syndrome. Establishing the appropriate level of air tightness in buildings is, therefore, a key aspect from the viewpoints of energy usage and comfortable occupant conditions. Poor detailing in past construction techniques means that older buildings encounter high leakage levels.
It is evident that in countries with long traditions in energy regulations (such as Germany and Denmark), the older stock demonstrates far lower air leakage levels compared to the old stock in Central & Eastern regions (such as Czech Republic, Latvia and Bulgaria). However, even with today's levels of air tightness, studies have shown that envelope leakage can increase the heating needs by 5 to 20 kWh/m²/a in a moderate climate (2 500 to 3 000 degree-days).

The **quality of windows** strongly influences living comfort and indoor climate. During the winter in cold climate zones, the cold surface of windows with insufficient heat insulation causes water condensation, as well as 'cold radiation', and lacking air-tightness causes infiltration. The corresponding lacks in comfort are often reduced by additional heating, whereas triple-glazed windows with heat protection glass prevent these lacks without the need of intensified heating.

On that basis, the most important technological innovation to satisfy insulation and air-tightness requirements turns out to be modern glazing solutions focused on the use of double and triple glazed units with inert gas (argon or krypton) between glazing panels and low emissivity coatings (BUILD UP, 2013).
An example of best performing window is the high g-value, low-e glass and krypton filling triple glazed window, with U values less than 0.7 W/m^{2}K.

Besides triple-glazing with high g-value, low-e glass and krypton filling, windows should incorporate an insulated window-frame, three gaskets and it has to be installed in an airtight way.
Nevertheless air-tightness causes higher humidity, so intensified venting could be necessary. This could be performed by an automatic ventilation device with integrated heat recovery.

Moreover using **shading systems** with different seasonal uses could give further advantages to reach the best configuration of eco-efficient buildings. Indeed, during summertime, the solar radiation entering the windows causes additional cooling requirements, therefore shading of windows reduces the cooling energy demand and influences the lighting of a building. Some of the most common external devices are shutters and blinds. Furthermore, shutters can reduce the heating demand by acting as a thermal barrier.

2. Energy performance

In relation to energy performance, this report summarizes the technology options to improving HVAC and lighting systems:

2.1_HVAC systems

The purpose of the HVAC (heating, ventilation and air conditioning) system of a building is to achieve comfortable conditions for the occupants, avoiding any source of nuisance. The design substantially changes across Europe, as the heating load is low in the south of Europe, or the cooling demand can be neglected in Nordic countries.

Under the term HVAC, a huge variety of technologies are available and, therefore, the definition of best environmental management practice becomes complex.
When designing a new building or renovating an existing one, the optimisation of the HVAC system has to consider an integrative design of the thermal balance of the building, taking into account the following aspects:

- envelope performance of the building
- potential solar gain: glazing and shading
- air leakages avoidance, air entrances (doors, gaps, etc.), air change rate fixing, heat recovery from exhaust air
- lighting system design (using natural sources as much as possible) and avoiding heat gains from lighting
- potential internal gains (from foreseen occupants, from internal appliances, waste heat from internal processes, etc.). Heat recovery from internal processes may be a source of 'free heat' leading to lower performance, e.g. from the refrigeration cycle or from waste hot water.
- monitoring and optimal control (which reduces maintenance and repair), flexible range of indoor air temperatures (19 – 26°C).

One consequence of the lack of integrated design can be oversizing that leads to less efficiency, so a right calculation of the energy demand of the heating system taking into account the integrated approach is needed.

HVAC technology is evolving not only to meet a lower energy demand while providing better indoor air quality, but also to address new issues (more renewable energy sources, higher primary energy efficiency) and new needs (hot water, heating, and cooling).

In particular heating and cooling technologies are presented in details.

<u>a. Heating technologies</u>

Some available technologies for the heating system may be considered as best practice such as passive solar air heating, solar thermal system, heat pumps (JRC, 2012).

- *Passive solar air heating*

This system can produce huge savings to the energy consumption of HVAC. When combined with good orientation, proper building structure, optimised envelope and construction materials, and internal heating gains recovery, the overall efficiency is significantly increased. Total heat loss can be reduced by 35% using passive solar methods.

- *Solar thermal systems*

These systems with evacuated tube collectors are a common and highly efficient form of simple solar heat collectors. Sunrays pass through the tube glass and are absorbed by metal stripes, in which the heat medium flows. Nevertheless the production of collectors is energy, CO_2 and especially material-intensive. Therefore, the total energy balance becomes positive after two to three years usually (energy payback time), depending upon site specific such as type of collector, solar intensity, etc.

- *Heat pump technologies*

The best practice of heat pump technologies*,* when applied to buildings with low, optimised heating demand produces great savings.

In details, heat pumps extract and upgrade low grade renewable heat stored in surrounding air, water, ground, etc., so that it can be circulated within HVAC systems to provide space and water heating.

Heat pumps function according to thermodynamic principles underpinning the basic refrigeration cycle. The external energy required by heat pumps to transport and upgrade heat from a heat source to the point of heating, and vice versa for cooling, is lower than the amount of heating or cooling energy provided by the heat pump, potentially resulting in significant energy savings compared with conventional heating or cooling systems.

b. Cooling technologies

Space cooling best practices are mainly for demand reduction through the use of some of the following techniques:

- heat absorption during daytime in summer by increasing the size of heat sinks
- use of cool roofs (reflecting incoming radiation from the sun)
- green and brown roofs (cooling by evaporative absorption)

These measures above should be regarded only as complementary to other mainstream technologies (JRC, 2012):

- *Passive cooling*

This technology involves cooling without using mechanical apparatus that consume power. For this, the urban microclimate is the major factor influencing the performance of passive cooling technologies through:

- *Optimal insulation*, shadings and overhangs and air change rate. Integrated designs between internal heat gains during summer and how to release this heat to the surroundings should be studied in detail.

- *Opening windows* to promote natural ventilation and cooling when temperature difference is appropriate (e.g. during night time). Night ventilation (cross or single sided ventilation) can produce energy savings when studied and optimised according to the surroundings.

- *Wind towers* are a well-known technology, used for more than three thousand years and used in traditional architecture. Currently, it is used as an element of natural ventilation installations, reducing the energy consumption of mechanical ventilation and reducing the temperature of indoor climates. Wetted wind towers can remove the need for active cooling, through evaporative cooling in warm, dry climates (Hughes et al., 2012).

- *Active cooling*

Some innovative and commercially available technologies for active cooling are (JRC, 2012):

- *Desiccant and evaporative cooling (DEC)* is an open air conditioning system. As open systems need fresh air as input, DEC combines the tasks of ventilation, dehumidification and air conditioning. At first, fresh air is dehumidified by an adsorption process, where special materials such as lithium chloride on cellulose, silica gel, metal silicates or zeolites adsorb water into their structure. The adsorption energy is passed onto the air, so that warm and dry air is the product of this process. The air is pre-cooled with cold discharged air via an air-to-air heat exchanger. Afterwards, a humidifier provides liquid water, which evaporates and thereby reduces the air temperature, as the evaporation energy needed is withdrawn from the fresh air.

- *Absorption chillers* are closed systems and use the principle of thermal compression to provide cooling. A refrigerating medium is absorbed and another is evaporated, usually liquid medium, thereby drawing heat from the surrounding and passing heat onto another surrounding. In typical household applications, water is used as the refrigerating medium.

2.2_Lighting systems

Lighting is responsible for a significant fraction of the energy consumption of any building, so energy savings on electrical lighting could reduce significantly the environmental performance during building use.
The use of light can be divided in two categories:

1. *Natural light:* directly comes from the sun through glazing. The orientation of the building, building surroundings and the availability of external light are the main factors affecting natural light systems. The availability of natural light may affect the thermal balance of the building, especially if the insulation capacity of windows is not sufficient. Again, an integrative approach may be needed for these techniques.

2. *Artificial light:* artificial lighting consumes a significant amount of electricity. Two types of artificial lighting have to be considered:
    - basic lighting: light supplied for the basic needs of building occupants
    - special lighting: designed to support lighting needs for special purposes

There is not a unique solution for energy savings in the lighting concept. Lighting, as an energy consumer, has to be optimised with a fixed strategy, first, reduce the energy demand and second, use efficient devices. Reduction of demand can be achieved by using more natural light, but also with smart strategic concepts and control systems. Efficient devices refer to efficient lamps but can also be considered with efficient skylight systems (JRC, 2012).

In particular, techniques for increasing the use of **daylight** in a building could be a best practice to improve energy saving related to lighting. Nevertheless it depends on the local required and available luminance, the available space and the optical characteristics of the used systems:

- Windows: these elements are the most common way to let daylight into a space, usually multiple orientations must be combined to produce the right mix of light for the building.

- Skylights: roof light openings admit strong bright light (nearly three times the amount of vertical openings) and are an efficient lighting technique for the top floor of buildings. They are frequently found in northern climates, where daylight availability is lower.

- Combination with control system (daylight harvesting): daylight harvesting is the term for a control system that reduces artificial light in building interiors when natural light is available, in order to reduce energy consumption. Such a system can at the same time implement a whole lighting strategy. Lighting controls are mainly based on the use of two types of sensors: occupancy sensors and photo-sensors.

Furthermore, **efficient devices** could be considered as the way to reduce energy consumption of the lighting system. Using efficient lighting technology (when artificial lighting is needed) can lead to significant reductions in electricity consumption. The most common efficient types of bulbs used are divided into macro-categories:

- ‘household’-bulbs (standard incandescent and halogen bulbs, compact fluorescent lamps with integrated ballast, LED lamps)
- fluorescent lamps with separated ballast

Efficient devices, such as LED, can offer huge energy savings (up to 50 %). Nevertheless, the main benefit is achieved from the integration of efficient devices in an overall lighting strategy.

3. Renewable technologies

In relation to installation of renewable technologies, the most developed technologies are presented. The use of renewable energy sources should be regarded as a best environmental management practice after the implementation of measures to reduce energy demand. Table 1 summarises the main best practice renewable energy options for buildings. Heat pumps and geothermal systems utilise renewable aero-thermal, hydrothermal and geothermal energy but also require significant amounts of conventional energy (typically electricity) to operate (JRC, 2012).

Renewable energy technology	**Best practice description**	**Applicability**
Offsite renewable energy	Whatever it is not efficient to exploit renewable energy directly on site, the preferred best practice measure is to invest in renewable energy schemes, to install a renewable energy generating capacity off site, or to purchase ‘green’ electricity that can be traced to a specific renewable source that is not accounted for in national average (emission) factors for grid supplied electricity as per GHG.	All buildings typologies.
Biomass heating	The main source of biomass heating is wood or pellet boilers that may be used to heat water feeding DHW and HVAC systems. The use of gasifying boilers fed by logs also represents best practice. Best practice operation of wood boilers involves continuous operation at partial load wherever possible, in order to minimise emissions to air.	Best suited to non-urban areas with a local wood supply and where combustion emissions pose a lower health risk.
Solar thermal	Flat plate or evacuated tube solar collectors can be placed on buildings roofs. Solar thermal water heating is particularly well suited to buildings where occupancy and peak DHW demand occur in summer, coinciding with peak solar irradiance.	Any building with suitable exposure to the sun.
Solar photovoltaic	Solar photovoltaic cells can be installed on, or integrated into, the building envelope – in particular roofs, exterior walls and shading devices – to generate electricity. Generated electricity may be used for onsite processes or fed into the grid in order to avail of feed-in tariffs for solar electricity.	Any building with suitable exposure to the sun. More effective at lower latitudes and in sunny climates, but most cost-effective where high solar feed-in tariffs are available.

Wind turbines	Building-mounted wind turbines with a capacity of 1-6 kW are an emerging technology with low electricity outputs and typically poor return on investment compared with alternative RE options. Best practice is to install on-site free standing turbines of tens to hundreds of kW capacity where space and wind conditions allow.	Wind turbines are a good option for green electricity investment by all building users.

Table 1 - Major best practice renewable energy options for buildings (JRC, 2012)

2A.3 RENOVATION VS DEMOLITION AND RECONSTRUCTION

Among the strategy to enhance the energy and structural performance of the existing building stock, mention must be made to the possibility of demolishing and re-constructing a new building complying with the new codes requirements. So for each project a major question arises, whether it is more convenient to pursuit the renovation of the existing building or the demolition and reconstruction.

The Reference Document on Best Environmental Management Practice in the Building and Construction Sector (JRC, 2012) states that before building demolition or deconstruction, the reuse of buildings should always be a preference because it:

- avoids the construction of new buildings, and so the **consumption of further resources**: in the previous chapters the analysis of the construction impact on the environment shows that the 50% of raw material is used every year for construction and housing, and a corresponding amount of energy to produce, transport and process it: converting an old building generally takes only a third as much material.
- avoids the huge environmental impact, especially at local level, produced by a demolition and reconstruction project: the main products of demolition through conventional methods or through selective deconstruction are **waste** to be treated, materials to be re-processed and a brownfield to be recovered as a green area or as a new building. Apart from these, other direct local impacts of deconstruction and demolition are quite important; these are dust, that can be harmful to health and can damage property, splinters, debris and dirtiness, noise and vibrations, that are created by explosions, machinery, falling construction parts and transferred through the ground to surrounding structures. The C&D waste covers 30% of the total amount of waste in the EU, and it was demonstrated that, during the construction of a building, the major quantity of material is produced at the beginning for the site clearing and the excavation and then during the construction of structure. In a renovation project, not only the demolition waste is reduced, but also the waste generated during these reconstruction processes are limited.
- reduces risks due to **hazardous materials handling**, accidents, etc.: demolition is a very dangerous process and several regulations concerning workplace safety must be respected.
- reduces impact on **biodiversity**. Often, old towers and other buildings are important habitats for protected species. Each alteration of a land ecosystem can compromise the survival of certain species and also lead to their extinction.
- respects the **value of the existing buildings**: for many people a building could have a great personal significance. Often the demolition of a structure means also the disruption of a home, an entire portion of a neighbourhood or a piece of the skyline of a city, with his historic and emotional implications.

Nevertheless, demolition may be a necessary requirement if the conditions of the existing building are far from optimal due to, for example, risk of collapse, presence of dangerous substances for health, after fires or earthquakes, etc.

A different issue is the renovation of monumental and historic buildings that have to be preserved for the culture and the memory of a country. In this case the demolition is never considered and great projects of restoration, conservation and maintenance must be conceived.

Renovation as the result of Life Cycle Analyses and Life Cycle Costs: benefits of renovation

Based on the previous considerations, the need to act on the European existing building stock both in terms of structural and energy performance is evident. This action entails decisions between demolition/reconstruction versus renovation.

The choice between these two alternatives is the result of a complex process. Nowadays, it must be backed by reliable energy consumption estimations, taking into account the expected energy/resource performances of the renovated building, the embodied energy/resources of materials and process costs for demolition or renovation, the potential reuse/recycle of building components material, the structural performance (E2B, 2012).

At the building's end of life, reliable evaluation methods and tools are required to choose between demolition or renovation. Enabling the optimum solution requires to be backed by a set of tools and methodologies that allow alternative building design options, by data to be compared against their costs of ownership and possibly additional value streams.
Life Cycle Thinking concept provides a series of tools and methodologies that could ease this complex task. In particular Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) approaches can provide an appropriate support in the decision making process. Indeed, Europe recognizes the importance of these methodologies to assess the environmental and economic performances of buildings, so that stakeholders could choose the best solution between various alternatives.
In details LCA and LCC are recognized to provide the best framework currently available for respectively assessing the potential environmental and economic impacts of components and systems, making easier the integration of sustainability concepts all along the building value chain.

In the light of a building renovation project, these procedures turn out to be really important in a decision making process because each single improvement measure has a cost and a saving associated with it, that are specific to a particular building, as well as ancillary benefits (BPIE, 2011):

- **Costs** can vary depending on whether improvement measures are installed individually or as a package, and also whether improvements are being undertaken at the same time as maintenance, repair or building upgrade/modernisation. For example, if HVAC equipment is at the end of its service life, the cost of the energy efficient option will be the marginal extra cost over a standard efficiency replacement.

- **Savings** will depend on the previous level of energy consumption, energy sources used, the price of energy, the lifetime of the measure and also future movements in energy prices. Some of the savings may be offset mainly when energy efficiency measures address fuel poverty, but overall this rebound effect may be partially compensated by other above mentioned factors (e.g. by the increase of energy prices or even by behavioural measures).

- New windows and efficient HVAC systems are known to increase the **value of a property**. The value of high levels of insulation and buildings integrated renewable technologies have yet to be fully appreciated by consumers, though this will change over time as the benefits of low energy consumption, a good energy rating (A-B) and a low carbon footprint become more evident, appreciated and accepted across society.

- **Additional user benefits** include lower noise levels and improved comfort from insulation and glazing, better indoor air quality and temperature control from new HVAC equipment, less operational maintenance or increased energy security and protection against price fluctuations through deployment of renewable energy resources that are not dependent on conventional distribution systems.

- **Societal and environmental benefits** range from reduced GHG emissions, improved energy security and alleviation of fuel poverty.

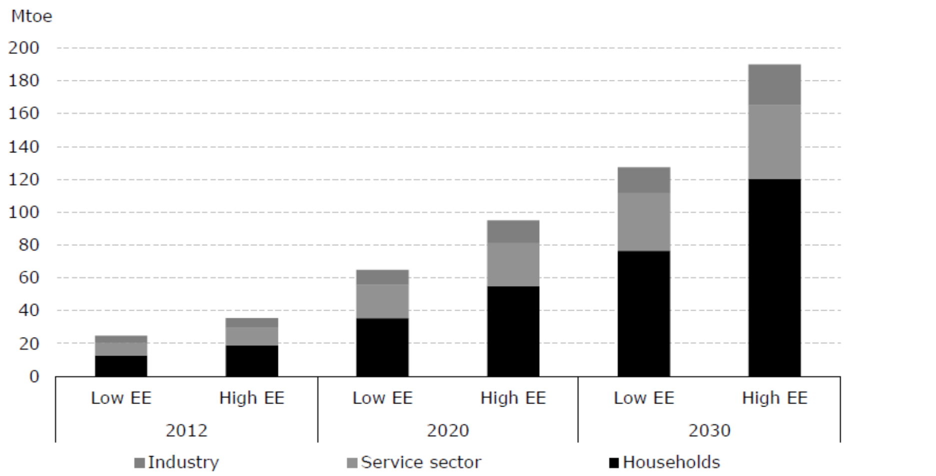
- **Socio-economic benefits** through development of new green businesses and employment opportunities

• The **environmental impact** of demolition and reconstruction projects is higher than that of renovation interventions. In the first case, the impact of the supplying material, construction, use, demolition and disposal of the existing building must be added to the impact of the entire new building in the life cycle assessment, thus two building impacts must be considered. In the case of renovation intervention, the impact of the old building is added to that associated to the renovation intervention, thus the environmental total impact is reduced.

Moreover, the renovation costs vary greatly among EU regions and countries, being influenced by many factors such as market development, prices of materials, financing cost, labour market costs and the existence of specific support programmes and policies.
For this reason a careful economic analysis is essential in a building renovation programme, considering the future value of improvements too. In that light LCC analysis could provide the best support, showing the real value of the investment through the actualization of future costs, applying a discount rate.
However a major refurbishment could significantly extend the life of buildings that would be soon demolished otherwise.

From an environmental point of view the renovation of the existing building stock is one of the most attractive and low cost options to reduce the emissions of CO_2 and potentially improve energy security by reducing imports of fossil fuels. Moreover a renovation is preferable than demolition and reconstruction in respective of resource efficiency, also considering the problem of disposal of demolition waste. The management of waste building materials and their potential reuse or recycling is indeed of primary importance to alleviate the decreasing availability of certain raw materials and avoid their further depletion, as well as to diminish the quantity of ultimate waste sent to landfills. In such a way, more sustainable approaches and more environmental friendly solutions than demolition are considered (E2B, 2012).
In this case LCA is a good tool to monitor the building environmental impacts from cradle to grave, so it could provide a quantitative analysis of ecological burdens during all the phases foreseen for a demolition/reconstruction project or for a renovation one.

Efficient renovation of buildings in the EU holds a large potential for **energy savings**. According to a study conducted by Copenhagen Economics for the Renovate Europe Campaign, the potential for achieving energy savings in 2012 is 25 Mtoe in the low Energy Efficiency (low EE) scenario (35 Mtoe in the high Energy Efficiency - high EE) (Fig. 65).

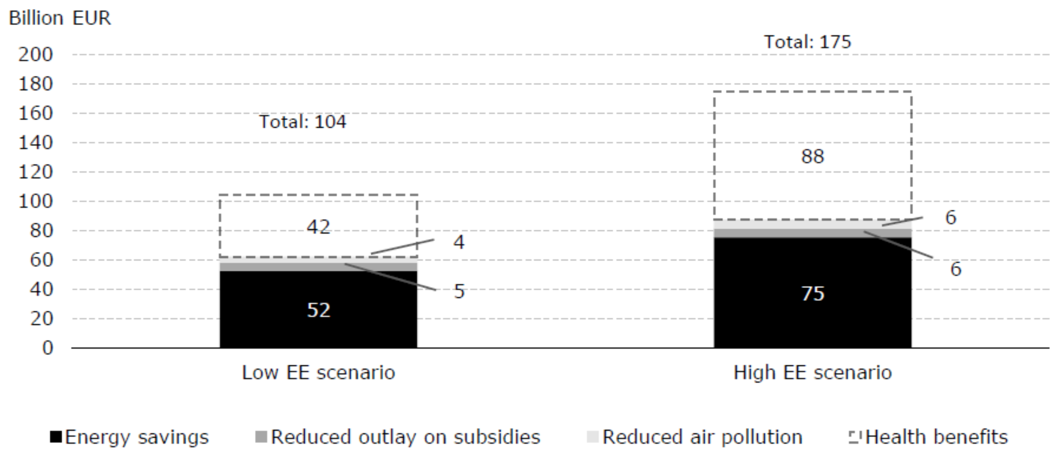


Source: Copenhagen Economics based on http://www.eepotential.eu/esd.php

Figure 65 – Accumulated energy saving potential over time (Copenhagen Economics, 2012)

In 2020 this potential is accumulated to 65 Mtoe in the low EE scenario (95 Mtoe in the high EE), which corresponds to approximately 5.4%of EU final energy demand (8.2%in the high EE). In 2030 the accumulated energy savings are increased to 127 Mtoe in the low EE scenario (190 Mtoe high EE), which corresponds to approximately 10.6% of EU final energy demand (15.8% in the high EE). The largest potential for renovating buildings lies in the household sector, followed by the service sector and industry.

In addition to the permanent benefits these renovations may bring, they will also a very needed stimulus to the European economy in time of economic underperformance, spare capacity and record low real interest rates in a number of countries.
In particular, according to Copenhagen Economics study, renovation opportunities could bring huge benefits to the EU economy over the coming decades. Based on available estimates of the potential for energy savings from renovation of buildings, this study suggests a monetised permanent *annual* benefit to society of €104-175 billion in 2020 (Fig. 66), depending on the level of investments made from 2012 to 2020.



Note: These results include the rebound effect, and can therefore not be compared with the sub-results derived in Chapter 1. We have applied a rebound effect of 20 per cent.

The total does not equal the sum of each element due to rounding.

Source: Copenhagen Economics

Figure 66 – Annual gross benefits to society from energy efficient renovation of buildings, 2020 (Copenhagen Economics, 2012)

In details, €52-75 billion from lower energy bills, and at least €9-12 billion from the **co-benefits** of reduced outlay on subsidies and reduced air pollution from energy production. If the health benefits from improved indoor climate are included, the benefits are increased by an additional €42-88 billion per year. These health benefits are evident, but very uncertain to estimate, and should be interpreted accordingly. If investments are continued after 2020, these annual benefits can be doubled by 2030 (Copenhagen Economics, 2012).

In addition harvesting the investment opportunities provided by energy efficiency renovations in the existing building stock, the EU Member States can stimulate economic activity at an appropriate time, which can give rise to jobs for 760,000 – 1,480,000 people and bring benefits to Gross Domestic Product of €153 - 291 billion depending on the level of investments. This corresponds to between 1.2% and 2.3% of EU GDP. These benefits are not permanent but instead a "one-off" benefit from stimulating activity in a period of economic underperformance.

Furthermore by reducing energy consumption and focusing on indoor climate issues, co-benefits of renovation projects can be achieved such as: reduced outlay of government subsidies and improved health, due to less air pollution and a better indoor climate, both of which also lead to fewer hospitalisations and improved worker productivity (Copenhagen Economics, 2012).

In short, the most direct and also the most significant benefits from renovation of buildings are the savings resulting from lower energy consumption and waste reduction.
As energy consumption is reduced, government tax revenue will decrease. The expected reduction in energy consumption in the different scenarios will give rise to a loss of tax revenue of € 5.2 billion or € 7.2 billion annually in 2020.
Finally by reducing energy consumption, the amount of air pollution will be reduced. In such a way an environmental and social benefits are obtained too.

There are likely to be additional benefits, which are more difficult to quantify. Three such benefits are the improved life quality of living in a more comfortable living environment e.g. through a high average living room temperature (benefits which goes beyond the health benefits), the value of reducing EU's energy supply dependence on third-countries and the reduced dependence on volatile fossil fuel prices.

All that considered, renovation of buildings has important macro-economic benefits and can substantially contribute to all three priorities of the Europe 2020 Strategy, as well as to the EU 2050 roadmap targets. Society as a whole will benefit the result of investments in energy saving measures for buildings, even before the climate benefits are taken into account. For these reasons renovation must be conceived in an holistic way, taking into account environmental, social and economic issues, therefore it should be studied with a sustainable approach, focusing also on structural performance. As a result, an integrated approach is preferable, which is life cycle oriented and multi-performance focused. In details, renovation has to guarantee safety and reliability, reduced environmental impacts, optimized life-cycle costs.

Although renovation turns out to be the best solution on existing building stock, the substantial renovation of the EU27 building stock is insufficiently covered by the existing legislation and hence the sectorial potential for creating cost-effective energy savings, jobs, welfare and economic growth is not properly exploited. To attract more private capital it is necessary to develop long-term renovation programmes with clear targets and monitoring, providing appropriate financial instruments and public financial leverage.

2B Critical discussion about the available requalification technologies for possible improvements of the renovation strategies

In this chapter a brief state of the art on the main seismic and energy requalification techniques was carried out. A variety of technology options for earthquake resistant, eco-efficient buildings exists and is already applied in all EU countries.

The comparative evaluation of new and available requalification technologies can be made by comparing some qualitative parameters, such as:

- **efficiency of the solution**: some renovation methods, often applied in the past and consolidated in the construction practice, revealed themselves ineffective and, in some case, also dangerous. In each requalification project it is very important to consider all possible drawbacks of a solution.
- **feasibility and costs**: some technologies, if not properly applied, could lead to unjustified costs.
- **impact on the environment**: the renovation technologies need to be eco-efficient with respect to the Best Environmental Management Practice suggestions. In the case of solutions having the same efficiency, the minimally impacting solution should always be preferred. The choice of the material could be optimized taking into account resource consumption, recyclability, performances, polluting (e.g. wood may be the more environmentally sound choice for building a family home compared to concrete if the timber comes from a sustainably managed forest nearby. But if the demand for timber as construction material was to exceed the supply of timber, promoting only wood frame houses would probably lead to a rebound effect, in this case, the deforestation - EIO, 2011).
- **minimal intervention criteria**: In the case of solutions having the same efficiency, the minimally impairing of the building integrity should be preferred.
- **re-convertibility of the requalification project**: considering that technology is fast developing and fast becoming obsolete, codes change, etc., it is always wiser to select technologies that can be easily disassembled, and verify the intervention reversibility. In this way the obsolete systems, as well as the possible damaged parts can be easily replaced with new components, and the integrity of the structure is not compromised. From this point of view better techniques are the dry-techniques.

The concept of sustainability for the rehabilitation of existing buildings is usually intended as a reduction of the building energy consumption. This reduction can be achieved by using renewable energy sources and eco-friendly materials; however, the structural deficiencies of these buildings can be so severe that an energy efficiency requalification or architectural redevelopment would leave these buildings dangerously unsafe. Recent earthquakes have emphasized the little forethought of these interventions: scenes after Emilia Romagna earthquake, showing broken new high-performance windows and solar panels, as well as wrecked thermal insulation elements clustered on top of the ruins of many buildings, should be remembered before granting national funds for the sole energy efficiency upgrade (Figure 67). This situation highlights how the rehabilitation leading concept of eco-sustainability, environmental quality, renewable energy and energy efficiency should be **integrated** with the fundamental building structural safety requirement: preservation of human life, achieved through structural retrofit interventions, should be framed among the priority objectives of a sustainable redevelopment plan.

Furthermore, in Europe, the requalification of existing buildings has always been approached by solving episodic, contingent problems exhibited by the building, either referring to specific energy deficiencies, or architectural or, more rarely, structural problems. The interventions have often been carried out mainly in emergency situations, without any general planning. The proposed solutions, although often innovative, have therefore been limited to solving only part of the problems, without considering the complexity and the interrelation of the deficiencies of the building system. Therefore, no integrated procedure has ever been proposed. Moreover, the interventions have often been carried out on isolated buildings, thus based on a case-by-case approach, without considering the **urban scale and context**.

In this scenario, a wise renovation strategy should be based on the effective "integrated" solution of all building deficiencies, and thus ensuring not only **energy efficiency** but also its **structural safety**, the architectural quality and urban environment regeneration. These objectives should be all achieved by respecting all of the minimum environmental impact principles and minimum rehabilitation cost requirements.

Figure 67 - Example of the little forethought of a traditional intervention limited to the energetic and architectural redevelopment, without accounting for the structural safety. The image portrays a building severely damaged after the Emilia Romagna earthquake (2012)

Thinking to a building as a whole and promoting integrated renovation intervention it is possible to:

- **reach the best environmental performance**. An integrated solution to all renovation needs can be better conceived than a series of single interventions aimed at solving single deficiencies, entails limited waste and avoids negative interactions of the interventions (i.e. frequent damage to thermal insulation envelope to accommodate needed structural reinforcements, or damages of the structures to accommodate new in plant facilities);
- **minimize the entity of the requalification**: Unlike traditional episodic interventions, the design of a single integrated solution allows the quantity of the employed materials and labour to be minimized, reducing both duration time of the intervention and costs;
- **obtain a more organic result**: the aesthetic appearance of the renovated building can be more easily controlled and obtained when implementing a unique integrated requalification

project;

- **enhancing living environment quality.** The quality and efficiency of an integrated intervention should also be assessed with reference to the achieved living environment quality, the health and well-being of the inhabitants, as required by the World Health Organization's study about the environmental burden of disease associated with inadequate housing**.**
- **pursuit urban requalification**: integrated renewal of existing buildings should be considered as part of a general urban requalification. Each intervention should be conceived and carried out by taking into account its impact on the urban scale, or as a chance for requalifying an entire district. Such an intervention might require urban planning restrictions and regulations to be revisited and upgraded.
- **guarantee structural safety** of unsafe building stock
- **guarantee energy efficiency** of the obsolete building stock. Innovative integrated solutions should be designed to fully incorporate technologies that deliver significant energy efficiency improvements.
- **promote knowledge growth**. Last but not least, a multidisciplinary approach requires the synergic integration and synthesis of single expertise toward the design of a more efficient and innovative solution, which overcomes the weaknesses of the traditional uncoordinated intervention methodology, and stems as an opportunity for knowledge growth and scientific excellence promotion.

Aiming at conceiving the requalification of the building as a whole, new strategies and methodologies are needed, new materials and new techniques must be discovered and the principles of the Best Environmental Management Practice must be applied.

Innovative integrated solutions should be regarded as an efficient alternative to existing building demolition and reconstruction, which can no longer be extensively pursuit for the unbearable environmental load of the production of new construction materials, as well as to avoid excessive demolition waste which needs to be processed, disposed or recycled; or as an alternative to the upgrading of the sole architectural and energetic performances.

3. FINAL REMARKS AND RESEARCH NEEDS

This document was aimed at defining the research needs for assessing the technology options for earthquake resistant, eco-efficient buildings. To this end, an in-depth survey on the main building typologies in Europe and on the state of preservation of the existent building stock was carried out and some important requalification needs were identified, both in terms of energy efficiency and structural safety. The study emphasised that given the present crisis in the new building construction sector, the research community should better focus on the renovation field. Europe is an intensively constructed area, and to achieve some important objectives, like the reduction of the total CO_2 emissions or the increase of people safety during seismic events, the more urgent need is the refurbishment of the great already existing building stock.

In the document, a brief state of the art on the main available seismic and energy requalification techniques was also carried out. The choice of the more suitable technology options should be based on the comparative evaluation of parameters like efficiency, feasibility, costs, eco-efficiency and re-use.

Since some important targets are to be met for the energy requalification in 2020 and 2050 and that it is estimated that many European buildings do suffer of a high seismic vulnerability, the research of the new technology options should rapidly fill these gaps. This goal could be reached only if the seismic and energy aspects are treated together. Old buildings at the end of their life span should be seen as something that must be led back to a new life as a whole.

The major limit of many refurbishment interventions carried out in the latter years on the existent building stock was that interventions were only aimed at the solution of only one aspect of the problem, either aesthetic, energetic or structural deficiencies.

Based on the results of this analysis, the main research needs of technology options for earthquake resistant and eco-efficient buildings must focus on both innovative materials and advanced technologies that should be combined to obtain integrated solutions of the problems.

3.1 REMARKS ON THE POLICIES AND PROGRAMS/BARRIERS AND MAJOR LEGISLATIVE, FINANCIAL RESTRICTIONS

A large number of people contribute to decide if and when improving the performances of existent buildings. There are literally millions of building owners and also very large numbers of decision makers – managers, developers – who decide and plan possible interventions on all of the buildings, but especially in multi-family, commercial and public buildings. What is important for policy making is to better understand the factors affecting those decisions in order to design and implement policies which will more effectively promote energy and seismic efficiency investments and actions (BPIE, 2011).

The BPIE survey deals with this important issue, identifying the main barriers and challenges to be overcome for the requalification interventions to become feasible (Figure 68).

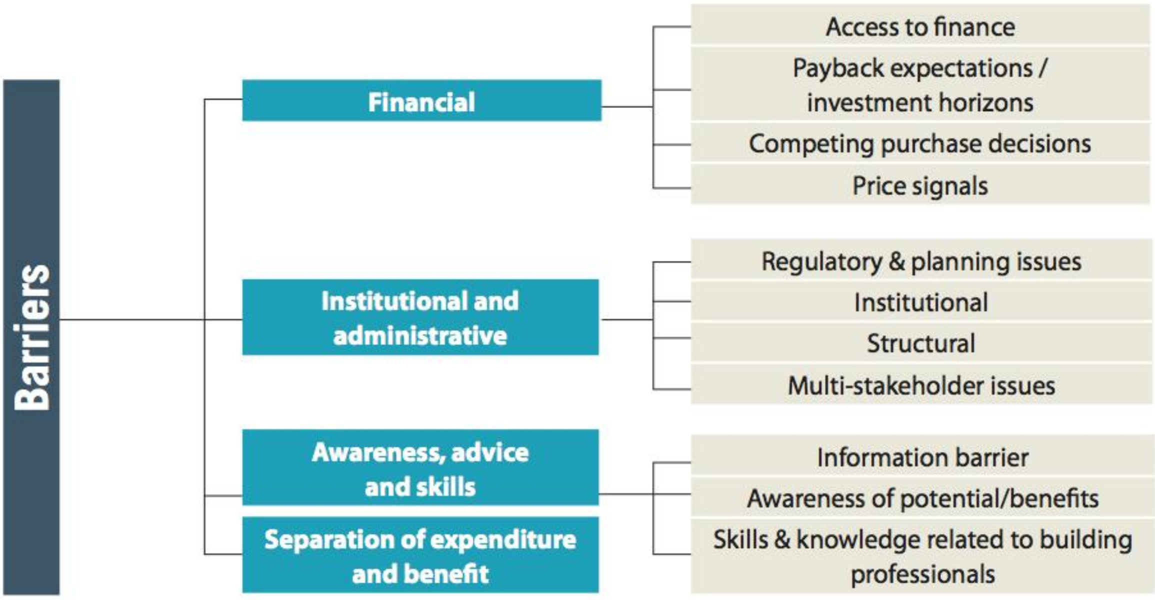


Figure 68 - Classification of barriers as identified in the BPIE survey (BPIE, 2011)

Financial barriers were recognised as one of the highest ranking barrier; undoubtedly, any investment in renovation requires money. Shortage of funds and/or inability to secure finance on acceptable terms is generally one of the most cited barriers to investing in energy efficiency measures. This applies at the level of the individual householder, businesses (large or small), social housing providers and the public sector, particularly in the aftermath of the credit crunch (BPIE, 2011).

Another important barrier is institutional and administrative, with a variety of regulatory and planning obstacles. These range from various degrees and speeds at which EU Directives have been implemented by autonomous regions within a Member State, to energy market barriers, such as the approvals process for building integrated technologies. Evidence from some Member States as Italy indicates that 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 (BPIE, 2011). In addition, since a lot of Directives has been issued in the recent years for the eco-efficient buildings, there is a lack of legislation about the seismic renovation of the existent buildings. This implies little control on the renovation and no funds for the seismic assessment of the building stock.

There are many barriers relating to awareness, information and technical expertise. Undoubtedly, for the market to work smoothly, correct and appropriate information is essential. Without the right combination of necessary conditions, the consumer may only choose to undertake renovation measures when it is absolutely necessary, as is the case for the replacement of equipment when it breaks down, typically after a strong earthquake.

Finally, the separation between expenditure and benefits is probably the most complex and long-standing barrier in relation to existing buildings, particularly in countries where there is a high share of rental accommodation in the residential sector, but also because of the typology of occupancy in the non-residential sector. This barrier is sometimes considered a financial barrier and, understandably, there are financial implications. It is also sometimes considered to be an institutional barrier. The problem originates 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. 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 a stalemate with nothing happening.

Various barriers exist also where there are multiple owners and/or occupiers of buildings. Regarding ownership and responsibility, it is worth noting that it can be very difficult to agree on investments in multi-family residential buildings if many different property owners have to either approve a decision or make a financial contribution (BPIE, 2011).

Other important challenges to the renovation project realization are the supply chain, the quality of workmanship, and the disturbance. The disturbance is a real barrier and is the practical issue of what happens to the building occupier when a major renovation is being undertaken: occupants may not want to withstand the disruption or the building downtime typical of any major building renovation. 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 (4-10 weeks) (BPIE, 2011).

Consequently, in order to address the challenge of renovating the existing building stock enhancing energy performance and seismic resistance, and to keep pace with the ambitious aims of the European Union for improving eco-efficient performances of the existent buildings, further improvements of the EU and national frameworks are needed. Some suggestions are proposed by the BPIE survey and summarized in the following.

At EU level, it is necessary to strengthen the existing legislation with binding measures and to establish a roadmap for the renovation of the EU27 building stock. The EU legislation should call upon Member States to prepare detailed deep renovation plans comprising regulatory, financial, informational and training measures. Having a predictable long-term deep renovation roadmap will provide confidence to the business sector and will avoid the risk of falling short after 2020 and of creating unwanted economic problems (BPIE, 2011).

National Governments should eliminate market barriers and administrative bottlenecks for the renovation of the housing stock. Improving the efficiency of buildings will generate significant economic benefits for society, including an important impact in terms of employment in the construction industry, the sector most affected by the economic crisis. Improving the energy and seismic performance of buildings should be seen as a positive force for economic recovery.

In order to foster the deep renovation of the building stock, Member States should develop long-term comprehensive regulatory, financial, educational and promotional packages addressing all the macroeconomic benefits (BPIE, 2011).

3.2 DISCUSSION OF POSSIBLE RESEARCH NEEDS FOR ASSESSING TECHNOLOGY OPTIONS FOR EARTHQUAKE RESISTANT AND ECO-EFFICIENT BUILDINGS

Energy efficiency is a key factor in securing the transition to a ‘green’ resource efficient economy and to achieving the EU Climate and Energy objectives of a 20% reduction in the GHG emissions by 2020 and a 20% energy savings by 2020.

The construction sector is one of the most relevant consumers of energy in Europe, and has a huge impact on the economic, ecological and social environment. Meeting the European targets in terms of efficient use of natural resources and mitigation of the environmental impact requires immediate virtuous actions on this sector.

Furthermore, the European building stock is obsolete and very often does not satisfy the safety requirements of the new building codes, in terms of resistance to static and dynamic loads.

The study summarized in the previous chapters highlighted the no longer bearable environmental impact of the extensive construction of **new buildings**, as well as the economic resource reduction induced by the current financial crisis.

Considering that Europe is a very densely built land, Energy European targets and safety requirements can be only met by the sustainable **renovation of the existing building stock**.

The need of restoration affects a large building stock since a large portion of the existing buildings in Europe were built before the 60's and are characterized by low energy efficiency, living discomfort, poor structural performance with respect to both static and seismic loads. City suburbs are also characterized by low architectural and urban quality, and buildings are often clustered in vast and degraded areas. Interestingly, the sustainable renewal of existing buildings also entails the re-use of the urban available facilities which would be otherwise abandoned and demolished.

It is worth noting that nowadays in the renovation of building the **concept of sustainability** is usually intended as a reduction of the building energy consumption which can be achieved by using renewable energy sources and eco-friendly materials. However, the structural deficiencies of these buildings can be so severe that an energy efficiency requalification or architectural redevelopment would leave these buildings dangerously unsafe. This situation highlights how the rehabilitation leading concept of eco-sustainability, environmental quality, renewable energy and energy efficiency should be integrated with the fundamental building structural safety requirement: preservation of human life, achieved through structural retrofit interventions, should be framed among the priority objectives of a sustainable redevelopment plan. This underlines the importance of study integrated renovation interventions.

Among the possible strategies for the renovation of the existing building stock, the solution of the **demolition** of the obsolete buildings and the **reconstruction** of new buildings with better performances should not be extensively pursuit, as it entails even worse consequences on the environment than the construction of new buildings, mainly consisting in the production of new construction materials, and of excessive demolition waste which needs to be processed, disposed or recycled.

Despite **renovating the existing building stock** is acknowledged as the necessary step to meet the European Energy targets, recent data are strongly discouraging, highlighting a renovation rate across Europe of about 1%. With such a renovation rate the European Commission forecast that only half of the EU 20% target will be achieved in 2020.

In order to vitalize this sector, appropriate **financial and/or volumetric incentives** should be conceived and proposed, technological innovation, new decision making tools, as well as innovative renovation strategies should be promoted. For example, the interest on "nearly zero energy building" should be shifted towards "positive" energy building in order to compensate for the insufficient number of renewal interventions of existing buildings. Moreover, some specific incentives for improving structural performance of existent buildings should be introduced.

Based on the results of the analysis summarized in the previous chapters, **further research** is needed both to better assess the existing building characteristics, in order to refine their requalification needs, and to promote innovative technology options for earthquake resistant and eco-efficient buildings. Research should be focused on **innovative renovation solutions** aimed at promoting the sustainable renewal and the structural rehabilitation of the vast European building stock through effective **integrated** and concurrent solution of all building deficiencies, thus overcoming the major limit of the traditional "episodic" and "case-by-case" intervention approach, characterizing the refurbishment interventions carried out in the recent past. Integrated renovation projects should improve the **energy efficiency**, the **structural safety** and the **architectural and urban environment quality** at the same time. To this purpose also innovative materials, techniques and technologies should be conceived.

With respect to the traditional "episodic" approach, resulting in a series of un-coordinated interventions, the envisioned multi-disciplinary approach should promote integrated renovation works, which allow: (i) reaching the best environmental performance, limiting waste and avoiding negative interactions of the interventions; (ii) minimizing the impact and entity of the requalification by minimizing the quantity of the employed materials and labour, work duration time and costs; (iii) obtaining a more organic result by avoiding negative interactions between the interventions; (iv) enhancing living environment quality; (v) pursuing urban requalification; (vi) guarantying structural safety, and (vii) energy efficiency.

Such a multi-disciplinary renovation approach will favour the synergic integration and synthesis of the single expertise toward the development of more efficient and innovative solutions. Such research is therefore an opportunity for knowledge growth and scientific excellence promotion.

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Abstract

The construction sector corresponds to the largest industrial sector not only in economics terms, but also in terms of resource flow. Moreover, European citizens spend most of their lives inside buildings, therefore buildings turn out to be at the centre of social and economic activity.
In that light, Europe is involved in several initiatives and strategies aimed at making this sector one of the most competitive and innovative, focusing on the achievement of the environmental and energy targets in line with 2020 Europe Strategy and EU 2050 Roadmap, but also ensuring safety both in ordinary conditions and in presence of exceptional events, such as earthquakes.
While new buildings can be constructed with high performance levels, the older buildings typically need renovation measures, because of their low energy performance and seismic vulnerability.

This report has the aim to define research needs for exploiting old buildings potential to deliver energy and CO_2-emission saving and seismic performance improvement, as well as societal and economic benefits, so that energy efficient and earthquake resistant buildings can have a pivotal role in a sustainable future.
In the first part of the report, a detailed analysis of the main characteristics of European buildings in terms of age, size, ownership, location, structural typology is presented in order to define the predominant typology of the European building stock; the seismic hazard in Europe and the earthquake vulnerability of European buildings are then analysed and, finally, energy consumptions and environmental impacts in terms of use of resources, construction and demolition (C&D) wastes and CO_2 emissions are described.
The analysis of the present situation turns out to be essential in order to define the starting point to assess the current and new technology options, examined in the second part of the report and necessary to obtain eco-efficient and seismic resistant buildings. In addition benefits that a renovation project could bring against a demolition and reconstruction programme have been underlined.
Once these inputs have been defined, the requalification needs and the importance of improving renovation strategies, considered as outputs of the analysis, are examined for each of the two abovementioned parts of this study.
Finally a critical discussion on the importance of considering research needs for this topic has been carried out with a focus on barriers and challenges that could be found during a renovation programme.

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