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Applicability of the Sustainable Structural Design (SSD) method at urban/regional/national level

A methodology for sustainable building development

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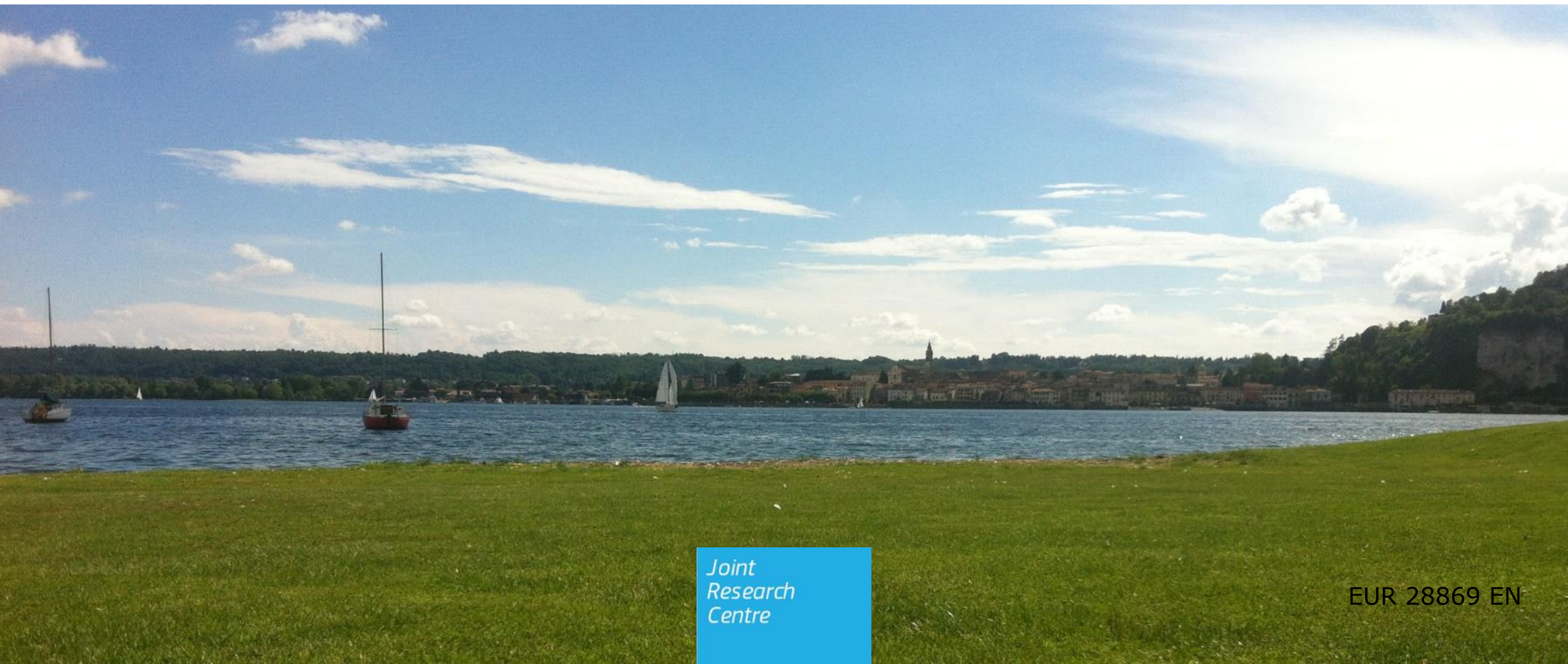

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A methodology for sustainable building development

Contents

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Abstract

The alarming data on world climatic change, resources impoverishment and increasing human diseases caused by environmental pollution has encouraged the modern society to feel committed in reducing the environmental issues and to adopt a sustainable approach to every human activity. Sustainability is an ambitious challenge for Europe development and European policy is addressed in investing massive resources for achieving sustainable goals.

Construction is one of the most impactful industrial sector because of the high consequences it generates on the society, the environment and the economy. Indeed, building constructions involve social aspects, as safety and comfort, economic aspects, as construction investments and maintenance, and environmental aspects, as energy consumption and emissions.

The present study derives from the development of a building design method, called Sustainable Structural Design (SSD) Methodology. This methodology is based on a multi-performance and life cycle-oriented approach, which includes the environmental aspects, related to energy consumption and CO_2 emissions, in structural design, performed with a simplified Performance Based Assessment (sPBA) methodology, in order to obtain a global assessment parameter in monetary terms.

Moreover, the study derives from the awareness about the structural condition of the European building stock, which is old and, in some cases, far from the structural safety required by the European codes. Thus, a simply applicable methodology, allowing the identification of the territorial areas which need a more urgent intervention is necessary. The application of the SSD methodology at territorial level could allow the inclusion of the main aspects of sustainability, identifying the areas which an intervention could reduce the energy consumptions, the CO_2 emissions and the structural losses of the included buildings.

Thus, this report aims at studying the applicability of the SSD methodology at territorial level, considering three different area dimensions, as countries, regions and cities, and identifying the right approach for each of them. Consequently, an SSD methodology at territorial level is developed and illustrated.

Introduction

Sustainable development is one of the most relevant topics of the last decades. It involves each branch of human activities, from agricultural to safety management areas. The global interest in sustainable development is also evident considering the massive investments that have been, and still are, carried out to guarantee a sustainable approach to the global growth and the management of human activities. In order to assure the sustainable development, interactions among environmental, social and economic parameters have to be involved.

The construction sector provides high contributions to the three dimensions of the sustainability. Indeed, according to the social dimension, people spend most of their time inside buildings, so a healthy and quality indoor environment has to be guaranteed; moreover, according to 2013 EU-28 data by Eurostat [1][2], construction sector provides a high contribution to the employment, accounting for 12.2 million people and 5.2% of the total employees. Considering the economic dimension, EU-28's construction sector was made up of more than 3.2 million enterprises in 2013 and generating EUR 487 billion of value added [1]. Moreover, 2014 data by Eurostat reveal that an 11.4% share of the EU-28 population lived in households that spent 40% or more of their equalised disposable income on housing [3]. Finally, considering the environmental dimension, buildings are responsible for approximately the 40% of the total energy consumption and the 36% of the total greenhouse gases in Europe [4].

Among the three dimensions, in the last years more attention has been given to the environmental issue. The global warming is generated by the increasing atmospheric concentration of the greenhouse gases (GHG), including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). EU Commission has revealed that the building sector is responsible of 36% of GHG emissions [4] and that more than 50% of building energy consumption and at least 80% of carbon dioxide emissions can be reduced by taking suitable measures [4]. In order to face this issue, several global agreements have been signed, starting from the Kyoto Protocol in 1997. The Paris Agreement [5], was signed during the last United Nations Climate Change Conference, which was held in Paris in December 2015. Paris Agreement has fixed the global commitment in the reduction of climate change, focusing the attention on transports, agriculture and, finally, on building sector. The final aims of the Agreement are: holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels; increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development and, finally, making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

In order to follow the ways indicated by the Agreements, several European Regulations have been published. The directive of the Energy Performance of the Buildings (EPBD), also called Directive 2010/31/EU [6], was issued as a result of Kyoto Protocol Agreement. The Directive promotes the improvement of the energy performance of buildings within the Union, giving requirements about the common general framework for a methodology for calculating the integrated energy performance of buildings and building units and about the application of minimum requirements to their energy performance. Moreover, it states the necessity to issue an energy performance certificate in order to provide information on the building energy consumptions. Starting from this Directive, the Member States have developed a certification system, called "energy performance certificate, EPC" to provide the annual value of energy consumption of buildings. Other EU policy initiatives and Regulations, mainly directed to improve the environmental performance of buildings including energy efficiency and eco-friendly materials, are the following:

- Energy Efficiency Directive [7]
- EcoDesign Directive (energy related products)
- Energy Labelling Directive (energy related products)

- EcoLabelling Regulation
- EcoLabel for Buildings (first priority office buildings)
- Energy Efficiency Action Plan (2007-2012, 2013-2020)
- Green Public Procurement (GPP)
- Construction and Demolition Waste (Waste Framework Directive)
- Lead Market Imitative (on Sustainable Construction)
- Resource Efficiency Roadmap–EC (DG/Env) communication on Sustainable buildings
- CPR →obligatory CE marking of CPs 1th July 2013–New: BRCW 7 Sustainable use of natural resources [8].

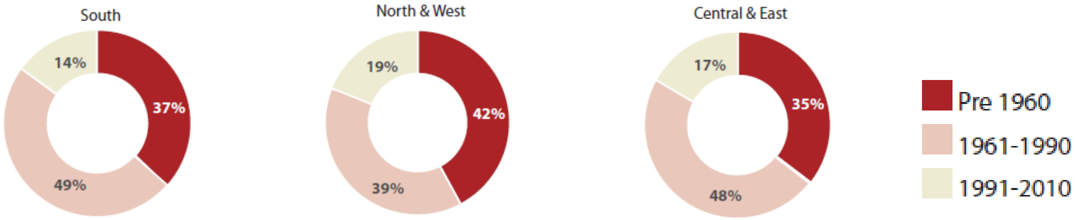
The growing interest in achieving the environmental efficiency of buildings has prevailed, somehow, on an important aspect of the buildings' performance: the structural safety. In some cases (Figure 1), this attitude has caused the annulment of the energy benefits and, consequently, the stultification of the investment plans. Indeed, as reported in the following images, the focus on energy efficiency of the buildings, neglecting their structural performances, can provoke significant economic and social consequences.

Figure 1. Examples of safety neglect in buildings with energy improvements. a) roof collapse of a building in Emilia Romagna Region (Italy) after the 2012 earthquake; b) roof collapse of a Municipal library in Sardinia Region (Italy) for gravity loads, in 2015

a) b)

The necessity of focusing the attention on structural performances of buildings is clear if statistics on construction age of European building stock are considered. According to the Buildings Performance Institute Europe (BPIE) [9] (Figure 2), around 40% of residential buildings have been built before 1960, when seismic codes had not been developed, yet, or did not consider the effective seismic action.

Figure 2. Highlights on the construction year of the European building stock



Source: BPIE

For these reasons, it is clear that a combined approach for evaluating the performances of buildings is necessary for including both the energy and the safety featuresof the buildings themselves, in order to create and maintain a sustainable building stock and, in order to optimize the initial investments, avoiding that structural flaws foil energy efficiency subsidies. Figure 3 shows the virtuous investment cycle of buildings: the initial investment for energy efficiency finances the safety improvement, which in turn protects the initial investment. Energy savings, due to energy efficiency renovations, can also pay for structural improvements, which contribute to strengthening the investment.

Figure 3. The virtuous investment cycle

In order to combine the environmental and the safety performances of buildings, the Sustainable Structural Design (SSD) methodology has been developed by Romano, Negro and Taucer in 2014 [10] and refined by Loli et al. [10]. The aim of the methodology is to equip the buildings with a single parameter, which includes environmental performances, regarding energy consumptions and equivalent CO_2 emissions, and the safety performance, regarding the structural costs. This parameter is provided in economic terms.

This methodology has been developed for single buildings. Nevertheless, it is interesting to enlarge the applicability field from building to territorial level in order to give the stakeholders a procedure for the identification of the areas where an environmental and structural intervention is more urgent and would be more efficient. Indeed, this methodology can support the administrations in addressing policy projects on the territory. Moreover, this combined approach is applicable considering each hazards occurring in the area of interest, being the seismic hazard an example.

The present report aims at developing the SSD methodology at national/regional/urban level. Each step of the methodology is analysed and, for the structural performance assessment, the attention is focused on the seismic hazard.

Focus on SSD Methodology motivation

Construction industry is one of the sectors that most contribute to the global environmental impacts. In recent years, the interest in achieving a more sustainable approach to the development of the built environment has been addressed mostly to the environment issues, as climate change and high-energy consumptions. The growing interest in attaining the environmental aims established by the global agreements, as Kyoto Protocol and Paris Agreement, has prevailed, somehow, on the structural performance of the buildings. The Sustainable Structural Design (SSD) methodology was developed for equipping the buildings with a single parameter, provided in economic terms, which includes environmental and structural performances. In the present report, the SSD methodology is developed at national/regional/urban level in order to give the construction industry stakeholders a procedure for the identification of the areas where an environmental and structural intervention is more urgent and would be more efficient.

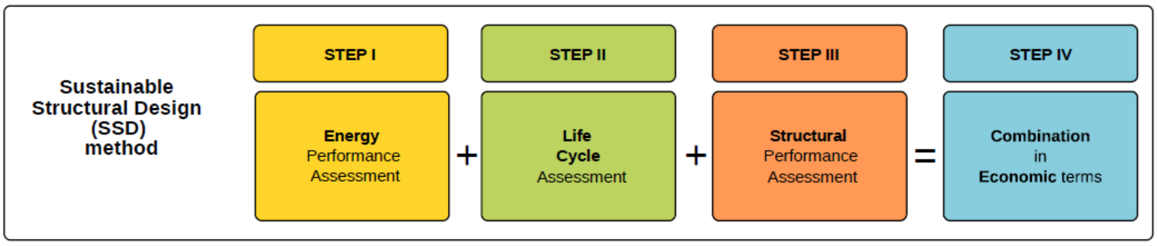
1 SSD methodology at building level

The Sustainable Structural Design (SSD) is a methodology aiming at supporting the general design process of buildings. It was developed by Romano, Negro and Taucer in 2014 [10], improved by Tsimplokoukou, Lamperti, Negro [8] and applied to a case study by Loli, Lamperti, Negro [10]. The methodology combines the structural and the environmental aspects of the buildings and summarises them in a single final parameter, provided in economic terms. It includes well-known approaches regarding the environmental assessment and the structural performance assessment of the buildings.

According to the SSD methodology, the environmental assessment can be achieved by considering the two main aspects of the environmental issues of the buildings: the energy consumption and the greenhouse gas (GHG) emissions. For addressing the final aim of the methodology, these two aspects are analysed separately.

The SSD Methodology is described by means of the framework shown in Figure 4. According to the figure, it is based on three main pillars, each of them corresponding to a procedure evaluation step: the Energy Performance Assessment; the Life-Cycle Assessment and the Structural Performance Assessment. The fourth step represents the conversion of the three identified pillars in economic terms, to address the Global Assessment Parameter of the SSD methodology. The four steps are better described hereafter.

Figure 4. Framework of the Sustainable Structural Design (SSD) Methodology



1.1 Step I: Energy Performance Assessment

The energy performance assessment step is formally part of the Life-Cycle assessment step, but it is performed separately from the second step of the methodology in order to easily address the operational costs of the buildings. In line with the life cycle energy assessment (LCEA) methodology, the total energy required during all the building life can be evaluated as:

$$E_{LC} = E_E + E_O + E_D \qquad (1)$$

where:

- E_{LC} is the life-cycle energy incurred at each phase of the building life;
- E_E is the embodied energy, i.e. the energy required for extracting, manufacturing and transporting the building materials and the energy required for the construction of the building (also called "pre-use phase");
- E_O is the operating energy, including the energy required for space heating, space cooling, water heating, illuminating, running appliances and other end-uses. It is expressed as a function of the annual operating energy, E_{OA}, and the life span of the building, L_B:

$$E_O = E_{OA} \cdot L_B \qquad (2)$$

— E_D is the demolition energy, i.e. the energy required for the demolition of the building, E_{DIS}, and the transportation of the debris and the other building materials to the landfill or recycling plants, E_T:

$$E_D = E_{DIS} + E_T \qquad (3)$$

The E_O value is herein treated separately from the other energy components and it is the only component estimated in the first step on the methodology. One main reason for computing this value separately is that the European policies are moving towards the reduction of the energy consumptions, reaching the goal of the widespread diffusion of nearly zero energy buildings (nZEB), as reported at Art. 9 of EU Directive 2010/31/EU [6]. For this reason, the control on the E_O component should be guaranteed by the methodology, in order to quantify the reductions. Another reason for considering the operating cost separately is that the energy prices can include energy taxes related to the carbon emissions related to the production of energy. In order to avoid that the CO_2 contribution is doubly evaluated in the cases the prices include the carbon-related taxes, two options can be chosen:

(a) remove the tax component from the energy price and proceed with the following steps of the methodology;

(b) consider the total energy price and, in the second step of the methodology, evaluate the CO_2 emissions only for pre-use phase and demolition phase of the building life-cycle.

1.2 Step II: Life-Cycle Assessment

Life-Cycle Assessment (LCA) is a methodology aiming at the evaluation of the environmental impacts of products and processes generated during their entire life cycle. For its generic nature, LCA methodology can be applied to each material/product/process entailing the generation of environmental impacts.

LCA procedures are regulated by the International Organization for Standards (ISO) series ISO 14040 [12] and ISO 14044 [13]. According to ISO 14040, LCA is addressed by following four steps, also shown in Figure 5. The first step of the LCA procedure is the Goal&Scope definition, where the goal, the Functional Unit (FU)[1] and the system boundary[2] of the LCA study are defined. The second step is the Inventory analysis (LCI), which involves the compilation and quantification of inputs and outputs for the studied system throughout its life cycle. The third step is the Impact assessment (LCIA) aiming at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the studied system. The last step of the LCA methodology is the Interpretation, in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations [12].

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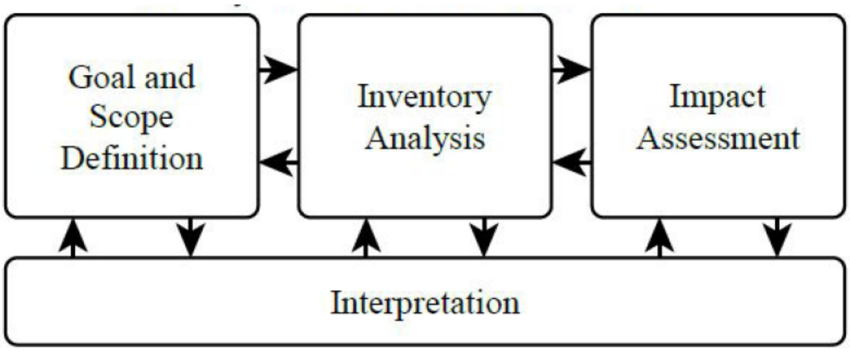
[1] The Functional Unit is the unit of measure of the studied system providing a reference to which the inputs and outputs can be related

[2] The system boundary is the system of the materials and processes included in the LCA analysis

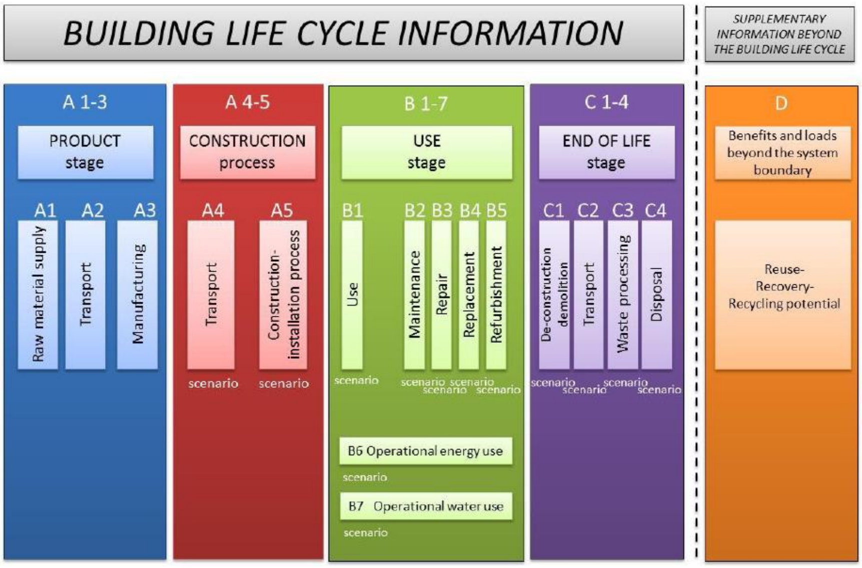
Figure 5. Life Cycle Assessment steps



Source: ISO 14040 [12]

The life-cycle assessment can be performed by means of specific software, which include international databases, collecting the sustainability data of the materials/products/processes[3] and impact assessment methodologies. Several LCIA methodologies are available for each LCA-based software, providing different environmental impacts, like IPCC 2007 GWP [14], Eco-Indicator 99 [15] and Cumulative Energy Demand (CED) [16]. Databases, methodologies and software are continuously updated. As discussed previously, in order to perform a LCA study, it is important to set the system boundary; for LCA analyses on buildings, EN 15978 [15] standardises the stages that should be included in the LCA study. Precisely, the system boundary of the buildings should include: (1) the pre-use phase (extraction and production of materials, E&P, and construction phases); (2) the use phase (ordinary maintenance of structural elements), and (3) the End of Life (EoL) phase (building demolition and material disposal) (Figure 6).

Figure 6. Definition of the life-cycle stages and system boundary for building systems



Source: EN 15978 [15]

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[3] The international databases for LCA analyses generally include environmental information about compositions, production processes, disposal scenarios of most of the existing materials, industrial processes and construction materials.

1.3 Step III: Structural Performance Assessment

The third step of the SSD methodology regards the assessment of the structural performance of the buildings.

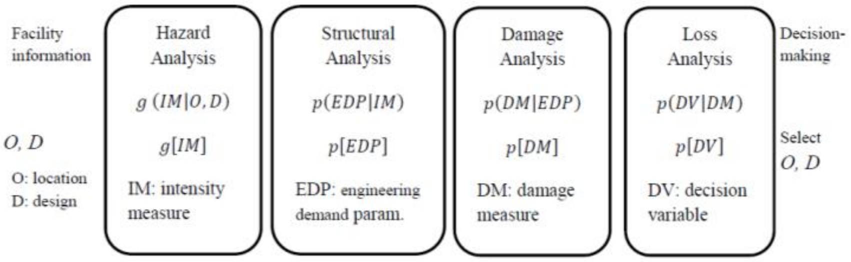
The modern structural performance assessment approach derives from the tragic losses caused by the earthquakes in Northridge, USA (1994) and in Kobe, Japan (1995), which have led to a complete re-examination of the building sector knowledges. Indeed, the last two decades have been characterized by the updates of the national technical codes for addressing the structural design with a Performance-Based approach. The performance-based approach can be based on the identification of performance levels, called "limit states", which the structure has to satisfy, in order to maintain some predefined features in case events of different natures occur. Therefore, it involves the implementation of probabilistic scenarios the structure could face during its lifespan in terms of uncertainties [18]. The uncertainties fall into three main categories, namely hazard uncertainties (as earthquakes, winds, flooding), structural uncertainties (as stiffness, material properties, structural capacity), and interaction mechanism uncertainties (as duration) [18]. To this regard, performance-based assessment (PBA) allows structural systems to be designed to fulfil the performance targets in terms of capacity, safety and quality. PBA approach also allows the costs associated to a structural solution and to a rehabilitation measure to be estimated, along with the expected losses the building could face during its lifespan, for the defined limit states. This can lead the different stakeholder categories to compare the alternative structural solutions and evaluate the more feasible/affordable one.

According to the global applicability of the PBA concepts, performance-based assessment can be realised for all the events that may occur during the building lifespan: fire (Performance Based Fire Assessment, PBFA), wind (Performance Based Wind Assessment, PBWA), hurricanes (Performance Based Hurricane Assessment, PBHA), as well as others.

Since the occurred earthquakes have led the development of a PBA concept, its first implementation has been realised for the earthquake events. The Pacific Earthquake Engineering Research (PEER) introduced the methodology framework for earthquakes, called PBEE (Performance Based Earthquake Engineering), which, nowadays, is the most robust methodology.

The PEER PBEE methodology is divided into four steps: (1) the ground motion hazard estimation, (2) the response estimation, (3) the damage estimation and (4) the loss estimation (Figure 7).

Figure 7. PEER PBEE framework methodology



The ground motion hazard estimation phase aims at the assessment of the probability that a seismic hazard occurs, given a defined location, *O*, and the building's design characteristics, *D*. This probability is defined as $g(IM|O,D)$, where *IM* is the intensity measure. Examples of IMs are peak ground acceleration (PGA), spectral acceleration (Sa), spectral velocity (Sv).

The response estimation phase aims at realising a structural analysis to estimate the structural response of a building, subjected to an earthquake having an intensity measure

IM. The response is measured in terms of Engineering Demand Parameters (*EDPs*). Examples of EDPs are inter-storey drifts and floor accelerations). The outcome of this phase is the value *g*(*EPD*|*IM*).

The damage estimation phase aims at evaluating the probability of having a structural damage (*DM*), given an *EDP*. This phase is achieved by defining fragility functions. The outcome of this phase is the value *g*(*DM*|*EDP*).

The loss estimation phase involves the probabilistic estimation of performance parameterised through decision variables (*DV*). Examples of *DV* are: economic loss, injuries, fatalities. DVs are related to DM of the previous phase. The outcome of this phase is the value *g*(*DV*|*DM*). According to this last value, stakeholders have the possibility to make decisions on structures.

The four components of the PEER PBEE methodology are then combined in the triple integral:

$$G\,(DV) = \iiint_0^{\infty} G(DV|DM) \left|\frac{dG(DM|EDP)}{dDM}\right| \left|\frac{dG(EDP|IM)}{dEDP}\right| dIM\; dEDP\; dDM \qquad (4)$$

1.3.1 Simplified Performance Based Assessment Method (sPBA)

A simplified version of the PEER PBEE method, called Simplified Performance Based Assessment (sPBA) has been introduced by Negro and Mola [19] in order to reduce the complexity and the amount of data needed for the loss assessment of structures. The proposed procedure can be applied also considering other hazards. As for the PEER PBEE methodology, sPBA follows four phases, which are described hereafter.

— Limit state definition

According to the damageability of the structure, the limit states are defined and the expected costs related to each limit state are evaluated. The damage limit states can be defined as: *low* damage, *heavy* damage, *severe* damage and loss of the building/collapse. The structural damage is evaluated in terms of the inter-storey drift (IDR), which is evaluated by means of the fragility curves for each damage level.

— Structural analysis

The structural analysis aims at the evaluation of the peak ground accelerations (*PGAs*) causing the IDR values defined at the previous step. This correlation is assessed through skeleton curves obtained from Incremental Dynamic Analyses (*IDA*) or from Pushover analysis, which lead to the definition of the peak ground acceleration versus inter-storey drift ratio for each damage state.

— Hazard analysis

The PGAs provided by the previous step are converted in probability of exceedance. The relation between the return periods (T_R) and the *PGAs* are provided by the modern technical codes. As an example, Italian seismic code [20] provides a set of values of PGA for nine return periods, and it is possible to evaluate the *PGAs* of different T_R by using the following interpolating formula:

$$log(a_g) = log(a_{g1}) + log\left(\frac{a_{g2}}{a_{g1}}\right) \cdot log\left(\frac{T_R}{T_{R1}}\right) \cdot \left[log\left(\frac{T_{R2}}{T_{R1}}\right)\right]^{-1} \qquad (5)$$

where:

- a_g is the PGA referred to a defined damage state
- T_R is the return period corresponding to that damage state
- a_{gi} are the previous and successive values of PGA, taken from the seismic map
- T_{Ri} are the return period corresponding to a_{gi}

Once the T_R values are known, the probability of exceedance R_n, in n years is expressed as follows:

$$R_n = 1 - \left(1 - \frac{1}{T_R}\right)^n \tag{6}$$

— Cost analysis

The total cost of the building is the sum of the initial costs for the building construction and the expected total losses during building lifespan. The expected total loss is the sum of repair costs, evaluated by the structural engineer, and downtime costs referred to each limit state. The latter represents the losses caused by the building lack of functionality and is estimated after the contractor evaluates the time needed to repair the damages. Therefore, the expected loss C_i, for the i-th limit state, is evaluated as follows:

$$C_i = E\left(Loss_{repair}|IM\right) + E(Loss_{downtime}|IM) \tag{7}$$

Once the costs C_i associated to the attainment of each limit state and the respective probability of exceedance R_i have been calculated, the total expected loss, L, considering all the limit states is evaluated as follows:

$$L = \sum_{i=1} C_i \cdot (R_i - R_{i+1}) \tag{8}$$

Finally, the total cost for structural performance assessment is evaluated with the following expression:

$$C_{TOT} = I + L \tag{9}$$

where I is the initial construction costs of the building.

1.4 Step IV: Global Assessment Parameter of the SSD Methodology

The first three steps of the SSD methodology lead to the estimation of different quantities, having different units of measure: kWh or gas m^3 for the energy (step I), $kgCO_{2,eq}$ for the equivalent environmental impacts (step II) and € for structural costs (step III). The last step of the methodology aims at unifying the building performance outputs in order to provide a unique sustainability value in monetary unit, called "global assessment parameter", R_{SSD}.

The conversion of the energy outputs in monetary unit can be achieved by using the data provided by Eurostat [21] for each Member State and for households and industrial consumptions. Therefore, the total energy costs are evaluated as follows:

$$R_{E(energy)} = Q_E \cdot P_E \tag{10}$$

where:

- Q_E is the amount of energy consumption (in kWh or m^3)
- P_E is the energy price (in €/kWh or €/ m^3)

The conversion of the environmental impacts, evaluated as mass of equivalent carbon dioxide, in monetary unit can be addressed by means of the information given by the European Union Emission Trading System (EU ETS) [22]. The prices of equivalent carbon dioxide are estimated according to a procedure developed by EU ETS: each Member State agrees on the maximum national emission limit, approved by the European Commission; then the MS allocate allowance values to their industrial operators, who are able to buy or sell such allowances, named European Emission Allowances (EUA) [23] The price is finally set according to the number of permits issued. Therefore, the environmental impact costs referred to carbon footprint are evaluated with the following expression:

$$R_{E(CO_2)} = Q_{CO_2} \cdot P_{CO_2} \tag{11}$$

where:

- Q_{CO_2} is the amount of equivalent CO_2 (in kg or tonne)
- P_{CO_2} is the carbon dioxide price (in €/$kgCO_{2,eq}$ or €/$tonneCO_{2,eq}$)

The global assessment parameter, R_{SSD}, can be evaluated with the following expression:

$$R_{SSD} = R_{E(CO_2)} + R_{E(energy)} + C_{tot} \tag{12}$$

where:

- C_{tot} is the structural cost given by the sum of building initial costs and building losses

Focus on the SSD Methodology at building level

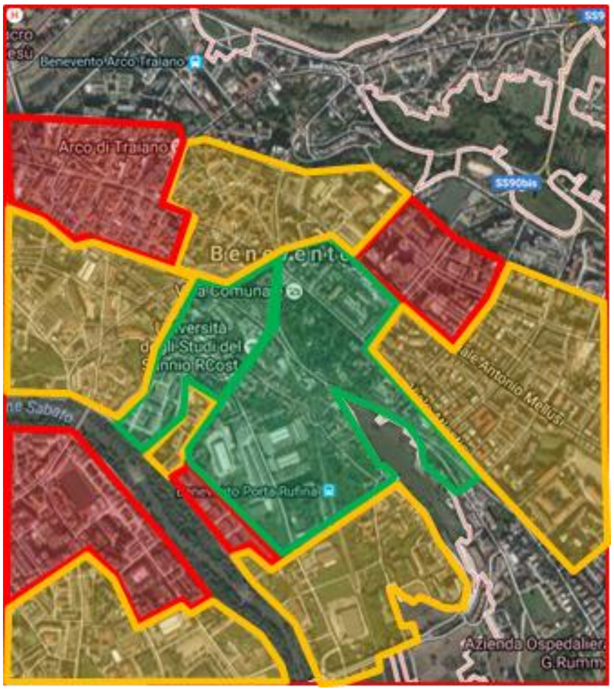
The Sustainable Structural Design (SSD) is a methodology is a methodology that aims to support the overall building design process. The SSD Methodology is based on three main pillars, each of them corresponding to a procedure evaluation step: the *Energy* Performance Assessment; the *Life-Cycle* Assessment and the *Structural* Performance Assessment. The fourth step represents the conversion of the three identified pillars in economic terms, to address the Global Assessment Parameter of the SSD methodology. In the energy performance step, the energy consumed during the operational phase of the building is evaluated; in the Life-Cycle Assessment step, the CO_2 emissions generated during all the lifespan of the buildings are evaluated. In the structural performance assessment step, the initial costs and the expected economic losses caused by expected earthquakes are evaluated. Expected economic losses are calculated by means of the simplified Performance-Based Assessment methodology (sPBA). The fourth and last step aims at the conversion of the three parameters into a final one, called Global Assessment Parameter, R_{SSD}, expressed in economic terms. The conversion affects only the energy performance parameter and the Life-Cycle Assessment parameter, because the structural performance parameter is already provided in economic terms.

2 SSD Methodology at National/Regional/Urban Level

The Sustainable Structural Design methodology is a viable practical procedure providing each building with a parameter which summarizes the environmental and safety performances of the building itself. It is a useful procedure in the design phase, in order to establish the most efficient design solution for the building, but it is also very useful for existing buildings because it can provide a picture of the global performance condition of them.

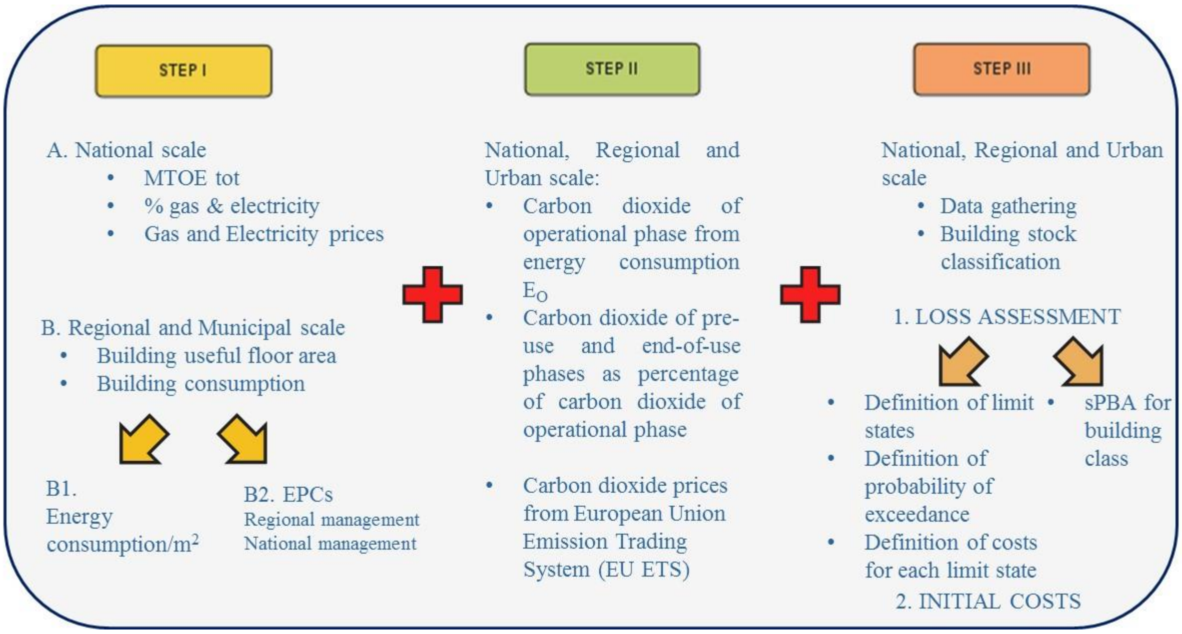
An important development of the SSD methodology is the application of it at territorial level. If the methodology was applied to small areas, like districts, cities or regions, or to big areas, like nations, it could be a sound method for supporting the administrations in addressing the policy projects on the territory. Indeed, if the building stock is classified into groups of buildings having similar structural and non-structural characteristics and the global assessment parameter is evaluated for each building group, the territory can be divided into areas having same R_{SSD} range. According to this classification, areas with highest values of R_{SSD} will result as the ones where a structural and energy intervention is more necessary. Figure 8 shows the results of the application of the SSD methodology at urban level: red areas represent the groups of buildings having the highest values of R_{SSD}, which need an urgent structural and energy intervention; yellow areas represent the groups of buildings with moderate necessity of structural and energy intervention; green areas represent the groups of buildings with low necessity of structural and energy intervention.

Figure 8. Example of the application of the SSD methodology at territorial level – red areas show groups of buildings with high values of RSSD, which would need an urgent structural and energy intervention; yellow areas represent groups of buildings with moderate necessity of intervention; green areas represent group of buildings with low necessity of intervention.



In order to reach the described aims, the development of the SSD methodology at territorial level has to be described. Figure 9 shows the steps for developing the SSD methodology at national/regional/urban level.

Figure 9. Framework of the development of the SSD methodology at national/regional/urban level



As shown in Figure 9, the SSD methodology at territorial level is based on the same steps of the SSD methodology at building level.

Step I represents the energy performance assessment step. The energy performance parameter can be obtained following two different procedures:

— **Procedure A**, for evaluations at national level

— **Procedure B**, for evaluation at regional and urban levels

Procedure B can be divided into two sub-procedures: **B1**, where the energy consumption is provided by the European energy databases; **B2**, where the energy consumption is provided by the Energy Performance Certificates.

Step II represents the life-cycle assessment (LCA) step. The LCA performance parameter is evaluated by using the same procedure for national, regional and urban levels.

Step III represents the structural assessment step. The structural assessment parameter is evaluated by using the same procedure for national, regional and urban levels. The third step consists in an initial phase of building data gathering and stock classification, followed by the loss assessment and the initial costs evaluation.

In the SSD methodology at territorial level, the **Step IV** is included in the three previous steps; indeed, each step ends with the evaluation of the parameters in economic terms.

Each step of the methodology is developed and described hereafter.

2.1 Step I - Energy performance

As described at the previous paragraph, energy performance assessment is achieved using two different procedures: procedure A, if energy consumptions are evaluated at national level, and procedure B, if energy consumptions are evaluated at regional or urban level.

2.1.1 Step I.A - Energy performance at national level

In order to provide information on energy consumptions of buildings at national scale, the support of the well-known European databases is required. Several European databases for building energy consumptions are available online. The present report refers to the following databases: Eurostat, IEA (International Energy Agency), BPIE (Buildings Performance Institute Europe), ODYSSEE. Moreover, to estimate the correct information on the building stock floor area, also IVL (Swedish Environmental Research Institute) database has been analysed. In order to provide correct information about the energy consumption, a comparison among the data provided by the mentioned databases is necessary.

2.1.1.1 ***Databases used for the energy and floor area comparisons***

2.1.1.1.1 Eurostat

Eurostat is a Directorate-General of the European Commission. Eurostat's mission is to provide statistical information to the institutions of the European Union, promoting the homogeneity of statistical methods across Member States.

Among the others, Eurostat provides data on supply, transformation and consumption of energy, energy prices and other indicators for the European countries from 1990 to 2014. Eurostat data on energy consumptions are yearly updated [24][25].

Data gathering is achieved with the collaboration of International Energy Agency (IEA) and United Nation Economic Commission for Europe (UNECE). Indeed, the annual energy data collection is based on the five joint questionnaires among: Eurostat/European Commission - International Energy Agency/OECD – UNECE/United Nations. They cover the five major energy sources (Solid fuels, Oil, Natural gas, Electricity and Heat, Renewables and Wastes). The questionnaires are received regularly from all EU Member States and are sent back to Eurostat by the competent National Statistical Authorities (NSI, Ministries, and Energy Agencies) [26]. Data are then subjected to validation checks. If there are any doubts as regards data quality, Eurostat contacts the Member State to provide necessary justifications or corrections [25].

2.1.1.1.2 IEA

The International Energy Agency (IEA) is an autonomous organisation, linked to the Organisation for Economic Co-operation and Development (OECD), which works to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA has four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide.

Basing on the data achieved from the Eurostat/IEA/UNECE questionnaires, IEA yearly develops datasheets, available at [27], providing free aggregate data and monthly energy statistics on the energy balance of 34 OECD countries and 6 other regions (Africa, non-OECD Americas, Asia, Non-OECD Europe and Eurasia, Middle East) for energy production and flows, separately. IEA also provides data on electricity generation and CO_2 emissions, for production and flows, separately. Data cover the time period 1971-2014, and are constantly updated.

2.1.1.1.3 BPIE

The Buildings Performance Institute Europe (BPIE) is a European not-for-profit organisation, delivering policy analysis, advice and implementation support, and focusing on the field of energy performance of buildings [28]. BPIE is the European partner of Global Building Performance Network (GBPN), a global organisation whose mission is to provide policy expertise and technical assistance to advance building energy performance and realise sustainable built environments [29].

In 2011, BPIE organised a survey for collecting existing data related to buildings and building policies of EU27 (i.e. EU before Croatia accession), Norway and Switzerland countries [9]. National data were provided by national institutes, research institutes and individual experts listed in [28] and [9]. Data have been gathered on the floor area of the building stock. For some countries, data in terms of the age, size, ownership (private/public), tenure (owner occupied, private or social tenant) location (rural/urban) and typical energy performance levels of the building stock have been also gathered [9]. The results of the 2011 BPIE survey can be consulted on the Data Search Tool by selecting a combination of countries, topics, building types and owner profiles.

2.1.1.1.4 ODYSSEE

The ODYSSEE-MURE Project is co-ordinated by ADEME [30], a French industrial and commercial institution, under the authority of the Ministers for research, ecology and energy, aiming at supporting and coordinating the transactions relating to the protection of the environment and energy management. ODYSSEE-MURE Project gathers representatives from the current 28 EU Member States plus Norway. It aims at monitoring energy efficiency trends and measures in Europe, using on two complementary internet databases: ODYSSEE, and MURE. ODYSSEE database is managed by Enerdata, an independent Research & Consulting firm on the global oil, gas, coal, power, renewable and carbon markets; it contains detailed energy efficiency and CO_2 indicators with data on industry, transport and households energy consumption, their drivers (activity indicators) and their related CO_2 emissions. MURE is managed by ISINNOVA, an independent Italian research institute supporting international, national and local public bodies for the analysis, the design, the implementation and the evaluation of sustainable policies in the fields of energy, environment, transport and mobility, urban planning, and knowledge society; MURE contains a description, with their impact evaluation whenever available, of all energy efficiency measures implemented at EU or national level [31]. Both the databases are updated once or twice a year. The partners of the projects include national Efficiency Agencies or their representatives within the European network of energy efficiency agencies [31].

ODYSSEE database provides, among others, data on energy consumption, stock of dwellings and floor area of dwellings for European and non-European countries and from 1990 to 2014. The mentioned data can be consulted by means of the tool available online [32].

ODYSSEE data sources include government ministries, statistical institutions, industry and transport associations and research institutions. The energy consumption for household heating is estimated by specialised organisation on the basis of surveys and modelling and endorsed by national energy agencies or institutions [33].

2.1.1.1.5 IVL

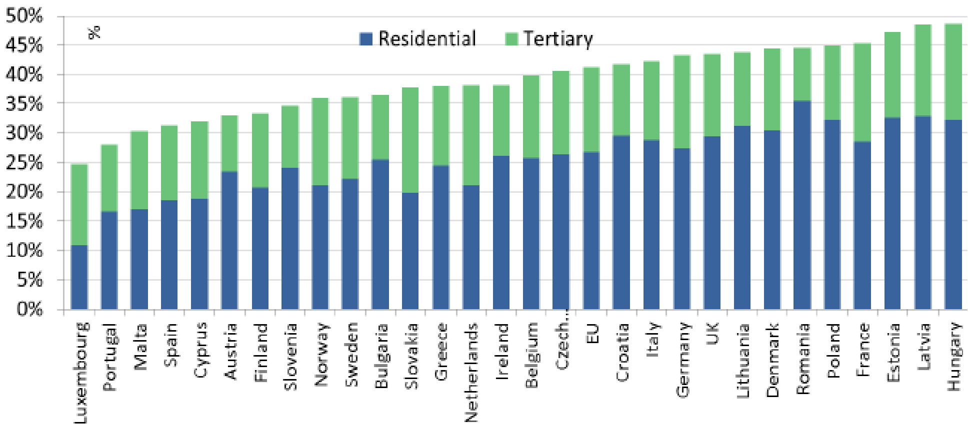
Other detailed data sets for the residential and commercial sectors for the EU27 countries, as well as Norway, Switzerland and Turkey, have been produced by the IVL, Swedish Environmental Research Institute, an institute which combines applied research and development with close collaboration between industry and the public sphere [34]. Precisely, the International Institute for Applied System Analysis (IIASA), an international scientific institute that conducts research into the critical issues of global environmental, economic, technological, and social change [35], has invited IVL to provide data to the GAINS Model, a model developed by IIASA to assess cost-effective response strategies for combating air pollution, such as fine particles and ground-level ozone. IVL has provided the following building stock statistics for 2005: total number of dwellings for each country from a variety of National statistic’s sources and from Werner [36]; average floor space for each country, calculated with the data from NBHBP [37] and adjusted to 2005 level [38].

There are also other EU-funded projects, as ENTRA NZE [39], which provide further information using data obtained from the abovementioned databases.

2.1.1.2 *Database comparison on national energy consumption*

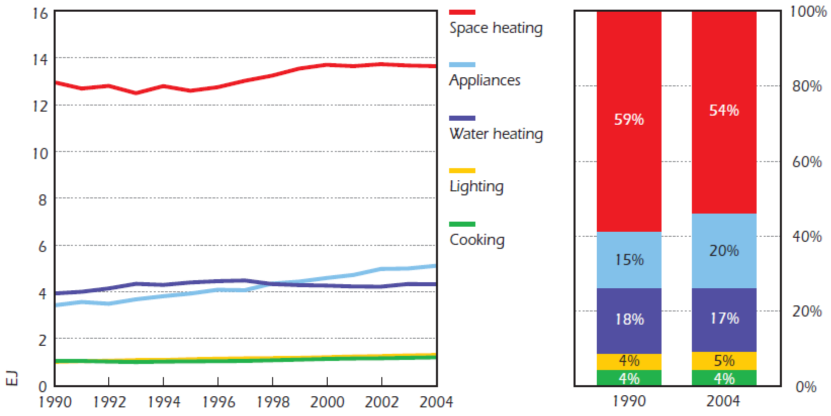
The comparison about the above-mentioned databases has been carried out by considering the energy consumption of household space heating, without considering data adjustments related to climatic variations (which are addressed to avoid the influence of cold winters on the final data). Indeed, according to ODYSSEE, at the EU level, around two thirds of the consumption of buildings is for residential buildings [40] (Figure 10). Moreover, according to Eurostat classification [41], energy-using activities in households can be summarized in: space heating, space cooling, water heating, lighting & appliances and other end-uses. Energy consumption related to household space heating covers more than the 50% of the total energy amount, as reported by IEA [42] (Figure 11).

Figure 10. Share of building in final energy consumption



Source: ODYSSEE, 2012

Figure 11. Household Energy Use



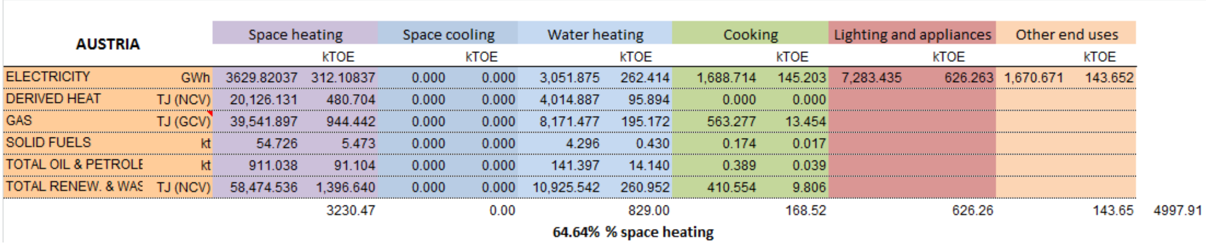
Source: IEA15

In order to evaluate the correct percentage of space heating on the total energy consumption, Eurostat data about household energy consumption divided by end-uses, which is available on [41] for 12 out of 28 EU Member States (Austria, Bulgaria, France, Greece, Latvia, Luxembourg, Netherlands, Portugal, Romania, Slovenia, Spain and United Kingdom), have been analysed. Firstly, the 12 Member States (MS) have been divided into three geographical areas: North, Central, South, according to MS classification presented in Table 1. Then, the percentage of space heating on the total energy consumption has been evaluated (in Figure 12, values for Austria are shown).

Table 1. Member State classification according to geographical location

Geo-Area	EU-28 Member States
NORTH	Belgium, Czech Republic, Denmark, Estonia, Finland, Germany, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Sweden, United Kingdom.
CENTRAL	Austria, Bulgaria, Croatia, France, Hungary, Romania, Slovakia, Slovenia.
SOUTH	Cyprus, Greece, Italy, Malta, Portugal, Spain

Figure 12. Evaluation of space-heating rate for Austria



AUSTRIA		Space heating		Space cooling		Water heating		Cooking		Lighting and appliances		Other end uses		
			kTOE		kTOE		kTOE		kTOE		kTOE		kTOE	
ELECTRICITY	GWh	3629.82037	312.10837	0.000	0.000	3,051.875	262.414	1,688.714	145.203	7,283.435	626.263	1,670.671	143.652	
DERIVED HEAT	TJ (NCV)	20,126.131	480.704	0.000	0.000	4,014.887	95.894	0.000	0.000					
GAS	TJ (GCV)	39,541.897	944.442	0.000	0.000	8,171.477	195.172	563.277	13.454					
SOLID FUELS	kt	54.726	5.473	0.000	0.000	4.296	0.430	0.174	0.017					
TOTAL OIL & PETROLE	kt	911.038	91.104	0.000	0.000	141.397	14.140	0.389	0.039					
TOTAL RENEW. & WAS	TJ (NCV)	58,474.536	1,396.640	0.000	0.000	10,925.542	260.952	410.554	9.806					
			3230.47		0.00		829.00		168.52		626.26		143.65	4997.91
						64.64%	**% space heating**							

Results for the 12 EU Member States are reported in **Table 2**. It can be observed that the space-heating rate is similar for the MS belonging to the same Geo-Area. According to this, an average value of space-heating rate for each Geo-Area has been defined, as shown in Table 3.

Table 2. Space-heating rate for 12 EU Member States, according to Eurostat data sources [41]

	Space-Heating rate	Geo-Area
Austria	64.64%	CENTRAL
Bulgaria	48.08%	CENTRAL
France	63.17%	CENTRAL
Greece	32.55%	SOUTH
Latvia	67.43%	NORTH
Luxembourg	70.65%	NORTH
Netherlands	66.49%	NORTH
Portugal	21.81%	SOUTH
Romania	66.53%	CENTRAL
Slovenia	65.95%	CENTRAL
Spain	36.56%	SOUTH
UK	60.30%	NORTH

Table 3. Space-heating rate for each European Geo-Area

Geo-Area	EU-28 Member States	Space-Heating Rate
NORTH	Belgium, Czech Republic, Denmark, Estonia, Finland, Germany, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Sweden, United Kingdom.	**65%**
CENTRAL	Austria, Bulgaria, Croatia, France, Hungary, Romania, Slovakia, Slovenia.	**60%**
SOUTH	Cyprus, Greece, Italy, Malta, Portugal, Spain	**30%**

In the present study, comparisons about household energy consumptions have been performed by considering the following databases:

- **Eurostat**, providing values for the energy spent in households for all the purposes, in kTOE;
- **ODYSSEE**, providing values for the energy spent in households for: all the end-uses and for single end-use separately (space heating, water heating, cooking, air conditioning, electrical appliances/lighting, captive electricity) in MTOE. Moreover, data about energy for space heating in kTOE/m^2 were available before September 2016 update. Residential building floor area refers to living area, also called "useful floor area". It is evaluated dividing total energy consumption for energy consumption related to 1 building's square meter, and in this case the database will be called "ODYSSEE 1", or multiplying the average building floor area by the number of permanently occupied dwellings, and the database will be called "ODYSSEE 2":

$$Useful\ floor\ area_{ODYSSEE\ 1} = \frac{(kWh_{TOT})_{space\ heating}}{\left(kWh_{TOT}/m^2\right)_{space\ heating}} \tag{13}$$

$$Useful\ floor\ area_{ODYSSEE\ 2} = Average\ dwelling\ floor\ area\ x\ N_{dwellings} \tag{14}$$

- **BPIE**, providing gross floor area and useful floor area for each Member State (for some MS, floor area is also related to residential building type) obtained from a survey, in 2011, and providing energy consumption in MWh for all the end uses and in kWh/m^2 for heating. (BPIE also provides data for cooling, lighting and end-use energy consumptions);
- **IEA**, providing values for household energy consumptions in kTOE.

Analysing the total energy consumption for households, the components reported in Table 4 are included for the considered databases.

Table 4. Total energy consumption components considered by each database

Database	Energy components
Eurostat	Electricity, Renewable energies, Gas, Heat, Solid Fuels, Total petroleum products
ODYSSEE	Coal, Oil, Gas, Heat, Wood and Electricity
IEA	Coal, Peat & Oil Shale, Crude, NGL & Feedstocks, Oil products, Natural Gas, Nuclear, Renewable & Waste, Electricity, Heat

BPIE uses Eurostat reference for energy composition. All the differences among the energy components of the analysed databases are reported in Appendix A.

Error! Reference source not found. summarizes the databases information described above. The table reports "N" if data regarding building stock (useful floor area), total energy consumption for all end-uses, for space heating and space heating/m^2 are not provided by the database, "Y" if they are provided, "C" is they are computable on the basis of on provided data, "S" if data are available for some Member States.

Table 5. Overall features of the analysed databases

	Countries	Years	Useful Floor Area	Total energy consumption for all end-uses	Total energy consumption for space heating	Total energy consumption for space heating/m^2	Data Source
Eurostat	European Countries (EU-28 + Iceland, Norway + EU Candidate Countries + Potential EU Candidate Countries + Moldova and Ukraine)	1990-2014	N	Y	S	N	Member States Questionnaires
IEA	OECD Africa, non-OECD Americas, Asia, Non-OECD Europe and Eurasia, Middle East	1971-2014	N	Y	N	N	Member States Questionnaires
ODYSSEE	EU-28	1990-2014	C	Y	Y	Y (Before September 2016)	Member States information
BPIE	EU-28 + Switzerland and Norway	2011	Y	Y	C	Y	Member States information
IVL	EU-27 + Norway, Switzerland and Turkey	2005	Y	N	N	N	Member States information, + [36][37]

As reported at page 21, in the present study evaluations on household space heating are addressed. Compared to other energy end-uses, space heating can better address the envelope performance of buildings, since heating is a consequence of construction and building design, more than of users' energetic needs and behaviour.

In order to provide data on space heating, a first comparison on household total energy consumption for all end-users among the abovementioned databases is needed. This value is then converted in space heating by means of the space-heating rate, according to Table 3.

Eurostat, ODYSSEE and IEA data are available for different years, but the most complete information are referred to 2011. On the other hand, BPIE data are collected heterogeneously for each country. Since BPIE survey was published in 2011, comparisons among the databases are achieved referring to 2011 and shown in Table 6.

Table 6. Comparisons among household total energy consumption for all end-uses data provided by the by the analysed databases

REFERENCE YEAR 2011 [MTOE]					
	ISO code	**Eurostat**	**IEA**	**ODYSSEE**	**BPIE**
European Union	EU28	281.12		281.11	
Austria	AT	5.86	6.29	6.36	6.63
Belgium	BE	7.94	7.61	7.71	7.43
Bulgaria	BG	2.38		2.39	2.38
Croatia	HR	2.63		2.63	
Cyprus	CY	0.35		0.33	0.35
Czech Rep.	CZ	5.98	5.99	5.98	6.02
Denmark	DK	4.40	4.40	4.51	4.40
Estonia	EE	0.94	0.94	0.94	0.97
Finland	FI	5.08	5.07	5.13	5.42
France	FR	37.62	37.94	37.77	42.08
Germany	DE	54.56	54.49	55.73	57.51
Greece	GR	5.49	5.47	5.47	4.83
Hungary	HU	5.47	5.48	5.49	5.14
Ireland	IE	2.77	2.74	2.84	2.72
Italy	IT	32.38	31.32	28.39	31.33
Latvia	LV	1.33		1.33	1.38
Lithuania	LT	1.54		1.52	1.53
Luxembourg	LU	0.46	0.46	0.48	0.43
Malta	MT	0.07		0.07	0.08
Netherlands	NL	10.25	9.75	9.65	10.29
Poland	PL	20.08	20.08	20.08	19.60
Portugal	PT	2.78	2.78	2.79	2.71
Romania	RO	7.86		8.26	8.06
Slovakia	SK	2.12	2.12	2.12	2.07
Slovenia	SI	1.26	1.21	1.21	1.19
Spain	ES	15.63	15.62	15.63	15.51
Sweden	SE	7.47	6.96	7.27	7.40
United Kingdom	GB	36.43	35.81	36.57	39.69
Norway	NO	3.95	3.95	3.89	4.03

Figure 13 shows the differences among the databases. It can be observed that the maximum difference between the databases is 13%. Error analysis has been addressed in order to establish the weighted error on the EU28+Norway population, considering Eurostat as benchmark. For weighted error estimations, data about European population have been obtained by Eurostat "demo_pjan" data [43].

Figure 13. Comparisons among the analysed databases (Benchmark: Eurostat)

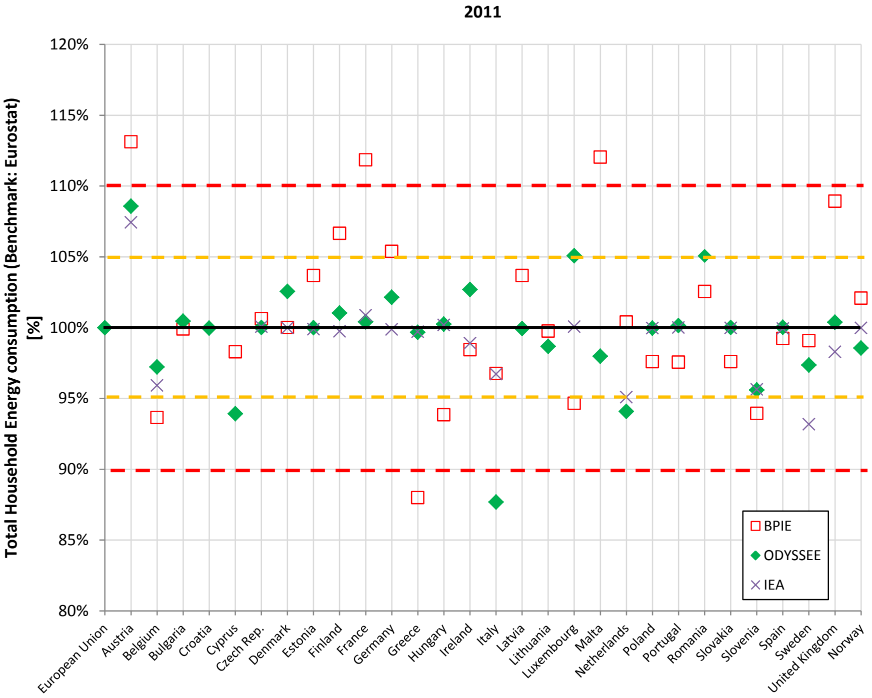


Table 7 shows the weighted errors, referred to the EU-28+Norway population, evaluated as the sum, for all the MS, of the product of the error and the population:

$$\text{WEIGHTED ERROR} = \sum_{i=1}^{N} error_i \cdot population_i \tag{15}$$

where:

- *i* is the i-th Member State
- N is the number of MS+Norway

It can be observed that IEA has the lowest error (1.36%); this is reasonable because IEA and Eurostat use the same data source. On the other hand, BPIE provides the highest error (5.28%). BPIE data for Austria, France, Greece and Malta are higher than 10%, if compared with Eurostat data; moreover, for 11 MS out of 29 analysed, data are higher than 5%. Considering ODYSSEE database, only Italy data are higher than 10% the Eurostat data, while in 6 MS out of 29, error is higher than 5%. Finally, IEA data are higher than 5% the Eurostat data only for Austria and Sweden; no countries have total energy consumption for all end-uses higher than 10%, if compared to Eurostat data.

Table 7. Weighted error referred to EU28+Norway population, Eurostat benchmark.

	POPULATION	ODYSSEE	BPIE	IEA
European Union EU-28	502,964,837	9,840		
Austria	8,375,164	717,806	1,098,989	622,341
Belgium	11,000,638	306,232	699,069	448,339
Bulgaria	7,369,431	33,749	6,874	
Croatia	4,289,857	1,305		
Cyprus	839,751	51,111	14,420	
Czech Rep.	10,486,731	175	65,552	7,686
Denmark	5,560,628	141,825	834	1,537
Estonia	1,329,660	0	49,048	1,476
Finland	5,375,276	55,427	357,759	14,067
France	64,978,721	263,248	7,700,364	563,266
Germany	80,222,065	1,719,446	4,327,517	105,218
Greece	11,123,392	36,283	1,335,813	31,384
Hungary	9,985,722	24,627	614,704	18,578
Ireland	4,570,881	122,934	71,131	50,435
Italy	59,364,690	7,312,663	1,921,034	1,946,488
Latvia	2,074,605	1,250	76,356	
Lithuania	3,052,588	40,275	7,584	
Luxembourg	511,840	25,974	27,348	370
Malta	414,989	8,396	49,951	
Netherlands	16,655,799	985,688	65,851	817,330
Poland	38,062,718	12,698	914,816	16,295
Portugal	10,572,721	14,825	257,253	91
Romania	20,199,059	1,023,882	516,571	
Slovakia	5,392,446	763	129,478	1,373
Slovenia	2,050,189	90,409	124,036	89,495
Spain	46,667,174	12,543	357,756	33,805
Sweden	9,415,570	248,455	87,010	642,929
United Kingdom	63,022,532	238,365	5,624,482	1,077,126
Norway	4,920,305	71,105	102,635	763
TOT EU28+Norway	507,885,142			
WEIGHTED ERROR		**2.67%**	**5.28%**	**1.36%**

Once the data referred to all end-uses have been assessed, the space heating energy consumption has been evaluated for all the EU28+Norway countries by using the space-heating rate. Table 8 summarizes the values of total space heating energy consumption for households, considering the four energy databases.

Table 8. Household final energy consumption for space heating – Comparisons among the databases

MTOE	ISO code	Geo Area	Space-Heating rate	Eurostat	IEA	ODYSSEE	BPIE
Austria	AT	CENTRAL	0.6	**3.51**	**3.78**	**3.82**	**3.98**
Belgium	BE	NORTH	0.65	**5.16**	**4.95**	**5.01**	**4.83**
Bulgaria	BG	CENTRAL	0.6	**1.43**		**1.43**	**1.43**
Croatia	HR	CENTRAL	0.6	**1.58**		**1.58**	
Cyprus	CY	SOUTH	0.3	**0.11**		**0.10**	**0.10**
Czech Rep.	CZ	NORTH	0.65	**3.89**	**3.89**	**3.89**	**3.91**
Denmark	DK	NORTH	0.65	**2.86**	**2.86**	**2.93**	**2.86**
Estonia	EE	NORTH	0.65	**0.61**	**0.61**	**0.61**	**0.63**
Finland	FI	NORTH	0.65	**3.30**	**3.29**	**3.34**	**3.52**
France	FR	CENTRAL	0.6	**22.57**	**22.77**	**22.66**	**25.25**
Germany	DE	NORTH	0.65	**35.47**	**35.42**	**36.23**	**37.38**
Greece	GR	SOUTH	0.3	**1.65**	**1.64**	**1.64**	**1.45**
Hungary	HU	CENTRAL	0.6	**3.28**	**3.29**	**3.29**	**3.08**
Ireland	IE	NORTH	0.65	**1.80**	**1.78**	**1.85**	**1.77**
Italy	IT	SOUTH	0.3	**9.71**	**9.39**	**8.52**	**9.40**
Latvia	LV	NORTH	0.65	**0.86**		**0.86**	**0.89**
Lithuania	LT	NORTH	0.65	**1.00**		**0.99**	**1.00**
Luxembourg	LU	NORTH	0.65	**0.30**	**0.30**	**0.31**	**0.28**
Malta	MT	SOUTH	0.3	**0.02**		**0.02**	**0.02**
Netherlands	NL	NORTH	0.65	**6.66**	**6.34**	**6.27**	**6.69**
Poland	PL	NORTH	0.65	**13.05**	**13.05**	**13.05**	**12.74**
Portugal	PT	SOUTH	0.3	**0.83**	**0.83**	**0.84**	**0.81**
Romania	RO	CENTRAL	0.6	**4.72**		**4.95**	**4.84**
Slovakia	SK	CENTRAL	0.6	**1.27**	**1.27**	**1.27**	**1.24**
Slovenia	SI	CENTRAL	0.6	**0.76**	**0.72**	**0.72**	**0.71**
Spain	ES	SOUTH	0.3	**4.69**	**4.68**	**4.69**	**4.65**
Sweden	SE	NORTH	0.65	**4.85**	**4.52**	**4.72**	**4.81**
United Kingdom	GB	NORTH	0.65	**23.68**	**23.28**	**23.77**	**25.80**
Norway	NO	NORTH	0.65	**2.57**	**2.57**	**2.53**	**2.62**

2.1.1.3 *Energy costs assessment*

Once the building energy consumptions are evaluated, the consumptions have to be converted into costs.

Energy cost depends on the energy typology; therefore, a classification of energy consumption is necessary. According to Eurostat, energy can be classified into: solid fuels, petroleum products, gas, electricity, derived heat, renewable energies. Eurostat provides only electricity and gas prices for each MS. As reported in Table 9, electricity and gas consumptions represent 61% of the total consumed energy in EU. Nevertheless, this value varies among 19%, for MS using alternative energies (as Latvia and Iceland), on the opposite side, the Netherlands have 93% of energy and gas consumption.

Table 9. Electricity + natural gas consumption percentage on total consumption.

MS	2011
European Union (28 countries)	60.92%
Euro area (19 countries)	61.28%
Belgium	60.10%
Bulgaria	41.77%
Czech Republic	53.87%
Denmark	34.52%
Germany (until 1990 former territory of the FRG)	57.74%
Estonia	23.28%
Ireland	46.28%
Greece	33.96%
Spain	63.71%
France	62.09%
Croatia	42.11%
Italy	74.19%
Cyprus	42.15%
Latvia	19.53%
Lithuania	24.04%
Luxembourg	63.50%
Hungary	71.96%
Malta	74.24%
Netherlands	92.94%
Austria	43.99%
Poland	28.22%
Portugal	51.79%
Romania	42.34%
Slovenia	30.82%
Slovakia	73.54%
Finland	36.86%
Sweden	49.76%
United Kingdom	88.67%
Iceland	19.94%
Norway	78.55%
Montenegro	38.24%
Former Yugoslav Republic of Macedonia, the	52.98%
Albania	46.80%
Serbia	46.82%
Turkey	46.89%
Bosnia and Herzegovina	52.57%

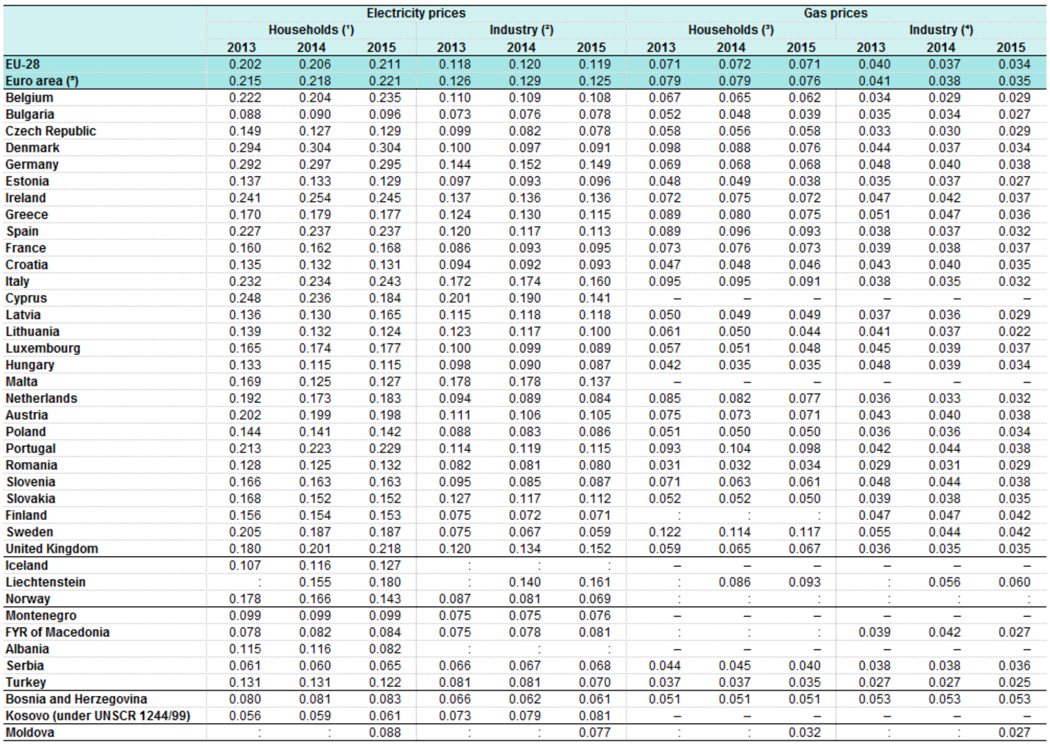
Kosovo (under United Nations Security Council Resolution 1244/99)	43.88%
Moldova	48.51%
Ukraine	73.59%

Source: Eurostat

In conclusion, for residential buildings, a selection criterion could be to choose the average energy consumption value between the two more similar data provided by Table 8 and to evaluate the respective gas and electricity amounts.

Energy costs for gas and electricity are provided by Eurostat [21] and are shown in Figure 14. As reported in [21], “prices presented in this article generally include taxes, levies and value added tax (VAT) for household consumers but exclude (deductible) VAT for industrial/business users”.

Figure 14. Electricity and Gas prices



	Electricity prices						Gas prices					
	Households (1)			Industry (2)			Households (3)			Industry (4)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
EU-28	0.202	0.206	0.211	0.118	0.120	0.119	0.071	0.072	0.071	0.040	0.037	0.034
Euro area (5)	0.215	0.218	0.221	0.126	0.129	0.125	0.079	0.079	0.076	0.041	0.038	0.035
Belgium	0.222	0.204	0.235	0.110	0.109	0.108	0.067	0.065	0.062	0.034	0.029	0.029
Bulgaria	0.088	0.090	0.096	0.073	0.076	0.078	0.052	0.048	0.039	0.035	0.034	0.027
Czech Republic	0.149	0.127	0.129	0.099	0.082	0.078	0.058	0.056	0.058	0.033	0.030	0.029
Denmark	0.294	0.304	0.304	0.100	0.097	0.091	0.098	0.088	0.076	0.044	0.037	0.034
Germany	0.292	0.297	0.295	0.144	0.152	0.149	0.069	0.068	0.068	0.048	0.040	0.038
Estonia	0.137	0.133	0.129	0.097	0.093	0.096	0.048	0.049	0.038	0.035	0.037	0.027
Ireland	0.241	0.254	0.245	0.137	0.136	0.136	0.072	0.075	0.072	0.047	0.042	0.037
Greece	0.170	0.179	0.177	0.124	0.130	0.115	0.089	0.080	0.075	0.051	0.047	0.036
Spain	0.227	0.237	0.237	0.120	0.117	0.113	0.089	0.096	0.093	0.038	0.037	0.032
France	0.160	0.162	0.168	0.086	0.093	0.095	0.073	0.076	0.073	0.039	0.038	0.037
Croatia	0.135	0.132	0.131	0.094	0.092	0.093	0.047	0.048	0.046	0.043	0.040	0.035
Italy	0.232	0.234	0.243	0.172	0.174	0.160	0.095	0.095	0.091	0.038	0.035	0.032
Cyprus	0.248	0.236	0.184	0.201	0.190	0.141	–	–	–	–	–	–
Latvia	0.136	0.130	0.165	0.115	0.118	0.118	0.050	0.049	0.049	0.037	0.036	0.029
Lithuania	0.139	0.132	0.124	0.123	0.117	0.100	0.061	0.050	0.044	0.041	0.037	0.022
Luxembourg	0.165	0.174	0.177	0.100	0.099	0.089	0.057	0.051	0.048	0.045	0.039	0.037
Hungary	0.133	0.115	0.115	0.098	0.090	0.087	0.042	0.035	0.035	0.048	0.039	0.034
Malta	0.169	0.125	0.127	0.178	0.178	0.137	–	–	–	–	–	–
Netherlands	0.192	0.173	0.183	0.094	0.089	0.084	0.085	0.082	0.077	0.036	0.033	0.032
Austria	0.202	0.199	0.198	0.111	0.106	0.105	0.075	0.073	0.071	0.043	0.040	0.038
Poland	0.144	0.141	0.142	0.088	0.083	0.086	0.051	0.050	0.050	0.036	0.036	0.034
Portugal	0.213	0.223	0.229	0.114	0.119	0.115	0.093	0.104	0.098	0.042	0.044	0.038
Romania	0.128	0.125	0.132	0.082	0.081	0.080	0.031	0.032	0.034	0.029	0.031	0.029
Slovenia	0.166	0.163	0.163	0.095	0.085	0.087	0.071	0.063	0.061	0.048	0.044	0.038
Slovakia	0.168	0.152	0.152	0.127	0.117	0.112	0.052	0.052	0.050	0.039	0.038	0.035
Finland	0.156	0.154	0.153	0.075	0.072	0.071	:	:	:	0.047	0.047	0.042
Sweden	0.205	0.187	0.187	0.075	0.067	0.059	0.122	0.114	0.117	0.055	0.044	0.042
United Kingdom	0.180	0.201	0.218	0.120	0.134	0.152	0.059	0.065	0.067	0.036	0.035	0.035
Iceland	0.107	0.116	0.127	:	:	:	–	–	–	–	–	–
Liechtenstein	:	0.155	0.180	:	0.140	0.161	:	0.086	0.093	:	0.056	0.060
Norway	0.178	0.166	0.143	0.087	0.081	0.069	:	:	:	:	:	:
Montenegro	0.099	0.099	0.099	0.075	0.075	0.076	–	–	–	–	–	–
FYR of Macedonia	0.078	0.082	0.084	0.075	0.078	0.081	:	:	:	0.039	0.042	0.027
Albania	0.115	0.116	0.082	:	:	:	–	–	–	–	–	–
Serbia	0.061	0.060	0.065	0.066	0.067	0.068	0.044	0.045	0.040	0.038	0.038	0.036
Turkey	0.131	0.131	0.122	0.081	0.081	0.070	0.037	0.037	0.035	0.027	0.027	0.025
Bosnia and Herzegovina	0.080	0.081	0.083	0.066	0.062	0.061	0.051	0.051	0.051	0.053	0.053	0.053
Kosovo (under UNSCR 1244/99)	0.056	0.059	0.061	0.073	0.079	0.081	–	–	–	–	–	–
Moldova	:	:	0.088	:	:	0.077	:	:	0.032	:	:	0.027

(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(2) Annual consumption: 500 MWh < consumption < 2 000 MWh; excluding VAT
(3) Annual consumption: 20 GJ < consumption < 200 GJ.
(4) Annual consumption: 10 000 GJ < consumption < 100 000 GJ; excluding VAT.
(5) 2013: EA-17. 2014: EA-18. 2015: EA-19.

Source: Eurostat [21]

2.1.1.4 ***Energy performance parameter at national level***

Finally, the energy performance parameter, corresponding to the households’ space heating, using national data, can be evaluated as:

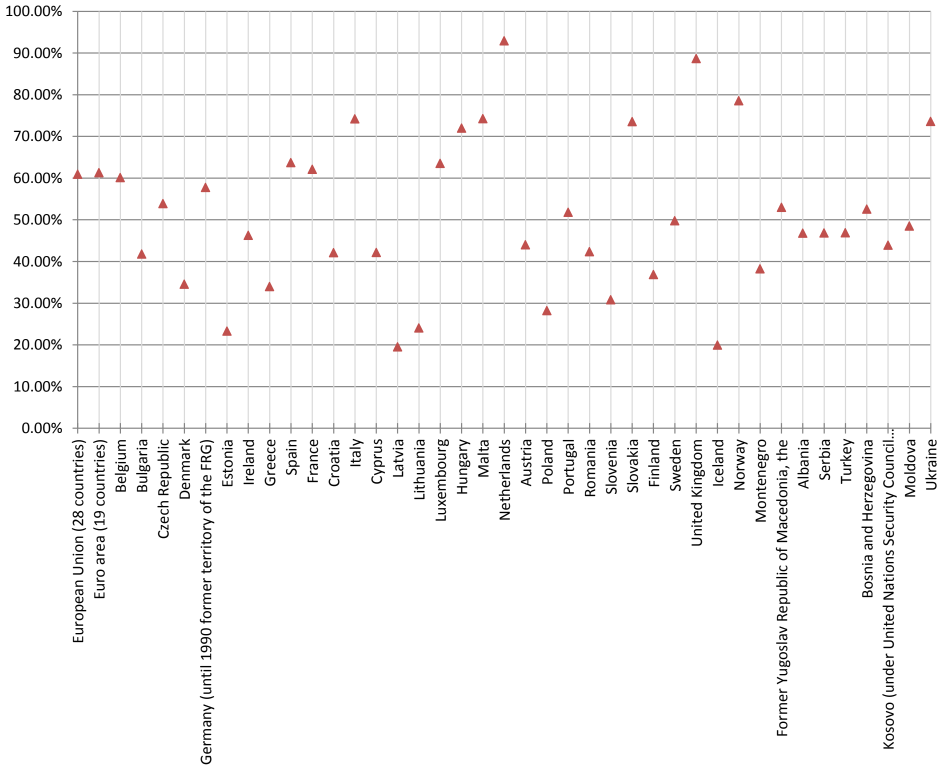
$$R_E^{Energy} = \left[\sum_{i=1}^{N} \sum_{j=1}^{M} \left(\%_i \cdot \frac{kWh_{TOT,i}}{year} \cdot \left(\frac{€}{kWh} \right)_i \right)_j \right] * L_B \qquad (16)$$

where:

- i represents the i-th component of the energy (as electricity and natural gas);
- j represents the j-th building occupancy class (as households, offices, schools,…);
- N represents the number of energy component considered;
- M represents the number of building occupancy class considered;
- $\%_i$ represents the percentage of the i-th energy component on the total, for the considered MS;
- $\frac{kWh_{TOT,i}}{year}$ represents the annual total energy consumption of the i-th energy component;
- $\left(\frac{€}{kWh}\right)_i$ is the price of the i-th component;
- L_B is the life span of the building.

Considered the available energy prices data, R_E^{Energy} can be evaluated only for electricity and natural gas consumptions. The sum of these two components covers 60% of the total energy consumption in Europe. Nevertheless, this amount is equal to 20% for some Member States (Figure 15). For this reason, for some Member States, the evaluation of the energetic costs, including only electricity and gas, can be inaccurate.

Figure 15. Percentage of natural gas and electricity consumption on total energy consumption for each Member State



2.1.2 Step I.B - Energy performance at regional/urban level

Energy performance evaluation of buildings in smaller territorial areas, as regions or cities, strictly needs the quantification of the buildings' useful floor area referred to the considered territorial area. Two different data sources can be used for assessing the energy performance of buildings: national databases (Procedure I.B1) and energy performance certificates data (Procedure I.B2). The former needs the evaluation of national and regional/urban useful floor area values; the latter needs the evaluation of only regional/urban useful floor area value.

2.1.2.1 ***Step I.B1***

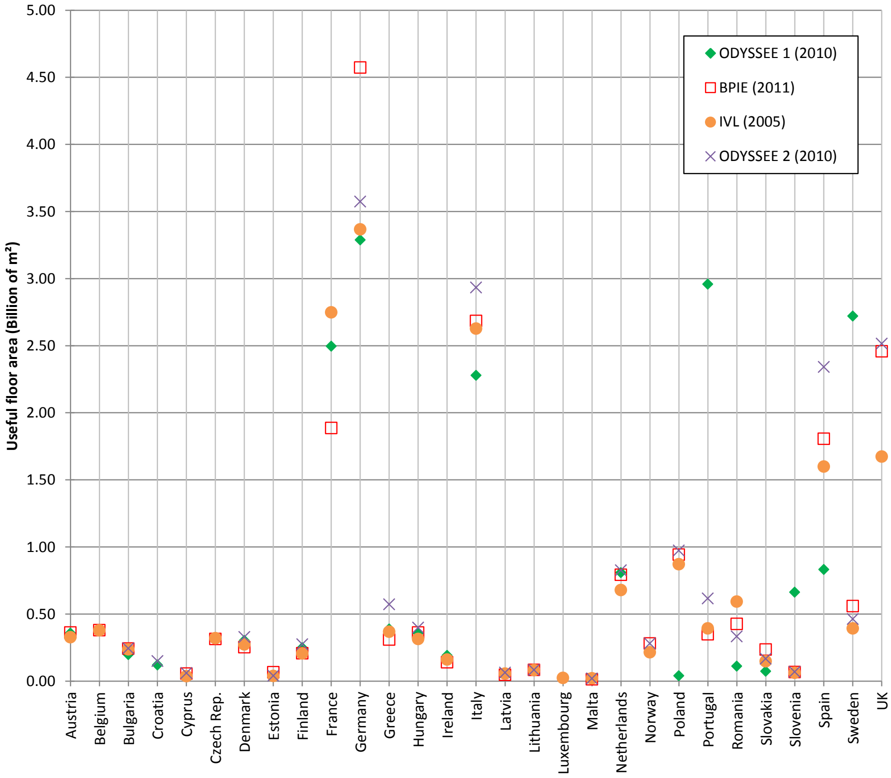
In order to use the same data source of the national energy performance assessment, an analysis on the useful floor area data at national level has been realised.

2.1.2.1.1 Building stock comparisons at national level

In the present paragraph, a comparison among the floor area data of the national building stock declared by the above-mentioned databases is performed.

Floor area can be reported in terms of gross floor area and useful floor area. Gross floor area is the total floor area of the building, including intermediately floored tiers, mezzanines, basements, etc., as measured from the exterior surfaces of the outside walls of the building [44]; useful floor area is the floor area of dwellings measured inside the outer walls, excluding cellars, non-habitable attics and, in multi-dwelling houses, common areas [45]. The building stock data here presented refer to *useful floor area*. Among the five databases listed at §2.1.1.1, only BPIE and IVL [38] declare the value of total useful floor area of buildings; nevertheless, according to energy consumption and building stock values declared by ODYSSEE, useful floor area can be evaluated (see §2.1.1.2).

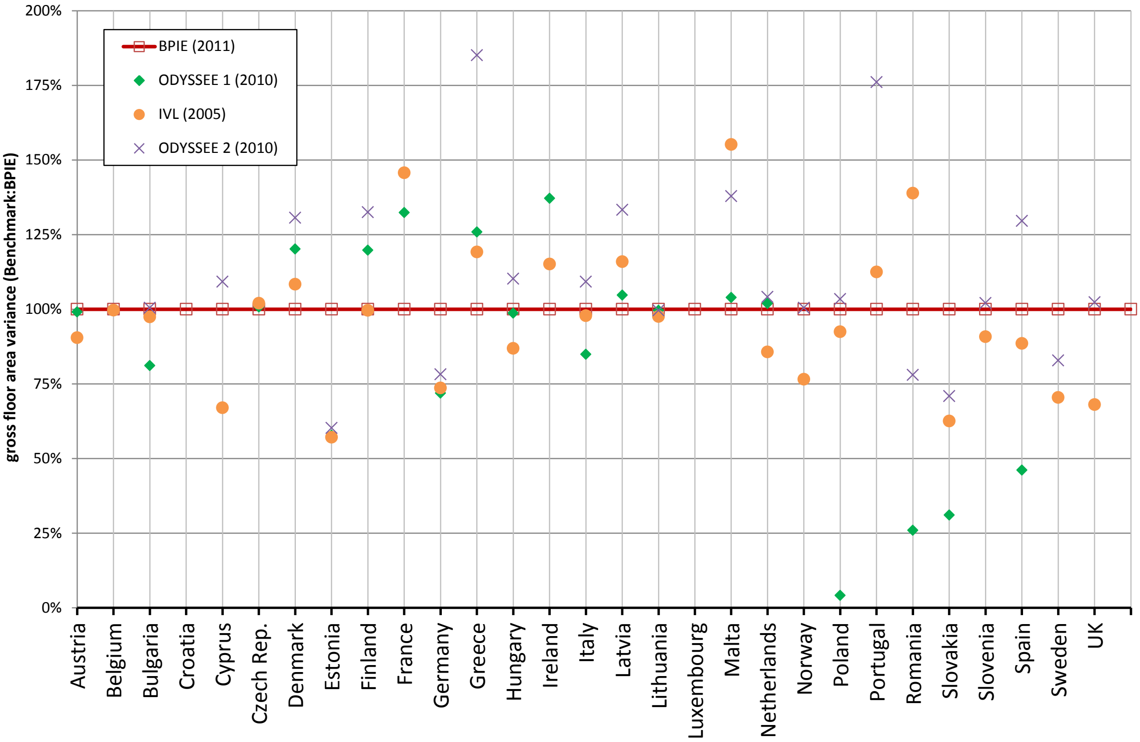
Figure 16. Useful floor area comparison



In addition, the area may also cover permanently occupied buildings or all buildings, including empty dwellings and non-primary residences. ODYSSEE clearly declares that useful floor area is referred only to permanently occupied households. BPIE and IVL do not specify it. Actually, according to [38], IVL data are evaluated by means of National Board of Housing, Building and Planning (NBHBP) Sweden [46] data; the NBHBP report [46] states that, for some countries, total dwelling stock is used instead of the permanently occupied building stock. For the mentioned reason, in the present report a more accurate analysis is not possible.

Figure 16 and Figure 17 show the comparison between the useful floor areas of residential buildings referred to ODYSSEE 1 and 2, BPIE and IVL databases (reference year for ODYSSEE data is 2010, for IVL data is 2005).

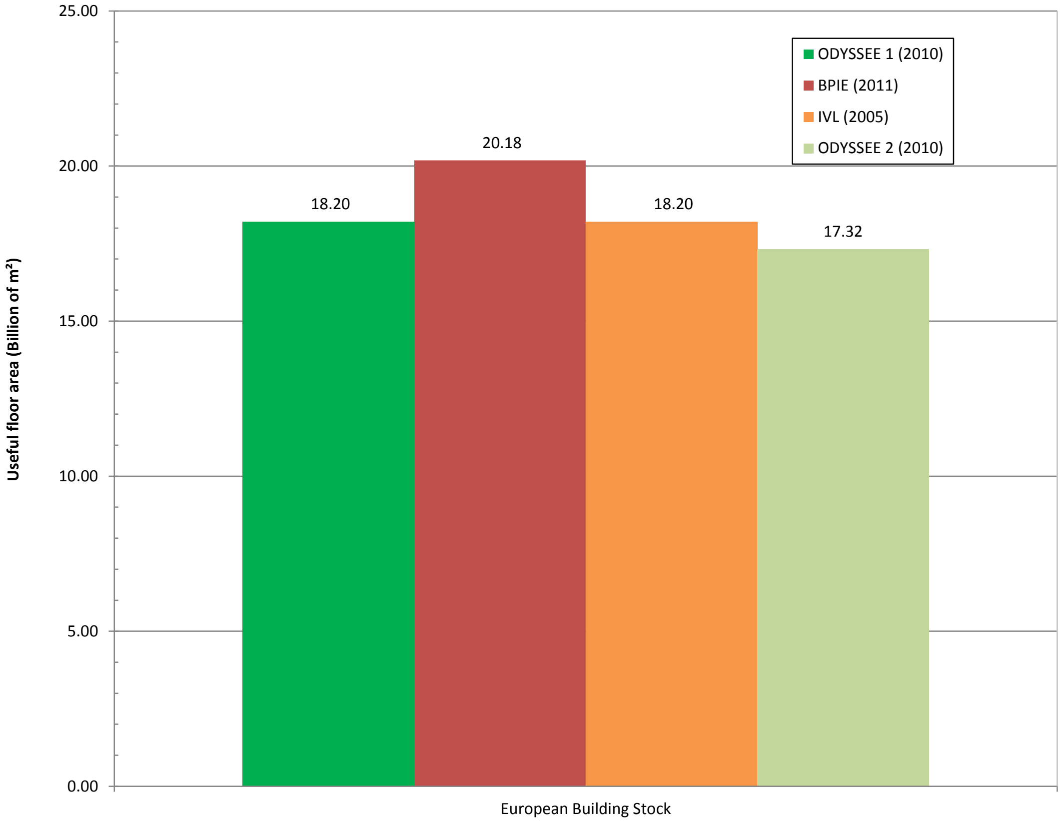
Figure 17. Useful floor area comparison (Benchmark: BPIE)



The figures show that useful floor areas well match for Austria, Bulgaria, Czech Republic, Hungary, Italy, Lithuania, Netherlands (the maximum difference among the databases of the listed countries is 20%); while they do not well match for Estonia (max difference 43%), France (max difference 46%), Greece (max difference 85%), Malta (max difference 55%), Poland (max difference 96%), Portugal (max difference 746%) Romania (max difference 74%), Slovakia (max difference 69%), Slovenia (max difference 887%), Spain (max difference 54%) and Sweden (max difference 387%). ODYSSEE 1 values for Portugal, Slovenia and Sweden are not shown because they are out of range.

Figure **18** also shows the comparisons of useful floor area of European building stock. Actually, BPIE data include all the EU28 Member States and Norway, while for other databases not all the MS are included. ODYSSEE 1 misses data from Belgium, Cyprus and United Kingdom; ODYSSEE 2 misses data from Austria, Belgium, Czech Republic, France, Ireland and Luxembourg; IVL misses data from Croatia. Data from BPIE are 10-15% higher than the total useful floor area provided by the other databases.

Figure 18. Overall comparison of building useful floor area

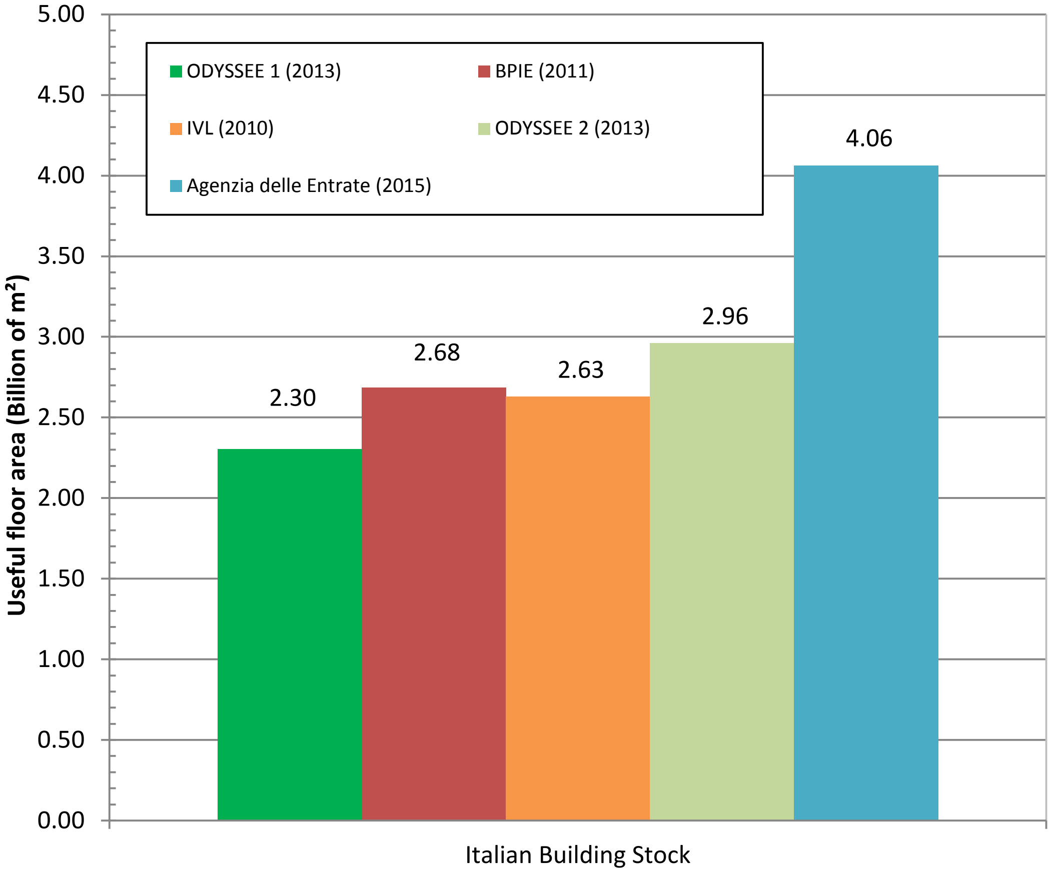


3.1.2.1.1.1 Building stock comparison check for Italy

A check on building stock for Italian households useful floor area has been carried out using the 2015 cadastre data provided by the Italian Agency of Revenue (Agenzia delle Entrate) [47]. The Agenzia delle Entrate (AE) aggregates the cadastre categories into 9 groups. Group A (from A/1 to A/11 excluding A/10, which regards data about offices and private practices) includes data about all the residential building typologies (rural, popular, terraced houses, villas, and others). According to the DPR 138-98 [48], the cadastre floor area is equivalent to the useful floor area. By summing the total area of the Group A buildings for each Italian province, the AE provides a value equal to 4.06 Billions of m^2. eclared by the AE.

Figure 19 shows the differences among the useful floor area values, considering the analysed databases (using the more recent data for a better comparison with the AE data) and data by Agenzia delle Entrate. Figure shows that data provided by AE are 37% to 76% higher than the analysed databases. Considering that the AE data correspond to the declared households' floor areas for evaluating the estate duties, these data can be considered as a lower bound; for this reason, it is unlikely that the correct useful floor area of the Italian building stock is lower than the value declared by the AE.

Figure 19. Italian comparison of building useful floor area, including data provided by the Agenzia delle Entrate - Osservatorio del mercato immobiliare [47]



2.1.2.1.2 Useful floor area energy consumption

In order to use the energy consumption data provided by the energy databases for each Member State for the regional/urban energy assessment, consumptions related to useful floor area are requested.

According to what already reported in Table 5, BPIE already provides values in kWh/m^2; moreover, before September 2016, also ODYSSEE database provides space heating consumption, with climatic correction, in kWh/m^2. Nevertheless, these data are not available for Eurostat and IEA databases. In order to provide these data, two options are possible:

1. BPIE useful floor area data can be used, and Eurostat and IEA energy consumptions per square meter are evaluated as for equations (17) and (18);
2. ODYSSEE 2 floor area data (number of dwellings * average floor area of dwelling) can be used, and Eurostat and IEA energy consumptions per square meter are evaluated as for equations (19) and (20).

$$\mathrm{kWh/m^2}_{ES\_BPIE} = \frac{kWh_{Eurostat}}{Useful\ floor\ area_{BPIE}} \qquad (17)$$

$$\mathrm{kWh/m^2}_{IEA\_BPIE} = \frac{kWh_{IEA}}{Useful\ floor\ area_{BPIE}} \qquad (18)$$

$$\mathrm{kWh/m^2}_{ES\_ODYSSEE} = \frac{kWh_{Eurostat}}{Useful\ floor\ area_{ODYSSEE\ 2}} \tag{19}$$

$$\mathrm{kWh/m^2}_{IEA\_ODYSSEE} = \frac{kWh_{IEA}}{Useful\ floor\ area_{ODYSSEE\ 2}} \tag{20}$$

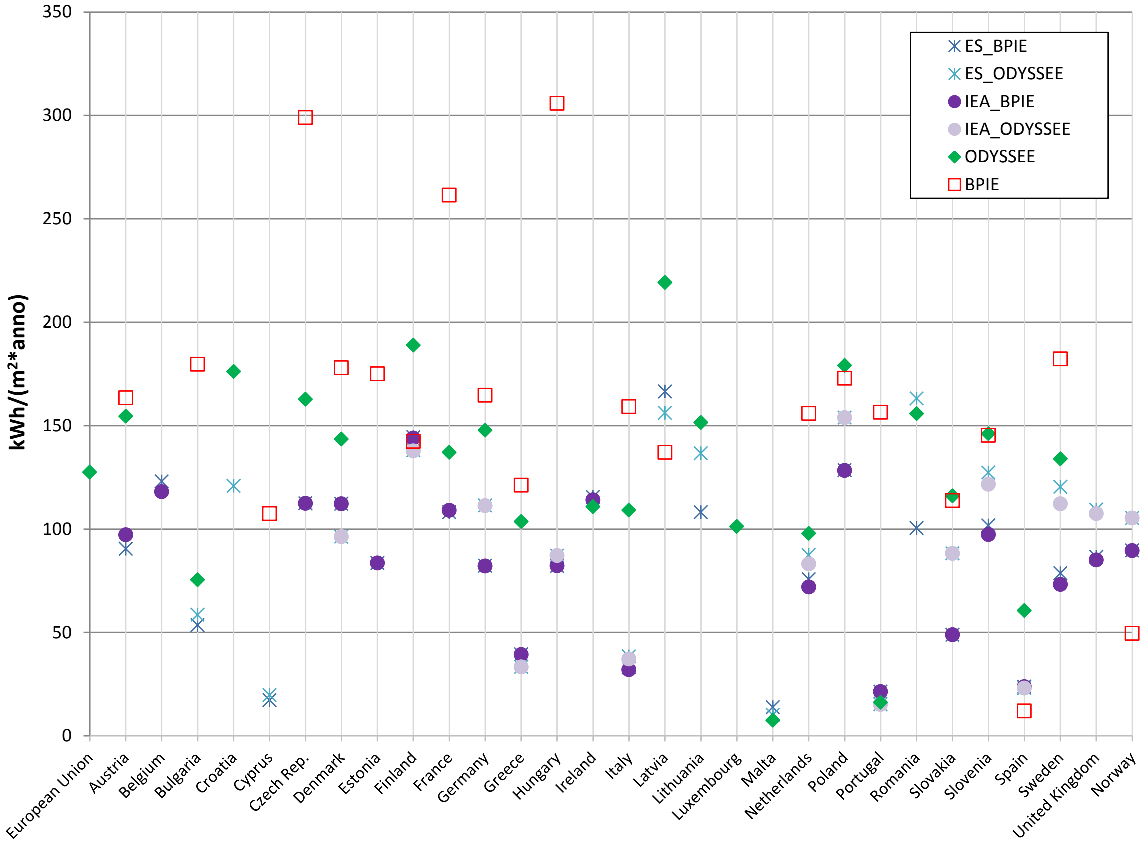
Differences among the databases, in kWh/(m^2×year) are reported in Table 10 and shown in Figure 20. Note that, in this table, ODYSSEE values refer to space heating with climatic correction.

Table 10. Comparisons among ES_BPIE, ES_ODYSSEE, ODYSSEE and BPIE in consumption/m^2.

REFERENCE YEAR 2011 [kWh/m^2]						
	ES_BPIE	**ES_ODYSSEE**	**IEA_BPIE**	**IEA_ODYSSEE**	**ODYSSEE**	**BPIE**
European Union					127.44	
Austria	113.10		121.50		154.54	163.38
Belgium	158.14		151.69			
Bulgaria	68.54	58.54			75.47	179.71
Croatia		120.85			176.11	
Cyprus	22.21	19.73				107.39
Czech Rep.	144.22		144.33		162.80	298.92
Denmark	131.97	96.34	131.94	96.31	143.50	177.92
Estonia	106.40		106.28			175.00
Finland	185.76	138.12	185.27	137.76	188.94	142.33
France	139.14		140.35		137.12	261.45
Germany	90.21	111.44	90.09	111.29	147.78	164.63
Greece	62.00	33.35	61.82	33.26	103.59	121.17
Hungary	105.68	87.00	105.87	87.17		305.83
Ireland	149.57		147.92		110.79	
Italy	42.08	38.39	40.70	37.13	109.15	159.10
Latvia	211.55	156.10			219.21	137.10
Lithuania	138.41	136.58			151.45	
Luxembourg					101.22	
Malta	17.84	10.14			7.51	
Netherlands	97.80	87.38	93.00	83.09	97.87	155.83
Poland	161.15	153.91	161.08	153.85	179.15	172.88
Portugal	27.77	15.12	27.77	15.12	16.24	156.43
Romania	128.67	163.08			155.75	
Slovakia	62.97	88.15	62.96	88.13	116.06	113.73

Slovenia	131.23	127.23	125.50	121.67	146.04	145.34
Spain	30.19	23.09	30.17	23.08	60.63	12.01
Sweden	101.10	120.39	94.20	112.17	133.93	182.20
United Kingdom	112.04	109.34	110.13	107.47		
Norway	106.81	105.29	106.79	105.28		49.50

Figure 20. Comparisons among ES_BPIE, ES_ODYSSEE, IEA_BPIE, IEA_ODYSSEE, ODYSSEE and BPIE in consumption/m^2.



Differences among the databases depend on the data provided by the considered MS.

A selection criterion could be to choose the average energy consumption value between more similar data; i.e. considering Finland, the energy consumption can be considered as the average value between 185.76, 138.12, 185.27, 137.76, 188.94 and 142.33 kWh/m^2 (163.03 kWh/m^2).

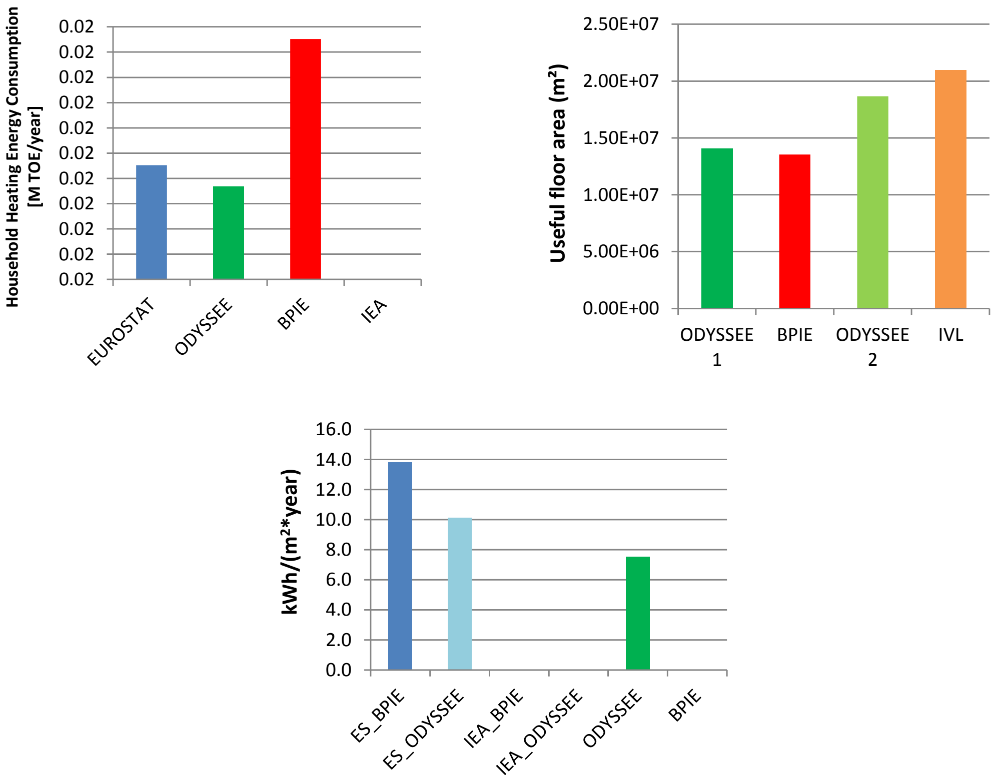
Considering the information analysed, it is clear that more precise data on household space heating energy consumptions for European Member States is necessary.

2.1.2.1.2.1 Member States Highlights

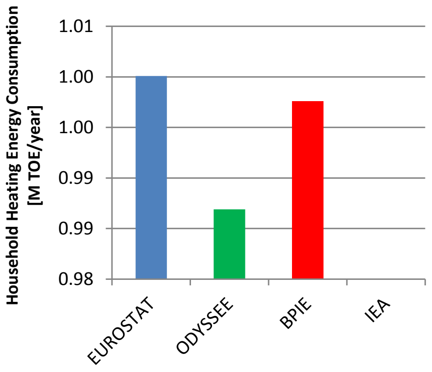
In order to have an overview of the household energy consumption, the abovementioned data are reported for some Member State. Precisely, Figure 21a and Figure 21b shows, respectively, the MS presenting the best and the worse matches among the data referred to the analysed databases.

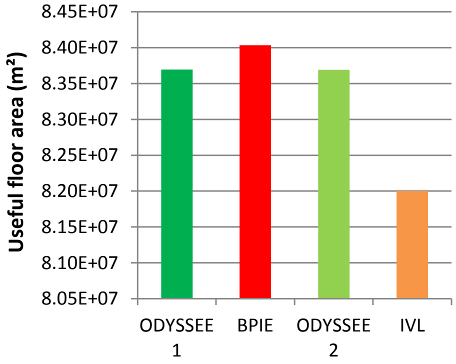
Figure 21a: MS Highlights on energy consumption and useful floor area comparisons – Malta, Lithuania and Belgium

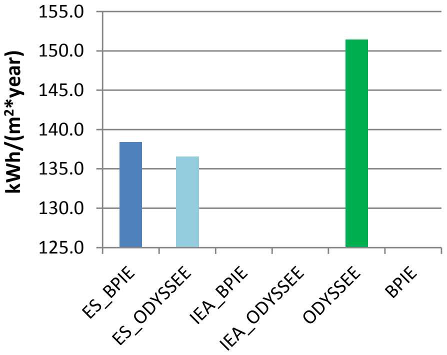
Malta



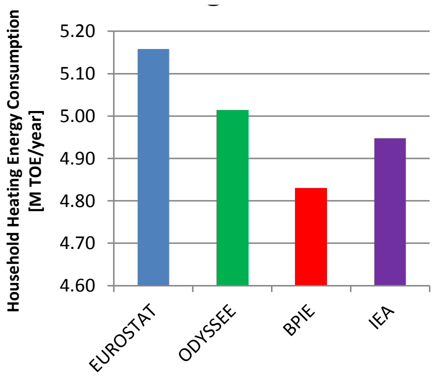
Lithuania

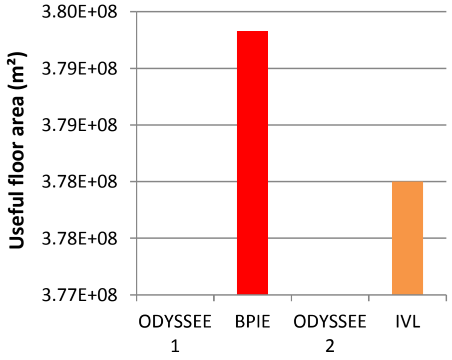

Household Heating Energy Consumption [M TOE/year]
1.01
1.00
1.00
0.99
0.99
0.98
EUROSTAT
ODYSSEE
BPIE
IEA


Useful floor area (m²)
8.45E+07
8.40E+07
8.35E+07
8.30E+07
8.25E+07
8.20E+07
8.15E+07
8.10E+07
8.05E+07
ODYSSEE 1
BPIE
ODYSSEE 2
IVL


kWh/(m²*year)
155.0
150.0
145.0
140.0
135.0
130.0
125.0
ES_BPIE
ES_ODYSSEE
IEA_BPIE
IEA_ODYSSEE
ODYSSEE
BPIE

Belgium


Household Heating Energy Consumption [M TOE/year]
5.20
5.10
5.00
4.90
4.80
4.70
4.60
EUROSTAT
ODYSSEE
BPIE
IEA


Useful floor area (m²)
3.80E+08
3.79E+08
3.79E+08
3.78E+08
3.78E+08
3.77E+08
ODYSSEE 1
BPIE
ODYSSEE 2
IVL

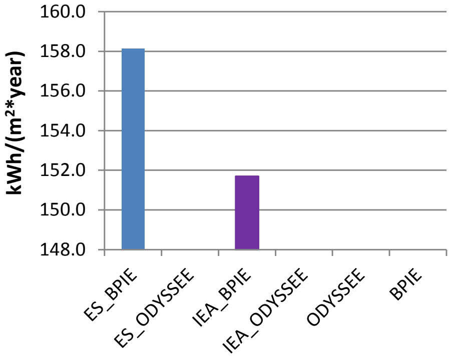
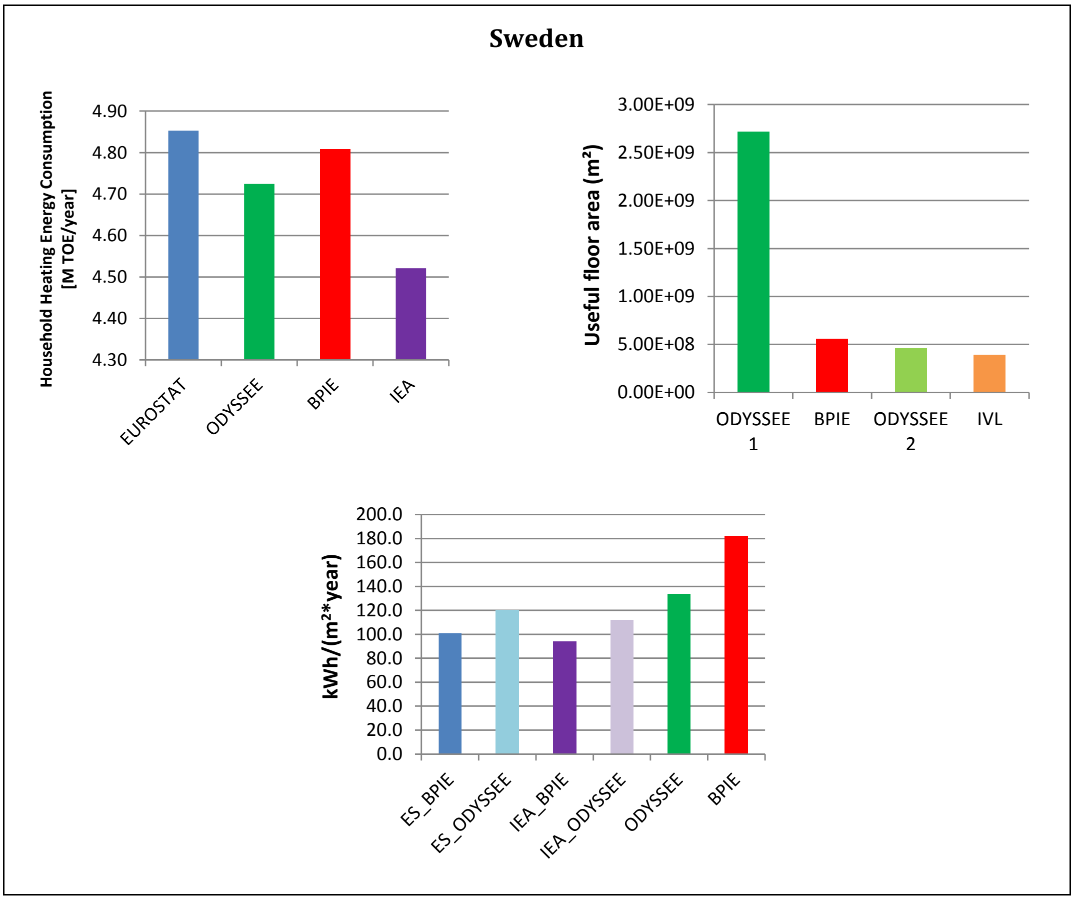
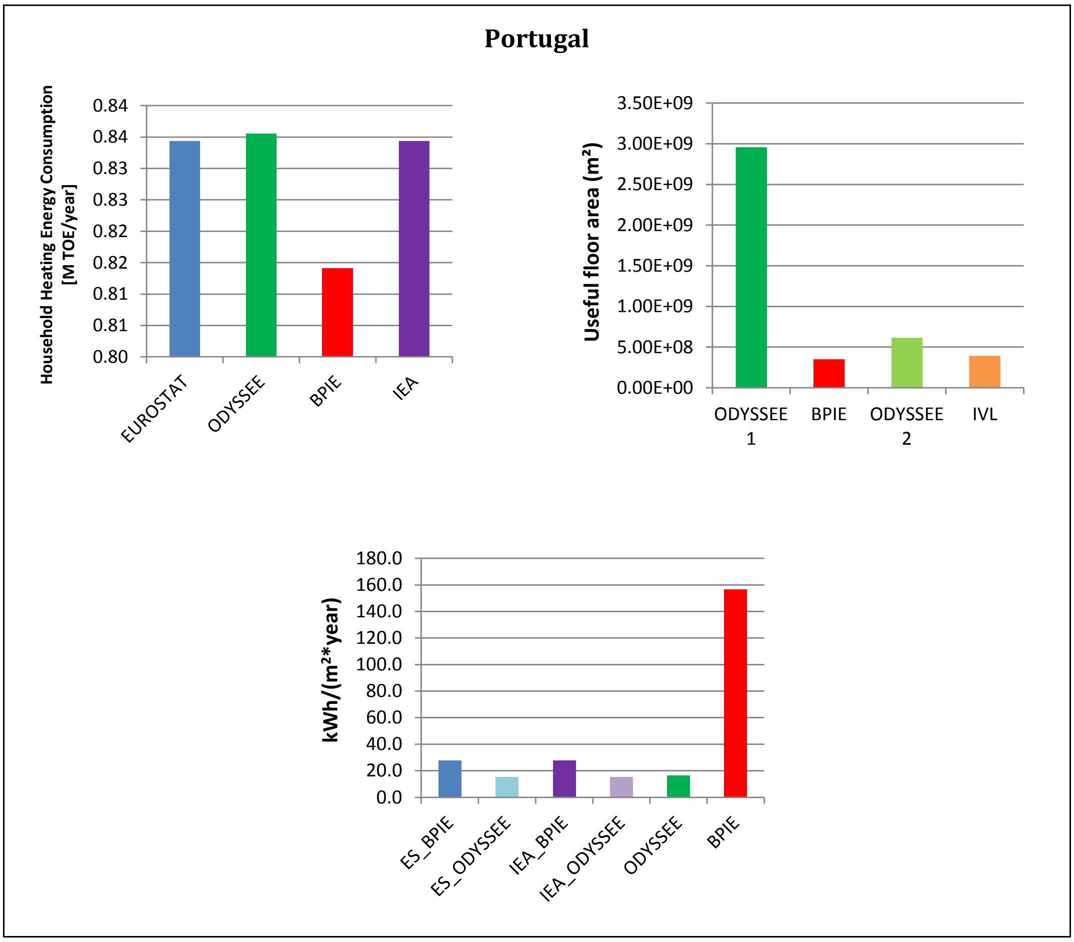

kWh/(m²*year)
160.0
158.0
156.0
154.0
152.0
150.0
148.0
ES_BPIE
ES_ODYSSEE
IEA_BPIE
IEA_ODYSSEE
ODYSSEE
BPIE

Figure 21b: MS Highlights on energy consumption and useful floor area comparisons –Sweden and Portugal





Figures show that, even if the total energy consumption for household space heating has a maximum error of 13% (as already analysed at page 26), differences among the floor area provided by the databases can cause a great difference in data regarding space heating per square meter, as shown for Sweden (88 kWh/m^2) and Portugal (141 kWh/m^2) cases. For other Member States, as Malta, Lithuania and Belgium, the differences among databases are very small (10 kWh/m^2, 15 kWh/m^2 and 6.4 kWh/m^2, respectively). As conclusion, it has to be asserted that a more uniform evaluation on floor area is needed in order to provide more correct information about the space heating consumption per square meter at national level.

2.1.2.1.3 Energy performance parameter at regional/urban level – Procedure I.B1

The energy performance parameter, corresponding to the households' space heating of buildings at regional/urban level, using national data, can be evaluated as:

$$R_{E,energy} = \left[\sum_{i=1}^{N} \sum_{j=1}^{M} \left(\%_i * \left(\frac{kWh_{TOT,i}}{m^2 \cdot year} \right)_{MS} * m^2{}_{region/city} \left(\frac{€}{kWh} \right)_i \right)_j \right] * L_B \tag{21}$$

where:

- *i* represents the *i*-th component of the energy;
- *j* represents the *j*-th building occupancy class (as households, offices, schools,…);
- *N* represents the number of energy component considered;
- *M* represents the number of building occupancy class considered;
- $\%_i$ represents the percentage of the *i*-th energy component on the total, for the considered MS;
- $\left(\frac{kWh_{TOT,i}}{m^2 \cdot year}\right)_{MS}$ represents the annual total energy consumption per square meter of the i-th energy component, referred to the considered MS;
- $m^2_{region/city}$ is the useful area of buildings' groups in the considered region or city;
- $\left(\frac{€}{kWh}\right)_i$ is the price of the i-th component;
- L_B is the life span of the building.

The useful floor area of the buildings' groups in the considered region or city, $m^2_{region/city}$, is a complicated value to be assessed. It can be obtained either according to the procedure described in §2.1.2.2.1 or by means of a field survey described at §2.3.1.

2.1.2.2 ***Step I.B2***

In order to obtain a more precise evaluation of the energy consumption of the buildings at regional or urban scale, information can be derived by the energetic classification of the buildings, which reveals their energy consumption.

As discussed before, the Directive 2010/31/EU of the European Parliament [6] states the necessity of improving the energy performance of buildings within the Union. The Directive fixes seven requirements (from (a) to (g)) for addressing the buildings energy performance. Point (e) regards the energy certification of buildings, which addresses the building energy consumptions. Indeed, articles 11, 12 and 13 provide the basic information for realizing and granting the energy certifications, stating that Member States shall ensure that an energy performance certificate is issued for (1) buildings or building units which are constructed, sold or rented out to a new tenant and (2) buildings where a total useful floor area over 250 m^2 is occupied by a public authority and frequently visited by the public. According to the Directive 2010/31/EU, all the Member States have adopted it issuing national codes [49] and have established independent control systems for energy performance certificates.

For some of the Member States (Italy, United Kingdom, Spain, Austria and Belgium [50]), the commitment in managing the EPCs is given to the Regional Authorities.

The methodology for addressing the regional energy costs is explained considering the case study of Italy. For all the other Member States having a regional management of the EPCs, the same procedure can be used, but regional information has to be obtained for the single Region according to the available data. On the other hand, for the Member States where the EPCs are managed by the National Authorities, the same procedure can be used, but the values regarding the energy consumption would not reflect the same data accuracy.

2.1.2.2.1 Regional energy assessment – The case of Italy

According to the Italian legislation, the Article 17 of the D.Lgs. 192/05 [51] that adopted the previous version of the Energy Performance of the Buildings Directive (EPBD), 2002/91/CE [52], has allowed the Italian Regions to define their own methodologies for the EPCs. On one hand, this policy has led to a more territorial-related data management and results; but on the other hand, it has led to more uneven and discrepant results of the national building energy performances. For this reason the guidelines for the EPCs, DM 26-

06-2015 [53], promotes the national management of the energy certificates. According to the guidelines, the non-renewable global energy performance index, expressed in kWh/(m^2 year) and leading to the building energy classification, is evaluated as follows:

$$EP_{gl,nren} = EP_{H,nren} + EP_{W,nren} + EP_{C,nren} + EP_{V,nren} + EP_{L,nren} + EP_{T,nren} \qquad (22)$$

where:

— $EP_{H,nren}$ is the non-renewable energy index for winter space heating

— $EP_{W,nren}$ is the non-renewable energy index for water heating

— $EP_{C,nren}$ is the non-renewable energy index for summer air-conditioning

— $EP_{V,nren}$ is the non-renewable energy index for internal mechanical ventilation

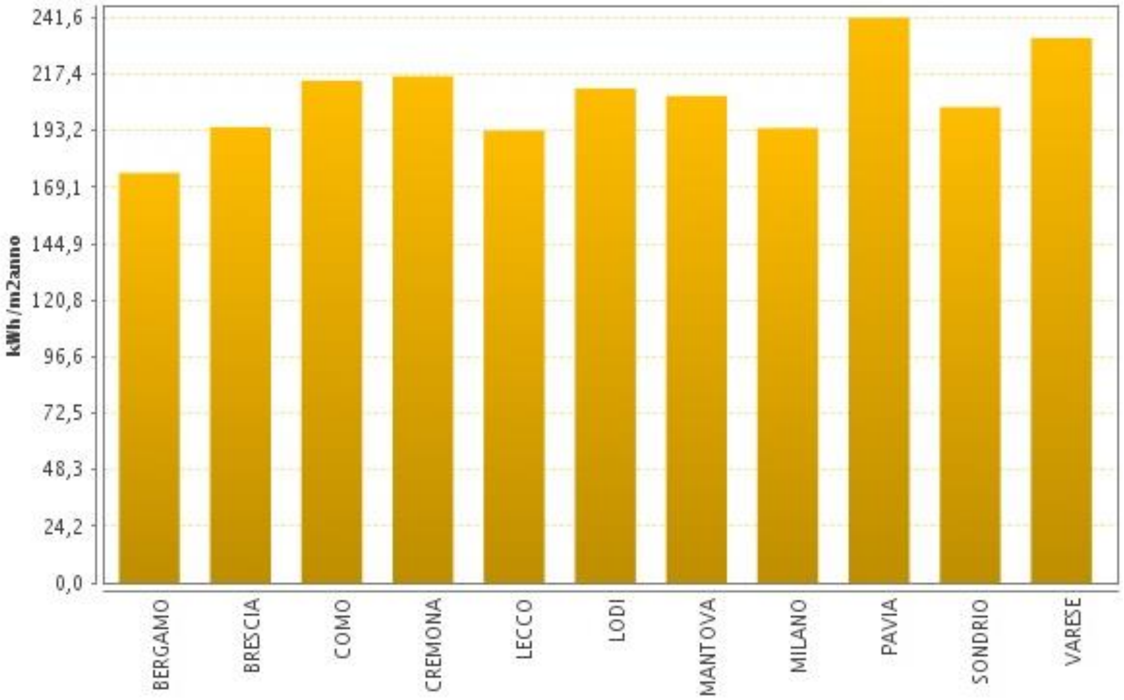
— $EP_{L,nren}$ is the non-renewable energy index for illumination

— $EP_{T,nren}$ is the non-renewable energy index for people transportation (lifts, escalators)

While focusing on the Italian Regions, different results have been achieved. For some Italian Regions, information about the energy consumptions are provided hereafter.

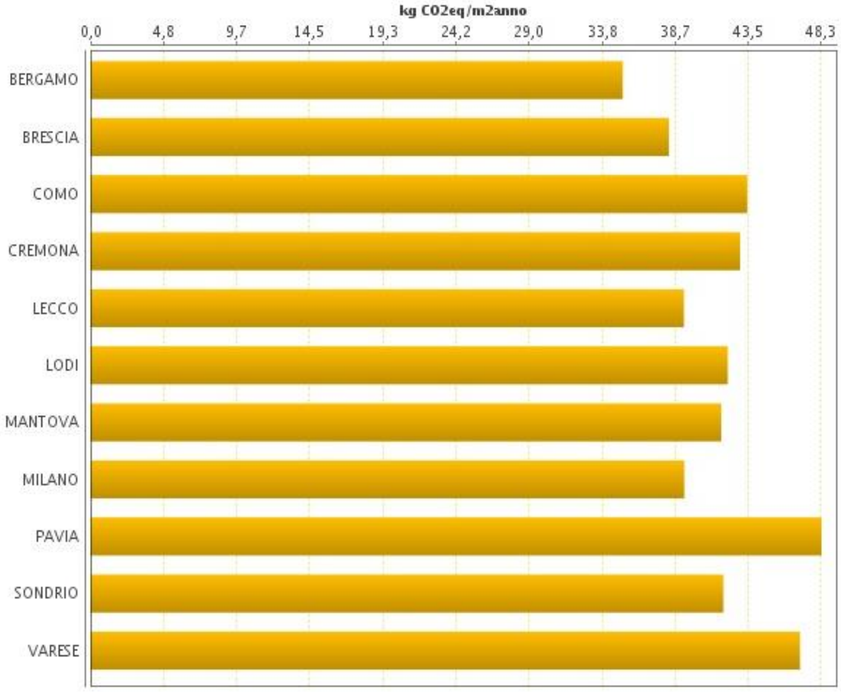
Lombardia Region provides EP_H values for each Province and Municipality, for residential and non-residential buildings and for three different uses (hotels and pensions, permanently occupied households, temporary occupied households). Moreover, it provides EP_W values for each Province and Municipality, for residential and non-residential buildings [54]. As an example, Figure 22 shows the average non-renewable energy index for winter space heating of each Province of Lombardia Region. In [54], also Municipality values are available.

Figure 22. Average EP_H for winter space heating of residential buildings, for each Lombardia Province



Lombardia Region also provides information about the CO_2 generated by the energy systems of the buildings. Average CO_2, expressed in equivalent CO_2, is provided for each Province and Municipality for residential and non-residential buildings. As example, Figure 23 shows the average CO_2^{eq} of the residential buildings for each Lombardia's Province.

Figure 23. Average CO_2^{eq} for residential buildings, for each Lombardia Province



Sicily Region provides the total EP_H values for each Municipality, for residential in kWh/(m^2 year) and non-residential buildings in kWh/(m^3 year) [55]. It also provides an interactive map showing these values (e.g. Figure 24 regards the map providing residential building EP_H).

Figure 24. Map of Sicily EP_H for winter space heating of residential buildings

The Regione Autonoma Valle D'Aosta provides a yearly report on the monitoring of energy certifications [56]. Precisely, the report shows the average energy performances of residential buildings (in kWh/(m2 year)), considering three different degree day areas4: area with DD<3000 days; 3000<DD<4000 days; DD>4000 days; and considering different construction periods, divided in 8 classes (Figure 25) for each year after 2006 (Figure 26).

Figure 25. Average energy performance in kWh/(m^2 year) of residential buildings for DD<3000 area in Valle D'Aosta Region

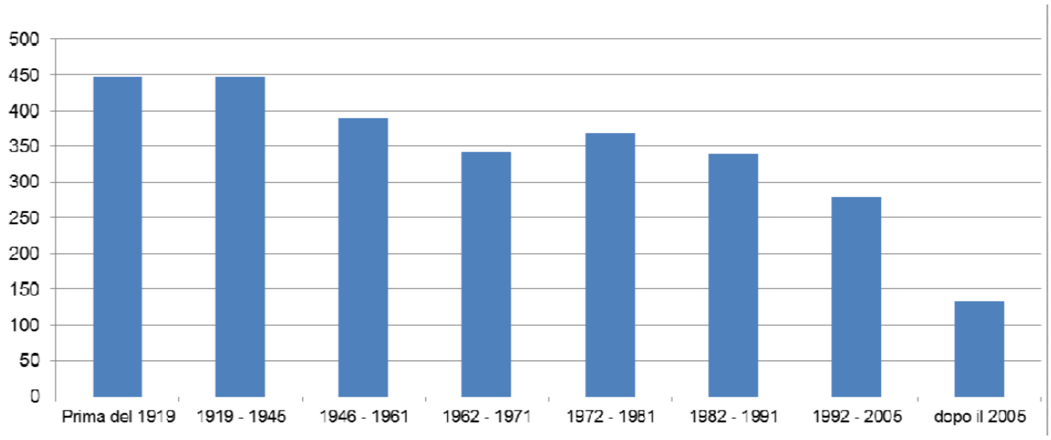
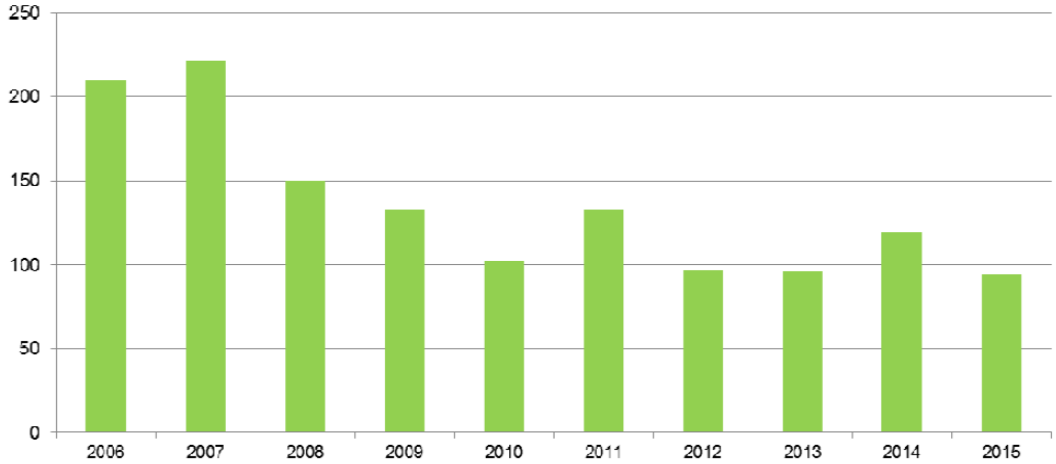


Figure 26. Average energy performance in kWh/(m^2 year) of residential buildings for DD<3000 area in Valle D'Aosta Region, for each year after 2006



Friuli Venezia Giulia (FVG) Region provides data regarding the average energy performance of: winter space heating, water heating, summer space cooling. Nevertheless, the data are available only for Regional Public Authorities and for regional notaries [57]. As for Lombardia Region, also FVG Region provides data about the CO_2 emissions related to the energy systems use in residential and non-residential buildings. Moreover, CO_2 emissions are provided for building construction years and for building use (hotels and pensions, permanently occupied households and temporary occupied households for residential buildings; offices, hospitals, churches, schools, sport facilities, industrial activities, shops for non-residential buildings). Figure 27 shows the average $CO_{2,eq}$ values for FVG Region, for non-residential buildings, built in 2000, and considering each non-residential use.

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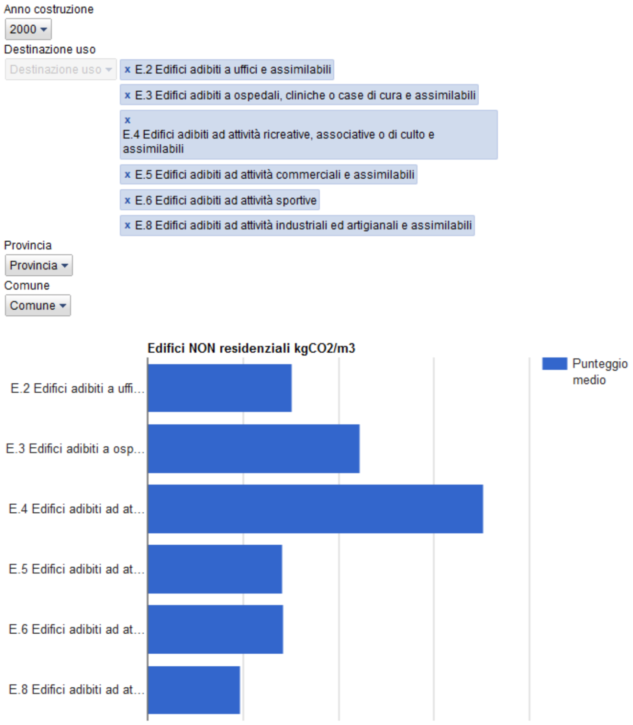
[4] Degree Day is the sum, extended to all the days of a conventional annual period of heating, of the daily differences (positive only) between the ideal conventional temperature for the heated environment (20° C), and the daily average temperature of the external environment.

Figure 27. Average $CO_{2,eq}$ for non-residential buildings, built in 2000



Anno costruzione

2000

Destinazione uso

Destinazione uso

- × E.2 Edifici adibiti a uffici e assimilabili
- × E.3 Edifici adibiti a ospedali, cliniche o case di cura e assimilabili
- × E.4 Edifici adibiti ad attività ricreative, associative o di culto e assimilabili
- × E.5 Edifici adibiti ad attività commerciali e assimilabili
- × E.6 Edifici adibiti ad attività sportive
- × E.8 Edifici adibiti ad attività industriali ed artigianali e assimilabili

Provincia

Provincia

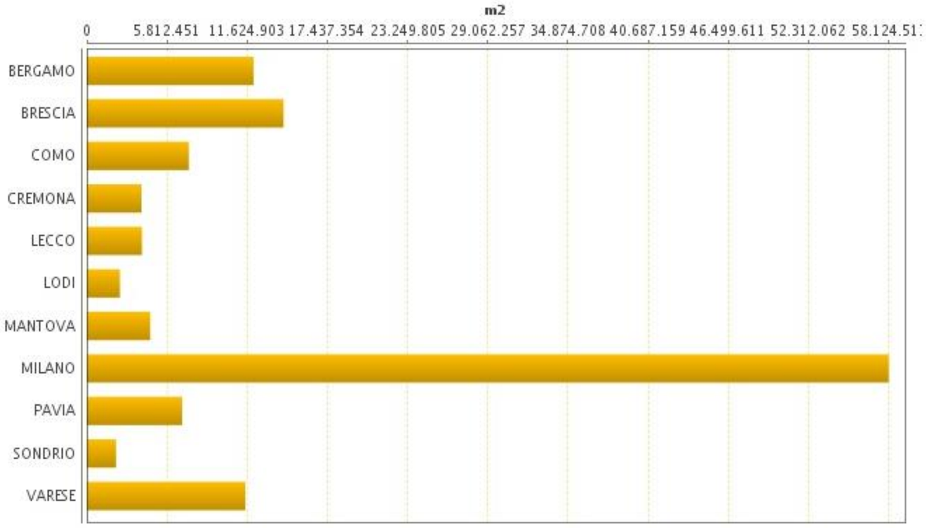
Comune

Comune

In order to evaluate the regional energy costs, the energy performance index has to be converted in Euro. At this aim, regional floor area of the buildings, percentage of gas and electricity consumptions on the total energy consumptions, and gas and electricity regional costs should be addressed.

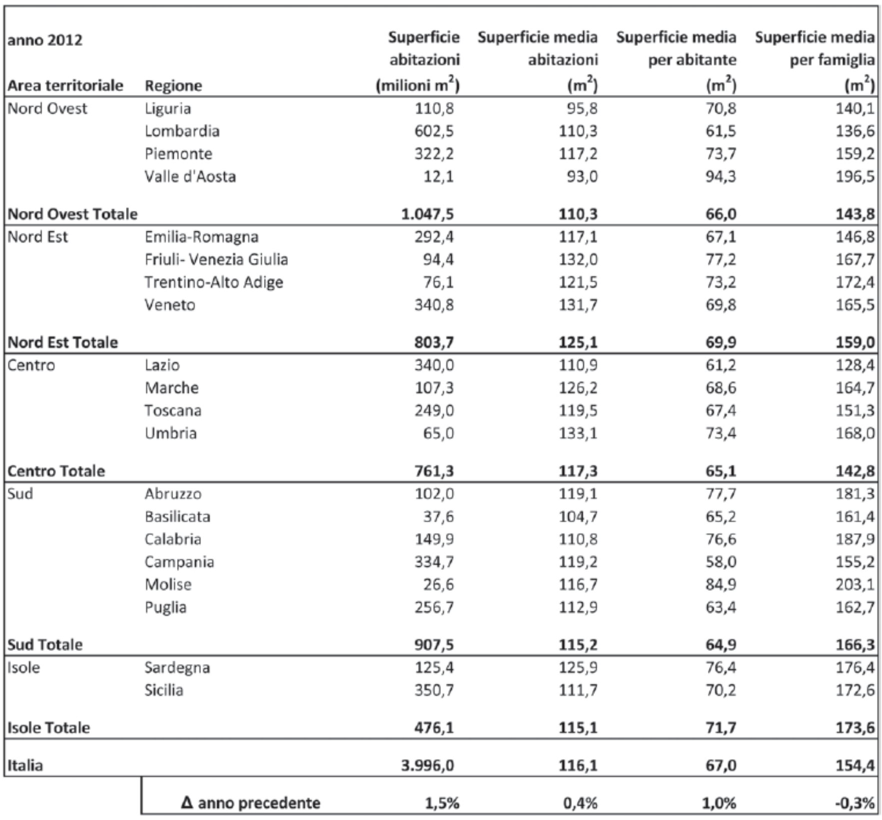
Among the Italian considered Regions, only Lombardia Region provides the total useful area of residential and non-residential buildings (Figure 28). This value is given in square meter unit, for each Province and Municipality of the Region. By summing the square meters of the total buildings floor area for each Province, the total building floor area of the Region is assessed [54].

Figure 28. Total useful area of residential buildings for each Lombardia Region Province



Useful floor area for Italian buildings can be also obtained by the Agenzia delle Entrate report [58]. Figure 29 shows the Agenzia delle Entrate estimation of the total floor area in million square meters (third column), divided for each Italian Region and referred to 2012.

Figure 29. Regional indicators of the household area



anno 2012 Area territoriale	Regione	Superficie abitazioni (milioni m^2)	Superficie media abitazioni (m^2)	Superficie media per abitante (m^2)	Superficie media per famiglia (m^2)
Nord Ovest	Liguria	110,8	95,8	70,8	140,1
	Lombardia	602,5	110,3	61,5	136,6
	Piemonte	322,2	117,2	73,7	159,2
	Valle d'Aosta	12,1	93,0	94,3	196,5
Nord Ovest Totale		**1.047,5**	**110,3**	**66,0**	**143,8**
Nord Est	Emilia-Romagna	292,4	117,1	67,1	146,8
	Friuli- Venezia Giulia	94,4	132,0	77,2	167,7
	Trentino-Alto Adige	76,1	121,5	73,2	172,4
	Veneto	340,8	131,7	69,8	165,5
Nord Est Totale		**803,7**	**125,1**	**69,9**	**159,0**
Centro	Lazio	340,0	110,9	61,2	128,4
	Marche	107,3	126,2	68,6	164,7
	Toscana	249,0	119,5	67,4	151,3
	Umbria	65,0	133,1	73,4	168,0
Centro Totale		**761,3**	**117,3**	**65,1**	**142,8**
Sud	Abruzzo	102,0	119,1	77,7	181,3
	Basilicata	37,6	104,7	65,2	161,4
	Calabria	149,9	110,8	76,6	187,9
	Campania	334,7	119,2	58,0	155,2
	Molise	26,6	116,7	84,9	203,1
	Puglia	256,7	112,9	63,4	162,7
Sud Totale		**907,5**	**115,2**	**64,9**	**166,3**
Isole	Sardegna	125,4	125,9	76,4	176,4
	Sicilia	350,7	111,7	70,2	172,6
Isole Totale		**476,1**	**115,1**	**71,7**	**173,6**
Italia		**3.996,0**	**116,1**	**67,0**	**154,4**
	Δ anno precedente	**1,5%**	**0,4%**	**1,0%**	**-0,3%**

Percentage of gas and electricity consumptions on the total energy consumptions can be extracted according to Eurostat data [59], for Italy (see Table 11).

Table 11. Gas and electricity percentage on the total energy consumption for each Member State [59]

	2014 Gas Percentage on the Total Energy Consumption %GAS [%]	2014 Electricity Percentage on the Total Energy Consumption %ELECTRICITY [%]
Austria	17.8	26.7
Belgium	39.1	22
Bulgaria	2.1	42
Croatia	19.9	22.2
Cyprus	-	42.3
Czech Rep.	29	21.4
Denmark	14.4	22

Estonia	5.9	16.8
Finland	0.6	36.2
France	28.9	34.4
Germany	35.5	21.6
Greece	6.1	39
Hungary	52.3	20.2
Ireland	20.6	25.6
Italy	51.3	18.7
Latvia	8.2	12.1
Lithuania	8.5	16.2
Luxembourg	47.1	17
Malta	-	76
Netherlands	70.1	21.6
Poland	16.6	12.7
Portugal	10	39.9
Romania	29.4	13.8
Slovakia	53.1	21.7
Slovenia	8.5	25.8
Spain	21	41.3
Sweden	0.5	47.7
United Kingdom	61.2	26.6
Norway	0.1	83.2

With regard to the energy costs, they vary if enhanced protection service market (Servizio di Maggior Tutela, in italian) or free market is considered. Free markets include all the energy companies, and the energy costs could be hard to extract. For this reason, the enhanced protection service market is considered. The AEEGSI (Italian Authority of the Electrical Energy, Gas and Water) [60] provides the Italian electricity and gas prices, variable every three months and equal for the Italian Regions. For the trimester October-December 2016, the energy rates are:

$$P_{electricity} = 0{,}159776 \frac{€}{kWh} \tag{23}$$

$$P_{gas} = 0.7191 \frac{€}{m^3} \quad [61] \tag{24}$$

2.1.2.2.2 Energy performance parameter at regional/urban level – Procedure I.B2

Once all the over mentioned values have been assessed, the energy costs can be evaluated according to the following expression:

$$R_{E,energy} = \left[\sum_{i=1}^{N} \sum_{j=1}^{M} \left(\%_i \times EP_{gl} \times m^2{}_{region/city} \times P_i \right)_j \right] \times L_B \tag{25}$$

where:

- i represents the i-th component of the energy;
- j represents the j-th building occupancy class (as households, offices, schools,…);
- N represents the number of energy component considered;
- M represents the number of building occupancy class considered;
- $\%_i$ represents the percentage of the i-th energy component on the total, for the considered MS;
- EP_{gl} represents the annual total energy consumption per square meter of the i-th energy component, referred to the considered region/city;
- $m^2_{region/city}$ is the useful area of buildings' groups in the considered region or city;
- P_i is the price of the i-th component;
- L_B is the life span of the building.

By using the percentage of the energy component on the total energy provided by Eurostat [59], the same equations can be used after evaluating the national prices for the considered energy component.

Focus on STEP I of SSD Methodology at national/regional/urban level: Energy

The first step of the SSD methodology at national/regional/urban level is the energy performance assessment. Different methods for assessing the energy performance of buildings can be used, if considering the size of the building area.

The energy consumption value considered in the present report is related to space heating, because space heating can better address the envelope performance of buildings; indeed, it is a consequence of construction and building design, more than of users' energetic needs and behaviour.

At national level (Step I.A), the energy consumption provided by the energy databases, as Eurostat, IEA and ODYSSEE can be used. A comparison on total energy consumption values provided by the databases is performed and maximum weighted error results equal to 5%.

At regional and urban levels (Step I.B), data on building stock useful floor area are essential. Thus, a comparison on useful floor area provided by the databases has been performed, but high discrepancies have been observed. Should useful floor area values will be reliable, energy consumptions will we evaluated in two different ways: using the same data source of the Step I.A (Step I.B1), or using energy data provided by the energy performance certificates (Step I.B2).

If energy data are referred to all end uses, space heating energy consumptions can be obtained by using a space-heating rate depending on the considered geographical area. The energy consumptions can be converted in economic terms by using the energy prices provided by Eurostat and the energy performance parameter R_E^{Energy} is assessed.

2.2 Step II – Life-Cycle Assessment

The second step of the SSD methodology aims at evaluating the total carbon dioxide emissions of the buildings at territorial level:

$$CO_{2_{LC}} = CO_{2_E} + CO_{2_O} + CO_{2_D} \tag{26}$$

Life-cycle assessment studies are highly time-consuming. In order to realize a correct life-cycle analysis of buildings, computation on materials, processes and transportation is required.

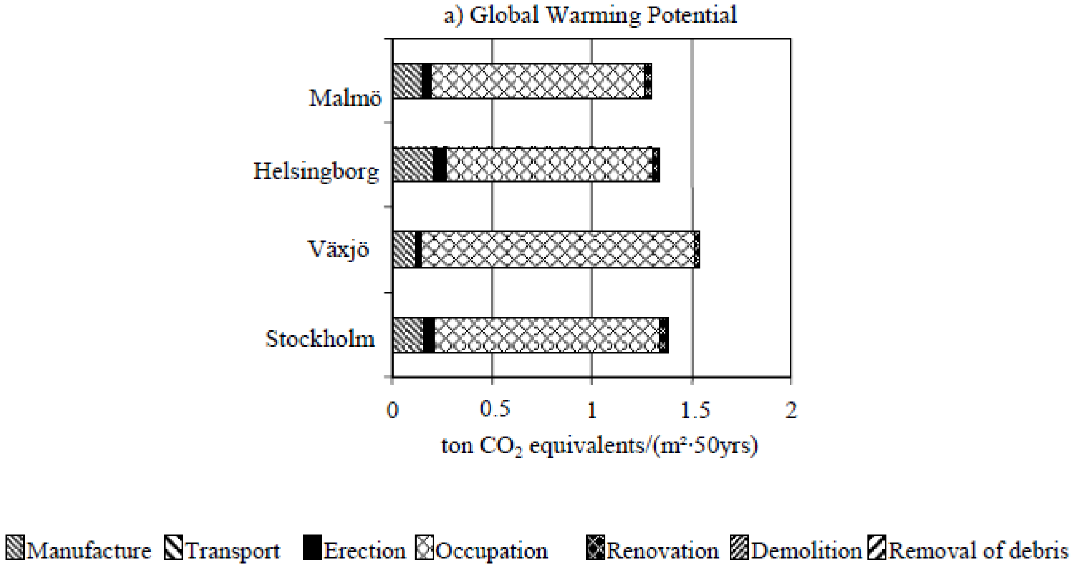
To simplify the LCA analysis, the emissions from the operational phase are obtaining by running in the LCA tools the amount of energy consumed during the building lifespan. Moreover, the contributions of the pre-use phase and the end-of-life phase are evaluated as percentage of the use phase, because the latter provides the highest amounts of carbon dioxide [62].

$$E_O \rightarrow CO_{2_O} \tag{27}$$

$$CO_{2_E} = \%CO_{2_O} \tag{28}$$

$$CO_{2_D} = \%CO_{2_O} \tag{29}$$

Figure 30. Global Warming Potential impact for life-cycle categories, as reported in [64]



The percentage can be derived by literature review. As example, information from Scheuer et al. [63] and Adalberth et al. [64] can be used. According to Scheuer et al. 96,5% of CO_2^{eq} emissions is generated by the use phase, 0,2% is referred to decommissioning phase and the remaining 3,2% is referred to pre-use phase (extraction of materials, material transportation and construction). According to Adalberth et al. (Figure 30), the average (of the four cities) percentage of pre-use phase on use phase is equal to 18%; whereas the average percentage of end-of-life phase on use phase is equal to 4,2%.

According to Loli et al. [10], the percentage of pre-use phase on use phase is equal to 11-13% and the percentage of end-of-life phase on use phase is 1,6-1,8%. For these reasons, the following percentages are considered:

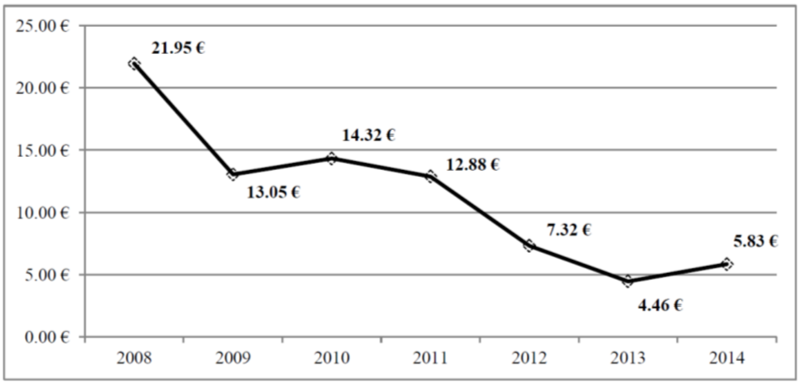
$$CO_{2_E} = 15\%\, CO_{2_O} \tag{30}$$

$$CO_{2_D} = 3\%\, CO_{2_O} \tag{31}$$

As discussed at page 15, the parameter for converting the CO_2 emissions in costs derive from international policies aiming at charging those who emit carbon dioxide. Indeed, this charge represents the price to pay in order to buy the right to emit one tonne of CO_2. Carbon dioxide charge can take the form of a carbon tax or of the requirement to purchase the right to emit. The latter system is called "CO_2 allowances" or "cap and trade".

In 2005 the European Union introduced the European Union Emissions Trading System (EU ETS), in order to reduce the EU emissions of man-made greenhouse gases. EU ETS controls the emissions of 11000 heavy energy-using installations (power stations and industrial plants) and airlines operating in 31 countries (all 28 EU countries plus Iceland, Liechtenstein and Norway). The number of plants controlled are responsible for 45% of the EU's greenhouse gas emissions [22]. The plant control is necessary to the EU ETS mechanism. EU ETS uses a "cap and trade" approach: indeed, a limit (cap) is set on the total amount of greenhouse gases that can be emitted by all participating installations. Allowances for emissions, called European Emission Allowances (EUA), are then sold or allocated for free, and can subsequently be traded. The EU ETS controls monitor and report the power stations and industrial plants emissions. If emission exceeds what is permitted by its allowances, a power station/plant must purchase allowances from others. Conversely, if an installation has performed well at reducing its emissions, it can sell its leftover credits. This approach gives companies the flexibility they need to cut their emissions in the most cost-effective way. The CO_2 price is determined by the market: if more allowances compared to demand are requested, a lower carbon price results; otherwise, a higher carbon price results.

Figure 31. Average carbon prices from 2008 to 2014



The EU ETS system has appointed the European Energy Exchange (EEX) [23] for auctioning general and aviation allowances on behalf of 25 Member States under the EU Emissions Trading System. EEX provides the CO_2 prices in terms of €/CO_2. Carbon dioxide price has undergone deep variations in the last decade (Figure 31); precisely, starting from 2005, the CO_2 prices has decreased from around 30 to 6 €/CO_2. Nevertheless, these values are referred to the yearly average, and moreover, they are very variable within the same year (in the last week of April 2006, the price dropped from 29 to 13 €/CO_2).

Once the equivalent amount of carbon dioxide generated by all the life cycle phases of the buildings is achieved, the cost of the environmental impact of global change, $R_{E(CO2)}$, can be evaluated as:

$$R_{E(CO_2)} = Q_{CO_2} \times P_{CO_2} \tag{32}$$

where:

— Q_{CO_2} is the amount of equivalent CO_2 (in kg or tonne)

— P_{CO_2} is the carbon dioxide price (in €/kg$CO_{2,eq}$ or €/tonne$CO_{2,eq}$)

In October 2016, P_{CO2} is equal to 5,81 €/CO_2.

Focus on STEP II of SSD Methodology at national/regional/urban level: LCA

The second step of the SSD methodology aims at evaluating the greenhouse gas emissions generated during the entire building life-cycle, including pre-use phase (from extraction and production of materials to construction phase), use phase and end-of-life phase. Life-cycle assessment of groups of buildings is a high resource-consuming activity. Thus, CO_2 emissions can be evaluated considering each building life phase as follows: a) CO_2 emissions related to use phase can be evaluated by converting in $CO_{2,eq}$ the energy consumed, as calculated in Step I, through the help of LCA software; b) CO_2 emissions related to pre-use and end-of-life phases can be calculated as a percentage of carbon dioxide emission of use phase, evaluated in scientific studies.

CO2 emission are then converted into costs with the help of the carbon dioxide price, provided by the EU ETS system, and the life-cycle performance parameter R_E^{CO2} is assessed.

2.3 Step III - Safety performance

Safety performance of buildings can be assessed by evaluating the expected losses generated by events that can occur during the building's lifespan.

According to Ramirez and Miranda [65], the methodologies for the loss assessment caused by natural hazards can be divided in two categories: methodologies for building-specific loss assessment and for regional loss assessment. The former, as described at § 1.3, can accurately identify the building vulnerability and the economic (and social) losses because of the rich information that can be provided by the single building. The latter can boast the ability of territorially identifying the vulnerability and the economic (and social) losses due to a defined hazardous event, which can lead to the estimation of the territorial risk mitigating operations.

The evaluation of the building safety performance at territorial scale implies the economic loss estimation of a large number of buildings, which, according to the area size and location, can show different features regarding the building characteristics themselves and the hazards they are exposed to.

Models for evaluating the economic losses caused by natural hazards, as floods, landslides, tsunamis, hurricanes, earthquakes, have been developed by different authors and can be imported in the SSD methodology at territorial level. The present report focuses on the earthquake loss assessment since the methodologies regarding the seismic performances of buildings are the most solid and studied so far. Indeed, the economic loss assessment at territorial scale was born in the United States as support at the building insurance industries, in order to estimate the losses for future earthquakes. The first economic loss assessment studies were conducted by Freeman [66] and were aimed at estimating likely earthquake losses of some US areas and building types for the insurance industry. Soon after, Stainbrugge [67] reported the earthquake loss estimation by the insurance companies to identify insurance premiums. In 1973, Whitman et al. [68] identified the probabilistic nature of earthquake losses and introduced the concept of damage probability matrices into loss estimation methodology.

Starting from these initial studies, earthquake loss estimation methodologies at territorial level have become more rigorous and the interest of the Applied Technology Council (ATC) [69] and the Federal Emergency Management Agency (FEMA) [70] led to the development of the first earthquake loss assessment software, called HAZUS® (HAZards U.S.) [71] [72]. Other software packages for the evaluation of the earthquake losses were developed during 1990s and 2000s; they all include the PEER PBEE methodology described at § 1.3, but they differ in the combination of the methods for developing the four steps of the methodology. Examples of earthquake loss estimation at territorial level are: ELER [73], SELENA [74], DBELA [75], StrucLoss [76], LNECLOSS [77], ESCENARIS [78], EQSIM [79], SIGE [80], and others.

On the wave of the development of methodologies for earthquake loss assessment, sPBA, described at § 1.3, represents a simplified method that can be applied at territorial level as described soon after. By following the same procedure proposed for the sPBA methodology at building level, the safety performance assessment at national/regional/urban level is performed hereafter.

Before developing the steps for the estimation of earthquake losses, two initial phases have to be highlighted: the collection of data referred to the buildings exposed to the considered hazards, and the classification of the buildings themselves into groups having similar structural and non-structural characteristics. Successively, paragraph §2.3.3 will deal with the development of the sPBA methodology steps at national/regional/urban level. Initial costs for buildings construction and, finally, total costs for structural performance are discussed in § 2.3.4 and § 2.3.5.

2.3.1 Data gathering

In order to apply the Sustainable Structural Design (SSD) at territorial scale, the existing building stock exposed to natural hazards and environmental risks has to be analysed. Data collection of buildings exposed to risks is a time-consuming and expensive activity. Several techniques for data gathering are available:

- remote sensing systems, which allow the identification of building location, planar view, built-up density, roof type, building age, geometrical parameters (shape, perimeter, size height, volume) through the use of satellite sensors;
- census survey, where data are available as statistical aggregations at the level of administrative units. Since they are sensitive information, rarely census data include cadastral data, providing information about: wall and roof material, age of construction, conservation state, number of floors, and number of households per building;
- field survey, which is the most resource-consuming technique but aims at collecting more precise data. In Italy, an ongoing field survey of all the existing building (CARTIS Project, founded by ReLUIS [81]) is collecting all the relevant building characteristics. Results from this survey could be used also for providing data on the total national floor area, which is useful for the energy performance assessment.

Moving from the first data gathering technique to the last one, more resources, in terms of time and money, are involved; nevertheless, it is clear that the quality and the quantity of the achievable information increase.

2.3.1.1 *CARTIS Project*

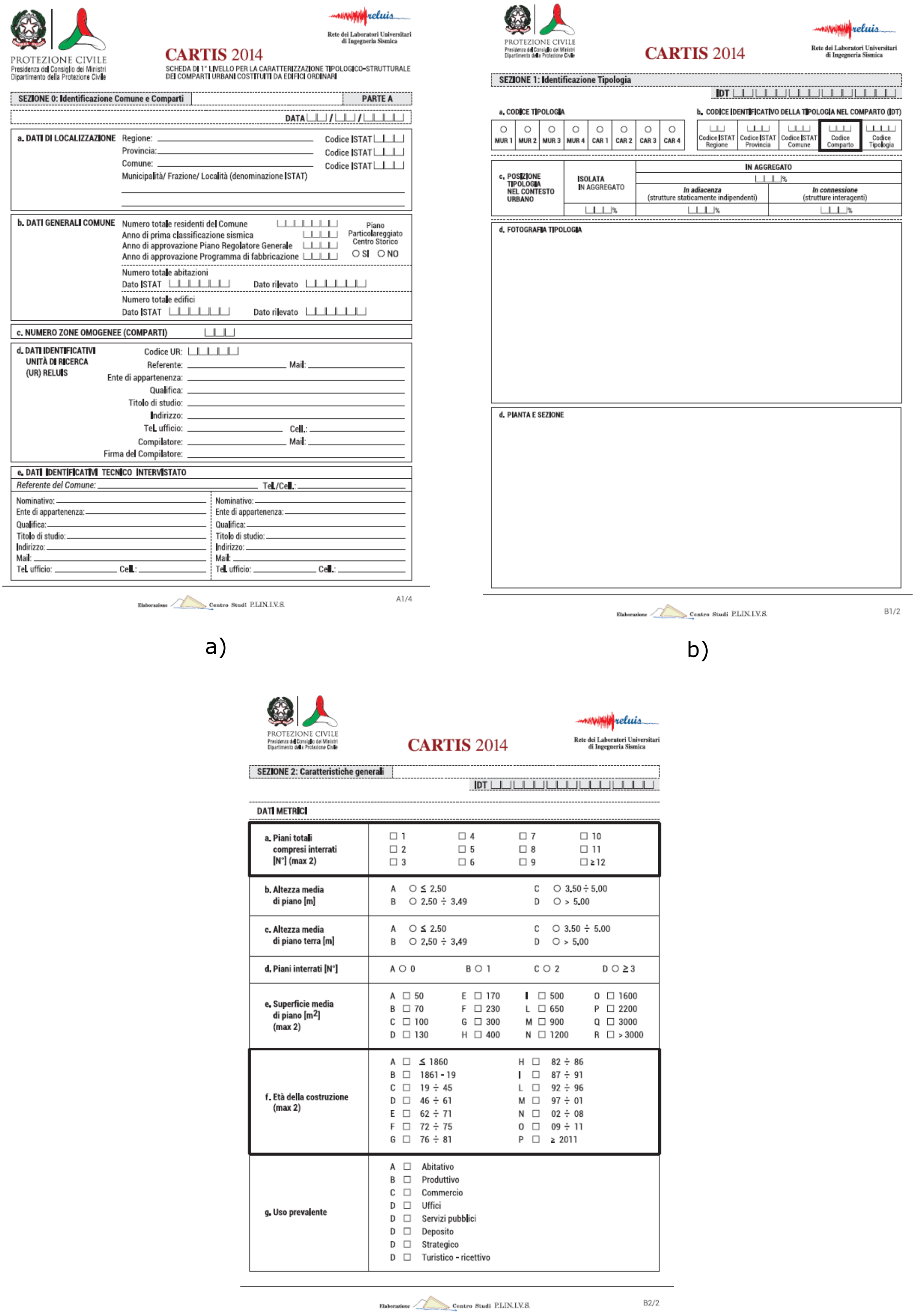
CARTIS Project, founded by the Italian Civil Protection and developed by ReLUIS (2014-2016) [81], is finalized at achieving a survey of residential and service buildings (excluding monuments, special and strategic structures) at municipality level, having similar characteristics in terms of urban fabric homogeneity (same construction age, construction materials, construction techniques, …). The group of similar buildings is called "comparto" (compartment). This field survey aims at investigating the national building stock for the identification of local construction characteristics. Indeed, different construction techniques have been developed on national territory during the centuries, according to different cultures and local conditionings that have influenced the construction quality.

CARTIS survey is realized by means of a CARTIS form, which is divided into four sections:

- Section 0, for the Municipal and Compartment identification;
- Section 1, for the typological identification of each considered Compartment;
- Section 2, for the identification of the generic characteristics of the Compartment typology;
- Section 3, for the structural characterization of the buildings. Section 3 is also divided into three sections: section 3.1A, for masonry and mixed structures characterization; section 3.1B, for reinforced concrete structures characterization; section 3.2 for additional building information

Figure 32 shows the CARTIS form to be compiled for each identified Municipal compartment.

Figure 32. CARTIS Project form: a) Municipal and Compartment identification; b) typological identification of each considered Compartment; c) generic characteristics of the Compartment typology; d) structural characterization of masonry and mixed structures; e) structural characterization of reinforced concrete structures; f) additional building information



PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Rete dei Laboratori Universitari di Ingegneria Sismica

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SCHEDA DI 1° LIVELLO PER LA CARATTERIZZAZIONE TIPOLOGICO-STRUTTURALE DEI COMPARTI URBANI COSTITUITI DA EDIFICI ORDINARI

SEZIONE 0: Identificazione Comune e Comparti — **PARTE A**

DATA ☐☐ / ☐☐ / ☐☐☐☐

a. DATI DI LOCALIZZAZIONE
Regione: ____ Codice ISTAT ☐☐☐
Provincia: ____ Codice ISTAT ☐☐☐
Comune: ____ Codice ISTAT ☐☐☐
Municipalità/ Frazione/ Località (denominazione ISTAT)

b. DATI GENERALI COMUNE
Numero totale residenti del Comune ☐☐☐☐☐☐☐
Anno di prima classificazione sismica ☐☐☐☐
Anno di approvazione Piano Regolatore Generale ☐☐☐☐
Anno di approvazione Programma di fabbricazione ☐☐☐☐
Piano Particolareggiato Centro Storico ○ SI ○ NO
Numero totale abitazioni
Dato ISTAT ☐☐☐☐☐☐ Dato rilevato ☐☐☐☐☐☐
Numero totale edifici
Dato ISTAT ☐☐☐☐☐☐ Dato rilevato ☐☐☐☐☐☐

c. NUMERO ZONE OMOGENEE (COMPARTI) ☐☐☐

d. DATI IDENTIFICATIVI UNITÀ DI RICERCA (UR) RELUIS
Codice UR: ☐☐☐☐☐
Referente: ____ Mail: ____
Ente di appartenenza: ____
Qualifica: ____
Titolo di studio: ____
Indirizzo: ____
Tel. ufficio: ____ Cell.: ____
Compilatore: ____ Mail: ____
Firma del Compilatore: ____

e. DATI IDENTIFICATIVI TECNICO INTERVISTATO
Referente del Comune: ____ Tel./Cell.: ____

Nominativo: ____	Nominativo: ____
Ente di appartenenza: ____	Ente di appartenenza: ____
Qualifica: ____	Qualifica: ____
Titolo di studio: ____	Titolo di studio: ____
Indirizzo: ____	Indirizzo: ____
Mail: ____	Mail: ____
Tel. ufficio: ____ Cell.: ____	Tel. ufficio: ____ Cell.: ____

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a)

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SEZIONE 1: Identificazione Tipologia

IDT ☐☐ ☐☐☐ ☐☐☐ ☐☐☐ ☐☐☐☐

a. CODICE TIPOLOGIA

○ MUR 1	○ MUR 2	○ MUR 3	○ MUR 4	○ CAR 1	○ CAR 2	○ CAR 3	○ CAR 4

b. CODICE IDENTIFICATIVO DELLA TIPOLOGIA NEL COMPARTO (IDT)

☐☐ Codice ISTAT Regione	☐☐☐ Codice ISTAT Provincia	☐☐☐ Codice ISTAT Comune	☐☐☐ Codice Comparto	☐☐☐☐ Codice Tipologia

c. POSIZIONE TIPOLOGIA NEL CONTESTO URBANO	ISOLATA IN AGGREGATO	IN AGGREGATO ☐☐☐%	
		In adiacenza (strutture staticamente indipendenti)	*In connessione* (strutture interagenti)
	☐☐☐%	☐☐☐%	☐☐☐%

d. FOTOGRAFIA TIPOLOGIA

d. PIANTA E SEZIONE

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b)

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SEZIONE 2: Caratteristiche generali

IDT ☐☐ ☐☐☐ ☐☐☐ ☐☐☐ ☐☐☐☐

DATI METRICI

a. Piani totali compresi interrati [N°] (max 2)	☐ 1 ☐ 4 ☐ 7 ☐ 10 ☐ 2 ☐ 5 ☐ 8 ☐ 11 ☐ 3 ☐ 6 ☐ 9 ☐ ≥12
b. Altezza media di piano [m]	A ○ ≤ 2.50 C ○ 3.50 ÷ 5.00 B ○ 2.50 ÷ 3.49 D ○ > 5.00
c. Altezza media di piano terra [m]	A ○ ≤ 2.50 C ○ 3.50 ÷ 5.00 B ○ 2.50 ÷ 3.49 D ○ > 5.00
d. Piani interrati [N°]	A ○ 0 B ○ 1 C ○ 2 D ○ ≥ 3
e. Superficie media di piano [m^2] (max 2)	A ☐ 50 E ☐ 170 I ☐ 500 O ☐ 1600 B ☐ 70 F ☐ 230 L ☐ 650 P ☐ 2200 C ☐ 100 G ☐ 300 M ☐ 900 Q ☐ 3000 D ☐ 130 H ☐ 400 N ☐ 1200 R ☐ > 3000
f. Età della costruzione (max 2)	A ☐ ≤ 1860 H ☐ 82 ÷ 86 B ☐ 1861 - 19 I ☐ 87 ÷ 91 C ☐ 19 ÷ 45 L ☐ 92 ÷ 96 D ☐ 46 ÷ 61 M ☐ 97 ÷ 01 E ☐ 62 ÷ 71 N ☐ 02 ÷ 08 F ☐ 72 ÷ 75 O ☐ 09 ÷ 11 G ☐ 76 ÷ 81 P ☐ ≥ 2011
g. Uso prevalente	A ☐ Abitativo B ☐ Produttivo C ☐ Commercio D ☐ Uffici D ☐ Servizi pubblici D ☐ Deposito D ☐ Strategico D ☐ Turistico - ricettivo

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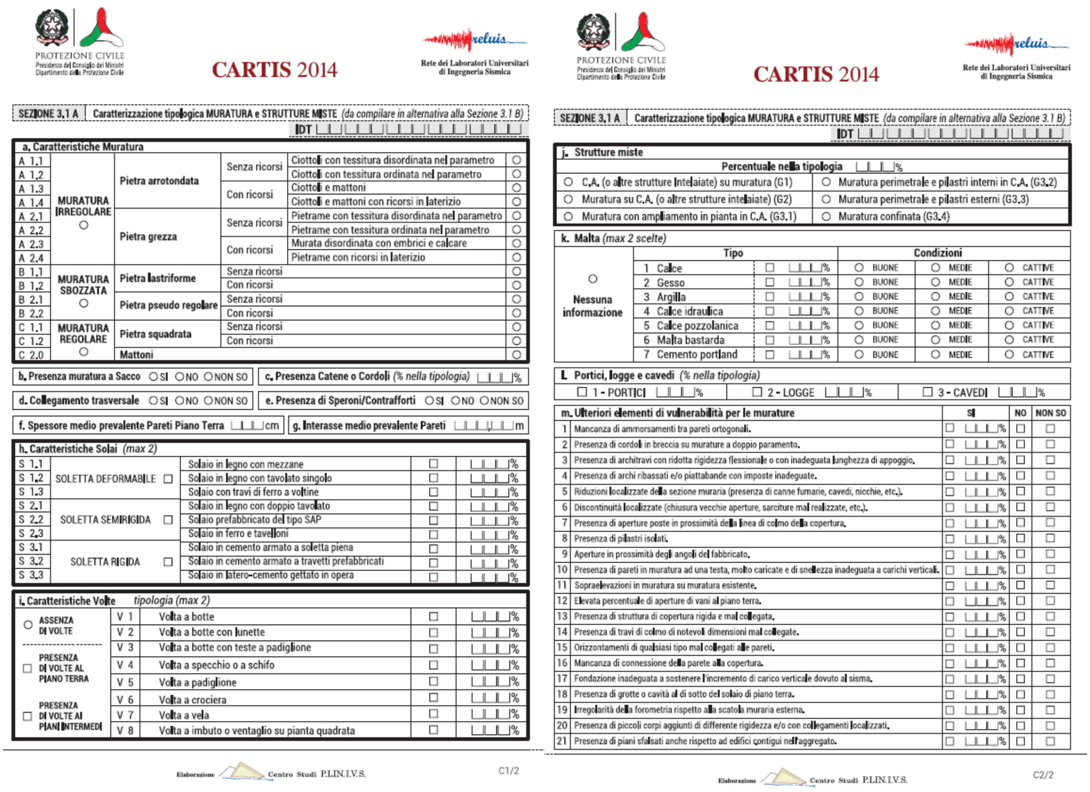
c)



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SEZIONE 3.1 A | **Caratterizzazione tipologica MURATURA e STRUTTURE MISTE** *(da compilare in alternativa alla Sezione 3.1 B)*

IDT ___

a. Caratteristiche Muratura

A 1.1	**MURATURA IRREGOLARE** ○	**Pietra arrotondata**	Senza ricorsi	Ciottoli con tessitura disordinata nel parametro	○
A 1.2				Ciottoli con tessitura ordinata nel parametro	○
A 1.3			Con ricorsi	Ciottoli e mattoni	○
A 1.4				Ciottoli e mattoni con ricorsi in laterizio	○
A 2.1		**Pietra grezza**	Senza ricorsi	Pietrame con tessitura disordinata nel parametro	○
A 2.2				Pietrame con tessitura ordinata nel parametro	○
A 2.3			Con ricorsi	Murata disordinata con embrici e calcare	○
A 2.4				Pietrame con ricorsi in laterizio	○
B 1.1	**MURATURA SBOZZATA** ○	**Pietra lastriforme**	Senza ricorsi		○
B 1.2			Con ricorsi		○
B 2.1		**Pietra pseudo regolare**	Senza ricorsi		○
B 2.2			Con ricorsi		○
C 1.1	**MURATURA REGOLARE** ○	**Pietra squadrata**	Senza ricorsi		○
C 1.2			Con ricorsi		○
C 2.0		**Mattoni**			○

b. Presenza muratura a Sacco ○SI ○NO ○NON SO

c. Presenza Catene o Cordoli *(% nella tipologia)* ___%

d. Collegamento trasversale ○SI ○NO ○NON SO

e. Presenza di Speroni/Contrafforti ○SI ○NO ○NON SO

f. Spessore medio prevalente Pareti Piano Terra ___cm

g. Interasse medio prevalente Pareti ___,___m

h. Caratteristiche Solai *(max 2)*

S 1.1	SOLETTA DEFORMABILE ☐	Solaio in legno con mezzane	☐	___%
S 1.2		Solaio in legno con tavolato singolo	☐	___%
S 1.3		Solaio con travi di ferro a voltine	☐	___%
S 2.1	SOLETTA SEMIRIGIDA ☐	Solaio in legno con doppio tavolato	☐	___%
S 2.2		Solaio prefabbricato del tipo SAP	☐	___%
S 2.3		Solaio in ferro e tavelloni	☐	___%
S 3.1	SOLETTA RIGIDA ☐	Solaio in cemento armato a soletta piena	☐	___%
S 3.2		Solaio in cemento armato a travetti prefabbricati	☐	___%
S 3.3		Solaio in latero-cemento gettato in opera	☐	___%

i. Caratteristiche Volte *tipologia (max 2)*

○ **ASSENZA DI VOLTE**	V 1	Volta a botte	☐	___%
	V 2	Volta a botte con lunette	☐	___%
☐ **PRESENZA DI VOLTE AL PIANO TERRA**	V 3	Volta a botte con teste a padiglione	☐	___%
	V 4	Volta a specchio o a schifo	☐	___%
	V 5	Volta a padiglione	☐	___%
☐ **PRESENZA DI VOLTE AI PIANI INTERMEDI**	V 6	Volta a crociera	☐	___%
	V 7	Volta a vela	☐	___%
	V 8	Volta a imbuto o ventaglio su pianta quadrata	☐	___%

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SEZIONE 3.1 A | **Caratterizzazione tipologica MURATURA e STRUTTURE MISTE** *(da compilare in alternativa alla Sezione 3.1 B)*

IDT ___

j. Strutture miste

Percentuale nella tipologia ___%

○ C.A. (o altre strutture Intelaiate) su muratura (G1)	○ Muratura perimetrale e pilastri interni in C.A. (G3.2)
○ Muratura su C.A. (o altre strutture intelaiate) (G2)	○ Muratura perimetrale e pilastri esterni (G3.3)
○ Muratura con ampliamento in pianta in C.A. (G3.1)	○ Muratura confinata (G3.4)

k. Malta *(max 2 scelte)*

	Tipo			Condizioni		
○ **Nessuna informazione**	1 Calce	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	2 Gesso	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	3 Argilla	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	4 Calce idraulica	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	5 Calce pozzolanica	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	6 Malta bastarda	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE
	7 Cemento portland	☐	___%	○ BUONE	○ MEDIE	○ CATTIVE

L Portici, logge e cavedi *(% nella tipologia)*

☐ 1 - PORTICI ___% ☐ 2 - LOGGE ___% ☐ 3 - CAVEDI ___%

	m. Ulteriori elementi di vulnerabilità per le murature	**SI**		**NO**	**NON SO**
1	Mancanza di ammorsamenti tra pareti ortogonali.	☐	___%	☐	☐
2	Presenza di cordoli in breccia su murature a doppio paramento.	☐	___%	☐	☐
3	Presenza di architravi con ridotta rigidezza flessionale o con inadeguata lunghezza di appoggio.	☐	___%	☐	☐
4	Presenza di archi ribassati e/o piattabande con imposte inadeguate.	☐	___%	☐	☐
5	Riduzioni localizzate della sezione muraria (presenza di canne fumarie, cavedi, nicchie, etc.).	☐	___%	☐	☐
6	Discontinuità localizzate (chiusura vecchie aperture, sarciture mal realizzate, etc.).	☐	___%	☐	☐
7	Presenza di aperture poste in prossimità della linea di colmo della copertura.	☐	___%	☐	☐
8	Presenza di pilastri isolati.	☐	___%	☐	☐
9	Aperture in prossimità degli angoli del fabbricato.	☐	___%	☐	☐
10	Presenza di pareti in muratura ad una testa, molto caricate e di snellezza inadeguata a carichi verticali.	☐	___%	☐	☐
11	Sopraelevazioni in muratura su muratura esistente.	☐	___%	☐	☐
12	Elevata percentuale di aperture di vani al piano terra.	☐	___%	☐	☐
13	Presenza di struttura di copertura rigida e mal collegata.	☐	___%	☐	☐
14	Presenza di travi di colmo di notevoli dimensioni mal collegate.	☐	___%	☐	☐
15	Orizzontamenti di qualsiasi tipo mal collegati alle pareti.	☐	___%	☐	☐
16	Mancanza di connessione della parete alla copertura.	☐	___%	☐	☐
17	Fondazione inadeguata a sostenere l'incremento di carico verticale dovuto al sisma.	☐	___%	☐	☐
18	Presenza di grotte o cavità al di sotto del solaio di piano terra.	☐	___%	☐	☐
19	Irregolarità della forometria rispetto alla scatola muraria esterna.	☐	___%	☐	☐
20	Presenza di piccoli corpi aggiunti di differente rigidezza e/o con collegamenti localizzati.	☐	___%	☐	☐
21	Presenza di piani sfalsati anche rispetto ad edifici contigui nell'aggregato.	☐	___%	☐	☐

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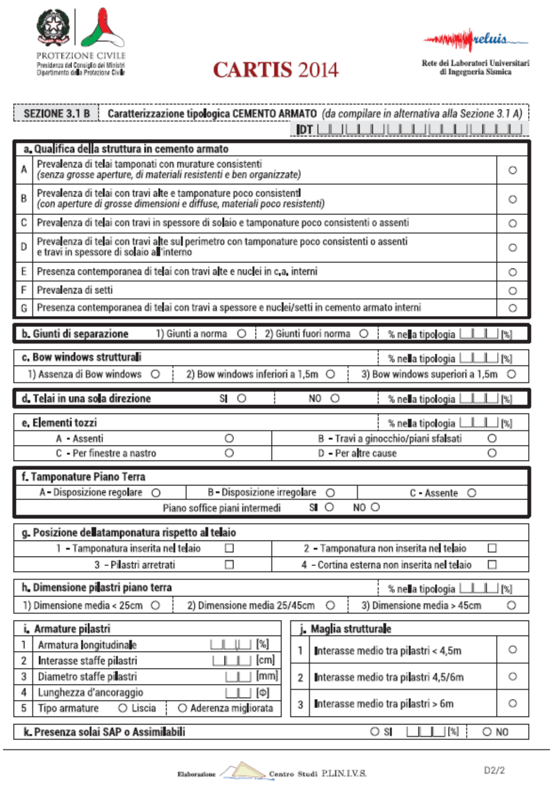
C2/2

d)



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SEZIONE 3.1 B | **Caratterizzazione tipologica CEMENTO ARMATO** *(da compilare in alternativa alla Sezione 3.1 A)*

IDT ___

a. Qualifica della struttura in cemento armato

A	Prevalenza di telai tamponati con murature consistenti *(senza grosse aperture, di materiali resistenti e ben organizzate)*	○
B	Prevalenza di telai con travi alte e tamponature poco consistenti *(con aperture di grosse dimensioni e diffuse, materiali poco resistenti)*	○
C	Prevalenza di telai con travi in spessore di solaio e tamponature poco consistenti o assenti	○
D	Prevalenza di telai con travi alte sul perimetro con tamponature poco consistenti o assenti e travi in spessore di solaio all'interno	○
E	Presenza contemporanea di telai con travi alte e nuclei in c.a. interni	○
F	Prevalenza di setti	○
G	Presenza contemporanea di telai con travi a spessore e nuclei/setti in cemento armato interni	○

b. Giunti di separazione 1) Giunti a norma ○ 2) Giunti fuori norma ○ % nella tipologia ___ [%]

c. Bow windows strutturali % nella tipologia ___ [%]
1) Assenza di Bow windows ○ 2) Bow windows inferiori a 1,5m ○ 3) Bow windows superiori a 1,5m ○

d. Telai in una sola direzione SI ○ NO ○ % nella tipologia ___ [%]

e. Elementi tozzi % nella tipologia ___ [%]

A - Assenti ○	B - Travi a ginocchio/piani sfalsati ○
C - Per finestre a nastro ○	D - Per altre cause ○

f. Tamponature Piano Terra
A - Disposizione regolare ○ B - Disposizione irregolare ○ C - Assente ○
Piano soffice piani intermedi SI ○ NO ○

g. Posizione dellatamponatura rispetto al telaio

1 - Tamponatura inserita nel telaio ☐	2 - Tamponatura non inserita nel telaio ☐
3 - Pilastri arretrati ☐	4 - Cortina esterna non inserita nel telaio ☐

h. Dimensione pilastri piano terra % nella tipologia ___ [%]
1) Dimensione media < 25cm ○ 2) Dimensione media 25/45cm ○ 3) Dimensione media > 45cm ○

i. Armature pilastri

1	Armatura longitudinale	___	[%]
2	Interasse staffe pilastri	___	[cm]
3	Diametro staffe pilastri	___	[mm]
4	Lunghezza d'ancoraggio	___	[Φ]
5	Tipo armature	○ Liscia	○ Aderenza migliorata

j. Maglia strutturale

1	Interasse medio tra pilastri < 4,5m	○
2	Interasse medio tra pilastri 4,5/6m	○
3	Interasse medio tra pilastri > 6m	○

k. Presenza solai SAP o Assimilabili ○ SI ___ [%] ○ NO

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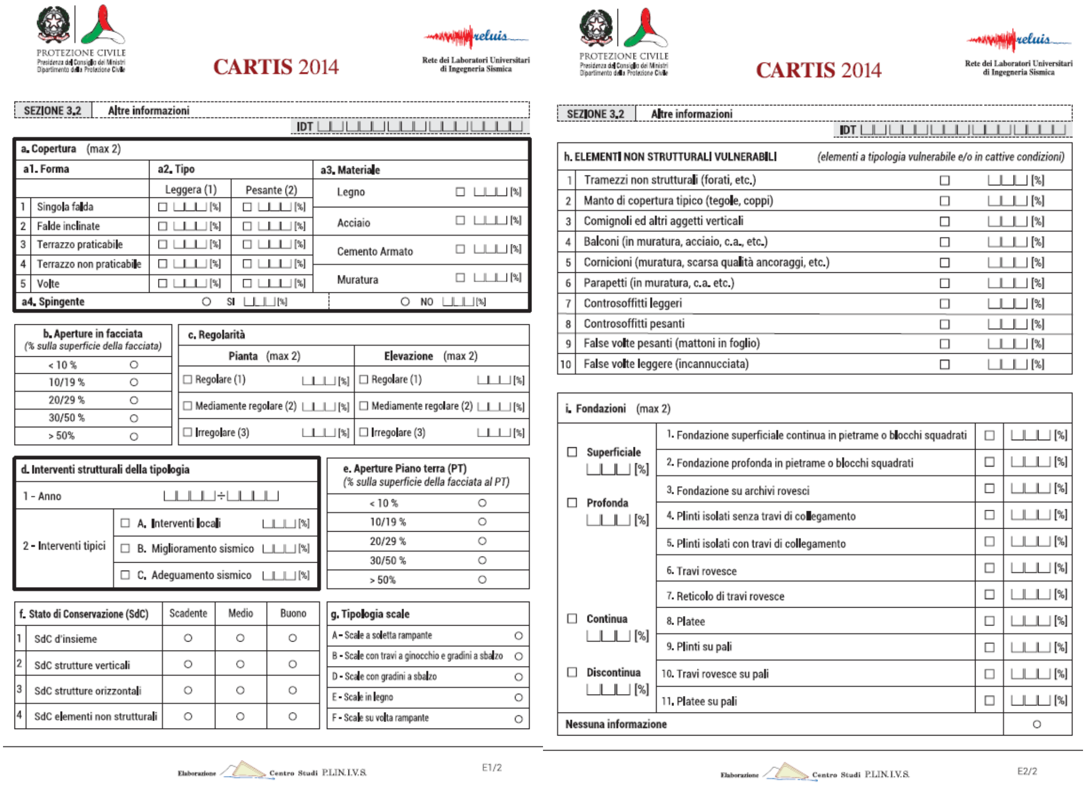
D2/2

e)



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SEZIONE 3.2	Altre informazioni

IDT └┴┘└┴┴┘└┴┴┘└┴┴┘└┴┴┘

a. Copertura (max 2)			
a1. Forma	a2. Tipo		a3. Materiale
	Leggera (1)	Pesante (2)	
1 Singola falda	☐ └┴┴┘ [%]	☐ └┴┴┘ [%]	Legno ☐ └┴┴┘ [%]
2 Falde inclinate	☐ └┴┴┘ [%]	☐ └┴┴┘ [%]	Acciaio ☐ └┴┴┘ [%]
3 Terrazzo praticabile	☐ └┴┴┘ [%]	☐ └┴┴┘ [%]	Cemento Armato ☐ └┴┴┘ [%]
4 Terrazzo non praticabile	☐ └┴┴┘ [%]	☐ └┴┴┘ [%]	Muratura ☐ └┴┴┘ [%]
5 Volte	☐ └┴┴┘ [%]	☐ └┴┴┘ [%]	
a4. Spingente	○ SI └┴┴┘ [%]		○ NO └┴┴┘ [%]

b. Aperture in facciata *(% sulla superficie della facciata)*	
< 10 %	○
10/19 %	○
20/29 %	○
30/50 %	○
> 50%	○

c. Regolarità	
Pianta (max 2)	Elevazione (max 2)
☐ Regolare (1) └┴┴┘ [%]	☐ Regolare (1) └┴┴┘ [%]
☐ Mediamente regolare (2) └┴┴┘ [%]	☐ Mediamente regolare (2) └┴┴┘ [%]
☐ Irregolare (3) └┴┴┘ [%]	☐ Irregolare (3) └┴┴┘ [%]

d. Interventi strutturali della tipologia	
1 - Anno	└┴┴┴┘÷└┴┴┴┘
2 - Interventi tipici	☐ A. Interventi locali └┴┴┘ [%]
	☐ B. Miglioramento sismico └┴┴┘ [%]
	☐ C. Adeguamento sismico └┴┴┘ [%]

e. Aperture Piano terra (PT) *(% sulla superficie della facciata al PT)*	
< 10 %	○
10/19 %	○
20/29 %	○
30/50 %	○
> 50%	○

	f. Stato di Conservazione (SdC)	Scadente	Medio	Buono
1	SdC d'insieme	○	○	○
2	SdC strutture verticali	○	○	○
3	SdC strutture orizzontali	○	○	○
4	SdC elementi non strutturali	○	○	○

g. Tipologia scale	
A - Scale a soletta rampante	○
B - Scale con travi a ginocchio e gradini a sbalzo	○
D - Scale con gradini a sbalzo	○
E - Scale in legno	○
F - Scale su volta rampante	○

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E1/2

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SEZIONE 3.2	Altre informazioni

IDT └┴┘└┴┴┘└┴┴┘└┴┴┘└┴┴┘

	h. ELEMENTI NON STRUTTURALI VULNERABILI *(elementi a tipologia vulnerabile e/o in cattive condizioni)*		
1	Tramezzi non strutturali (forati, etc.)	☐	└┴┴┘ [%]
2	Manto di copertura tipico (tegole, coppi)	☐	└┴┴┘ [%]
3	Comignoli ed altri aggetti verticali	☐	└┴┴┘ [%]
4	Balconi (in muratura, acciaio, c.a., etc.)	☐	└┴┴┘ [%]
5	Cornicioni (muratura, scarsa qualità ancoraggi, etc.)	☐	└┴┴┘ [%]
6	Parapetti (in muratura, c.a. etc.)	☐	└┴┴┘ [%]
7	Controsoffitti leggeri	☐	└┴┴┘ [%]
8	Controsoffitti pesanti	☐	└┴┴┘ [%]
9	False volte pesanti (mattoni in foglio)	☐	└┴┴┘ [%]
10	False volte leggere (incannucciata)	☐	└┴┴┘ [%]

i. Fondazioni (max 2)			
☐ Superficiale └┴┴┘ [%]	1. Fondazione superficiale continua in pietrame o blocchi squadrati	☐	└┴┴┘ [%]
	2. Fondazione profonda in pietrame o blocchi squadrati	☐	└┴┴┘ [%]
☐ Profonda └┴┴┘ [%]	3. Fondazione su archivi rovesci	☐	└┴┴┘ [%]
	4. Plinti isolati senza travi di collegamento	☐	└┴┴┘ [%]
	5. Plinti isolati con travi di collegamento	☐	└┴┴┘ [%]
	6. Travi rovesce	☐	└┴┴┘ [%]
	7. Reticolo di travi rovesce	☐	└┴┴┘ [%]
☐ Continua └┴┴┘ [%]	8. Platee	☐	└┴┴┘ [%]
	9. Plinti su pali	☐	└┴┴┘ [%]
☐ Discontinua └┴┴┘ [%]	10. Travi rovesce su pali	☐	└┴┴┘ [%]
	11. Platee su pali	☐	└┴┴┘ [%]
Nessuna informazione			○

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E2/2

f)

CARTIS survey will lead to the national data gathering on building stock and to the identification of groups of similar buildings (compartments).

2.3.2 Building stock classification

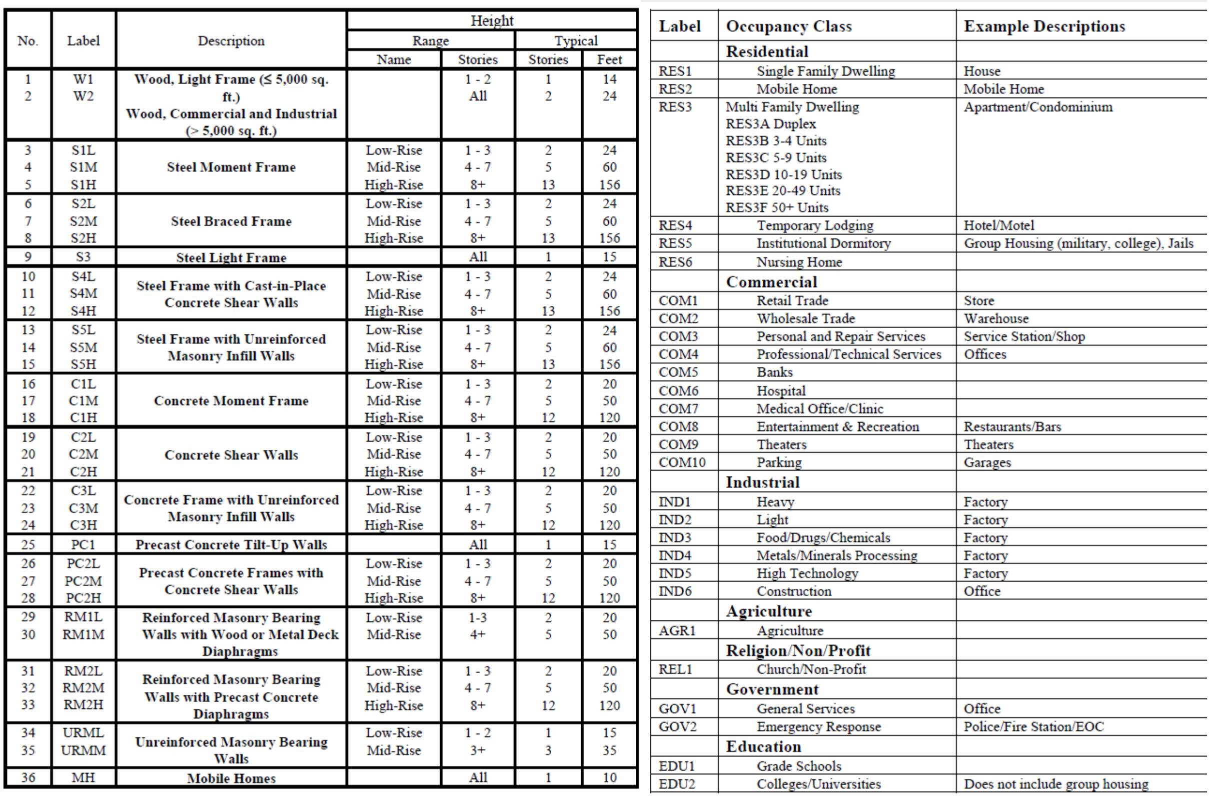
When the building stock information are gathered, the building groups having similar characteristics have to be tagged with a territorially homogeneous label. Several building stock taxonomies have been developed in past and recent years.

HAZUS software [72] and the European Commission funded RISK-UE project (RISK-UE, 2001-2004) [82] have identified two different building taxonomies that typify, respectively, the US and the European building stocks.

To account for structural and non-structural parameters of US building stock, **HAZUS** software has acquired the FEMA-178 classification [83], which includes 36 building classes having different structural materials (wood, steel, reinforced concrete, precast reinforced concrete and masonry), structural systems (framed structure, infill walls, bearing walls,…) and heights (three classes are distinguished depending of the number of floors). Moreover, to account for the occupancy parameters, HAZUS has developed a list of 33 building classes, grouped into seven macro categories. HAZUS classification is suitable for all the three considered hazard models (earthquake, wind and flood).

In Table 12., the list of the 36 HAZUS structural building types, with corresponding labels, descriptions, and heights is provided on the left, while the list of the 33 building occupancy classes, with corresponding labels and examples is provided on the right.

Table 12. Building Structure (Model Building) Types (left) and Building Occupancy Classes (right) according to HAZUS software [72]



No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	W1	**Wood, Light Frame (≤ 5,000 sq. ft.)**		1 - 2	1	14
2	W2	**Wood, Commercial and Industrial (> 5,000 sq. ft.)**		All	2	24
3	S1L	**Steel Moment Frame**	Low-Rise	1 - 3	2	24
4	S1M		Mid-Rise	4 - 7	5	60
5	S1H		High-Rise	8+	13	156
6	S2L	**Steel Braced Frame**	Low-Rise	1 - 3	2	24
7	S2M		Mid-Rise	4 - 7	5	60
8	S2H		High-Rise	8+	13	156
9	S3	**Steel Light Frame**		All	1	15
10	S4L	**Steel Frame with Cast-in-Place Concrete Shear Walls**	Low-Rise	1 - 3	2	24
11	S4M		Mid-Rise	4 - 7	5	60
12	S4H		High-Rise	8+	13	156
13	S5L	**Steel Frame with Unreinforced Masonry Infill Walls**	Low-Rise	1 - 3	2	24
14	S5M		Mid-Rise	4 - 7	5	60
15	S5H		High-Rise	8+	13	156
16	C1L	**Concrete Moment Frame**	Low-Rise	1 - 3	2	20
17	C1M		Mid-Rise	4 - 7	5	50
18	C1H		High-Rise	8+	12	120
19	C2L	**Concrete Shear Walls**	Low-Rise	1 - 3	2	20
20	C2M		Mid-Rise	4 - 7	5	50
21	C2H		High-Rise	8+	12	120
22	C3L	**Concrete Frame with Unreinforced Masonry Infill Walls**	Low-Rise	1 - 3	2	20
23	C3M		Mid-Rise	4 - 7	5	50
24	C3H		High-Rise	8+	12	120
25	PC1	**Precast Concrete Tilt-Up Walls**		All	1	15
26	PC2L	**Precast Concrete Frames with Concrete Shear Walls**	Low-Rise	1 - 3	2	20
27	PC2M		Mid-Rise	4 - 7	5	50
28	PC2H		High-Rise	8+	12	120
29	RM1L	**Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms**	Low-Rise	1-3	2	20
30	RM1M		Mid-Rise	4+	5	50
31	RM2L	**Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms**	Low-Rise	1 - 3	2	20
32	RM2M		Mid-Rise	4 - 7	5	50
33	RM2H		High-Rise	8+	12	120
34	URML	**Unreinforced Masonry Bearing Walls**	Low-Rise	1 - 2	1	15
35	URMM		Mid-Rise	3+	3	35
36	MH	**Mobile Homes**		All	1	10

Label	**Occupancy Class**	**Example Descriptions**
	Residential	
RES1	Single Family Dwelling	House
RES2	Mobile Home	Mobile Home
RES3	Multi Family Dwelling RES3A Duplex RES3B 3-4 Units RES3C 5-9 Units RES3D 10-19 Units RES3E 20-49 Units RES3F 50+ Units	Apartment/Condominium
RES4	Temporary Lodging	Hotel/Motel
RES5	Institutional Dormitory	Group Housing (military, college), Jails
RES6	Nursing Home	
	Commercial	
COM1	Retail Trade	Store
COM2	Wholesale Trade	Warehouse
COM3	Personal and Repair Services	Service Station/Shop
COM4	Professional/Technical Services	Offices
COM5	Banks	
COM6	Hospital	
COM7	Medical Office/Clinic	
COM8	Entertainment & Recreation	Restaurants/Bars
COM9	Theaters	Theaters
COM10	Parking	Garages
	Industrial	
IND1	Heavy	Factory
IND2	Light	Factory
IND3	Food/Drugs/Chemicals	Factory
IND4	Metals/Minerals Processing	Factory
IND5	High Technology	Factory
IND6	Construction	Office
	Agriculture	
AGR1	Agriculture	
	Religion/Non/Profit	
REL1	Church/Non-Profit	
	Government	
GOV1	General Services	Office
GOV2	Emergency Response	Police/Fire Station/EOC
	Education	
EDU1	Grade Schools	
EDU2	Colleges/Universities	Does not include group housing

The first Work Package (WP01) of the RISK-UE Project [82] has led to the analysis of the distinctive European features of existing buildings. To account for structural classification of the European and Mediterranean building stock, RISK-UE Project has proposed a list of 23 building classes, grouped by the structural types and material of construction (Table 13). Three different height classes (low-rise, mid-rise and high-rise) represent further sub-groups. The classification system, referred to as the Building Typology Matrix (BTM), is essentially based on structural materials, structural systems and number of floor, and does not include information about age and occupancy.

Table 13. Matrix of typology of selected structured European buildings according to RISK-UE [82]

Label	**Description**	**Sub-classification**	
M1	Stone Masonry Bearing Walls made of	Rubble stone, fieldstone (M11)	Low-rise 1-2 floors M11L
			Mid-rise 3-5 floors M11M
		Simple stone (M12)	Low-rise 1-2 floors M12L
			Mid-rise 3-5 floors M12M
			High-rise >6 floors M12H
		Massive stone (M13)	
M2	Adobe		Low rise 1-2 floors M2L
M3	Unreinforced Masonry Bearing Walls with	Masonry with wooden slabs (M31)	Low-rise 1-2 floors M31L
			Mid-rise 3-5 floors M31M
			High-rise >6 floors M31H
		Masonry vaults (M32)	Low-rise 1-2 floors M32L
			Mid-rise 3-5 floors M32M
			High-rise >6 floors M32H
		Composite steel and masonry slabs (M33)	Low-rise 1-2 floors M33L
			Mid-rise 3-5 floors M33M
			High-rise >6 floors M33H

		Reinforced concrete slabs (M34)	Low-rise 1-2 floors M34L
			Mid-rise 3-5 floors M34M
			High-rise >6 floors M34H
M4	Reinforced or confined masonry walls		Low-rise 1-2 floors M4L
			Mid-rise 3-5 floors M4M
			High-rise >6 floors M4H
M5	Overall strengthened		Low-rise 1-2 floors M5L
			Mid-rise 3-5 floors M5M
			High-rise >6 floors M5H
RC1	Concrete moment frame		Low-rise 1-2 floors RC1L
			Mid-rise 3-5 floors RC1M
			High-rise >6 floors RC1H
RC2	Concrete shear walls		Low-rise 1-2 floors RC2L
			Mid-rise 3-5 floors RC2M
			High-rise >6 floors RC2H
RC3	Concrete frames with unreinforced masonry infill walls	Regularly infilled walls (RC 31)	Low-rise 1-2 floors RC31L

			Mid-rise 3-5 floors RC31M
			High-rise >6 floors RC31H
		Irregularly infilled walls (RC 32)	Low-rise 1-2 floors RC32L
			Mid-rise 3-5 floors RC32M
			High-rise >6 floors RC32H
RC4	RC dual systems (RC frame and wall)		Low-rise 1-2 floors RC4L
			Mid-rise 3-5 floors RC4M
			High-rise >6 floors RC4H
RC5	Precast concrete tilt-up walls		Low-rise 1-2 floors RC5L
			Mid-rise 3-5 floors RC5M
			High-rise >6 floors RC5H
RC6	Precast Concrete Frames with Concrete Shear walls		Low-rise 1-2 floors RC6L
			Mid-rise 3-5 floors RC6M
			High-rise >6 floors RC6H
S1	Steel moment frame		Low-rise 1-2 floors S1L
			Mid-rise 3-5 floors S1M

			High-rise >6 floors S1H
S2	Steel braced frame		Low-rise 1-2 floors S2L
			Mid-rise 3-5 floors S2M
			High-rise >6 floors S2H
S3	Steel frame + unreinforced infill walls		Low-rise 1-2 floors S3L
			Mid-rise 3-5 floors S3M
			High-rise >6 floors S3H
S4	Steel frame + cast-in-place shear walls		Low-rise 1-2 floors S4L
			Mid-rise 3-5 floors S4M
			High-rise >6 floors S4H
S5	Steel and RC composite system		Low-rise 1-2 floors S5L
			Mid-rise 3-5 floors 5M
			High-rise >6 floors S5H
W	Wood structures		Low-rise 1-2 floors WL
			Mid-rise 3-5 floors WM

Starting from the building stock classification introduced by the European Commission funded RISK-UE project, a new building classification has been developed by **Giovinazzi** in 2005 [84]. The classification is more similar to the one proposed by HAZUS because it includes additional information. For all building typologies three classes of height have been considered (_L=Low-Rise, _M=Mid-Rise, _H=High-Rise), but, differently from RISK-UE building classification, the number of the floor differs from masonry (_L=1/2, _M=3/5, _H=≥6) and reinforced concrete buildings (_L=1/3,_M=4/7, _H=≥8). The building classification also takes in count the levels of seismic action (_I = zone I, _II = zone II, _III = zone III); and the ductility class (−WDC= without ductility class, −LDC= low ductility class, −MDC=medium ductility class, −HDC= high ductility class). Moreover, the type of horizontal structure has been considered for masonry buildings (wood slabs, M_w, masonry vaults, M_v, composite steel and masonry slabs, M_sm, reinforced concrete slabs M_ca).

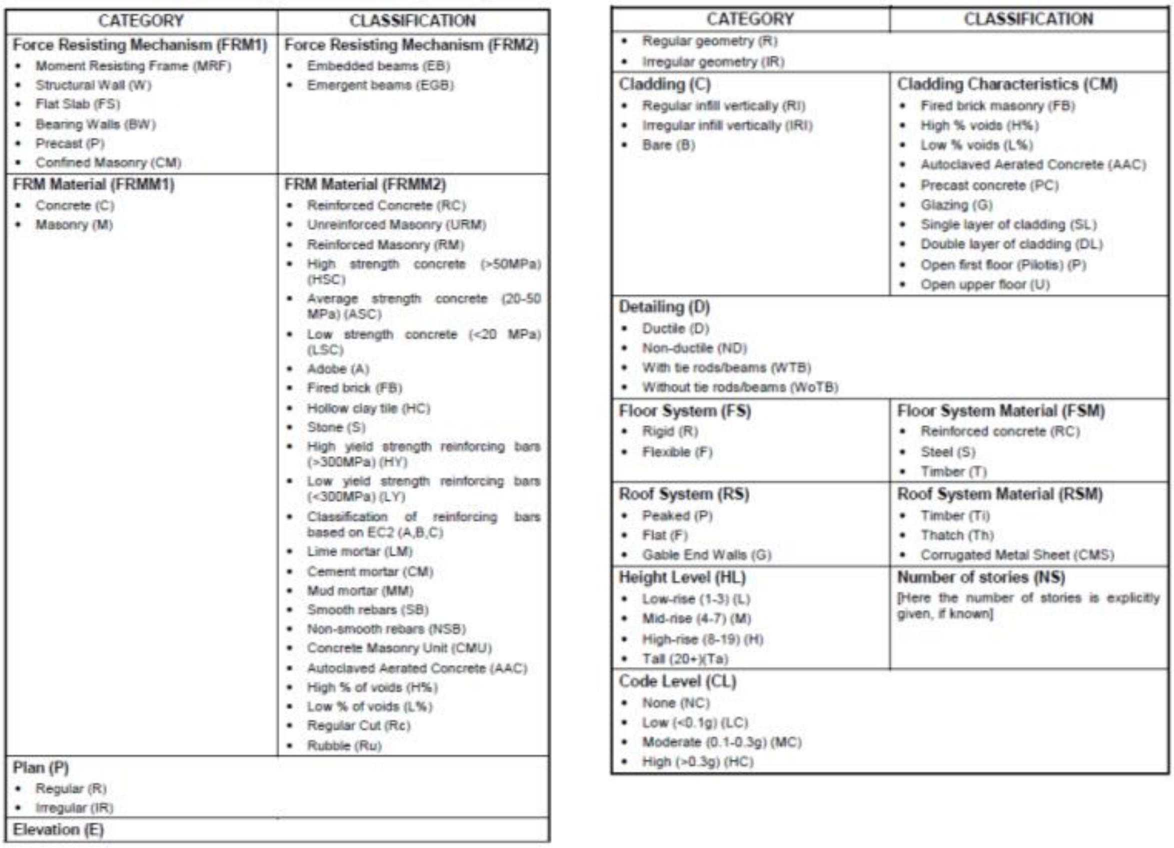
Jaiswal and Wald [85] have developed a global building stock using housing census and other statistical data coming from different sources, to be used in the PAGER (US Geological Survey's Prompt Assessment of Global Earthquake for Response) tool. This classification identifies 16 main categories and considers the materials, the structural systems and the number of floors.

Other considerable building taxonomies have been developed by **Coburn and Spence** [85], **MSK-64** (Medvedev-Sponheuer-Karnik), **EMS98** (European Macroseismic Scale) [86] and **WHE** (World Housing Encyclopaedia) [87]. Coburn and Spence building classification is based on the collected building typologies found in worldwide seismic areas. 24 building classes have been identified by Coburn and Spence [85] by considering characteristics about construction materials, structural systems and construction techniques. MSK-64 and EMS98 scales, respectively developed in 1964 and in 1998, are building typology catalogues basically realised in order to estimate the damage intensity on the buildings, soon after an occurred earthquake. MSK-64 is mainly based on the structural materials, while EM298 also considers the structural systems; consequently, EMS98 can better model the European building stock. WHE [87] is an Earthquake Engineering Research Institute (EERI) founded Project, aiming at building an online encyclopaedia of housing construction types in seismically active areas of the world. The WHE building classification includes 33 building typologies, which have been grouped considering construction materials, lateral load resisting systems and structural characteristics of the system.

Moreover, another building stock classification has been developed within the **Syner-G project**, a European collaborative research project funded by European Commission (Seventh Framework Program, Theme 6: Environment) to develop an integrated methodology for the systemic seismic vulnerability and risk analysis of buildings, transportation and utility networks and critical facilities. The Syner-G building classification [88] includes more information about buildings characteristics. The identified categories are shown in

Figure **33**. The building typology can be defined using the label put in the brackets for each parameter within a given category and following the order of the categories and classifications. As example, a building can be labelled as: MRF/C-RC/X/X/RI-FB-H%/ND/R-RC/X/L-2/NC; this building is a moment resisting frame (MRF), in reinforced concrete (C-RC) with regular external infill panels in brick with a high percentages of voids (RI-FB-H%), with non-ductile design details (ND), with rigid reinforced concrete floor (R-RC), low-rise, 2 storeys (L-2), not designed to a seismic code (NC). This taxonomy permits other categories and sub-categories to be easily added, in order to take into account all the different kinds of European buildings. The SYNER-G Project classification focuses only on masonry and RC buildings because they are identified as the main European building categories.

Figure 33. SYNER-G Taxonomy for RC and Masonry Buildings



CATEGORY	CLASSIFICATION
Force Resisting Mechanism (FRM1) • Moment Resisting Frame (MRF) • Structural Wall (W) • Flat Slab (FS) • Bearing Walls (BW) • Precast (P) • Confined Masonry (CM)	**Force Resisting Mechanism (FRM2)** • Embedded beams (EB) • Emergent beams (EGB)
FRM Material (FRMM1) • Concrete (C) • Masonry (M)	**FRM Material (FRMM2)** • Reinforced Concrete (RC) • Unreinforced Masonry (URM) • Reinforced Masonry (RM) • High strength concrete (>50MPa) (HSC) • Average strength concrete (20-50 MPa) (ASC) • Low strength concrete (<20 MPa) (LSC) • Adobe (A) • Fired brick (FB) • Hollow clay tile (HC) • Stone (S) • High yield strength reinforcing bars (>300MPa) (HY) • Low yield strength reinforcing bars (<300MPa) (LY) • Classification of reinforcing bars based on EC2 (A,B,C) • Lime mortar (LM) • Cement mortar (CM) • Mud mortar (MM) • Smooth rebars (SB) • Non-smooth rebars (NSB) • Concrete Masonry Unit (CMU) • Autoclaved Aerated Concrete (AAC) • High % of voids (H%) • Low % of voids (L%) • Regular Cut (Rc) • Rubble (Ru)
Plan (P) • Regular (R) • Irregular (IR)	
Elevation (E) • Regular geometry (R) • Irregular geometry (IR)	
Cladding (C) • Regular infill vertically (RI) • Irregular infill vertically (IRI) • Bare (B)	**Cladding Characteristics (CM)** • Fired brick masonry (FB) • High % voids (H%) • Low % voids (L%) • Autoclaved Aerated Concrete (AAC) • Precast concrete (PC) • Glazing (G) • Single layer of cladding (SL) • Double layer of cladding (DL) • Open first floor (Pilotis) (P) • Open upper floor (U)
Detailing (D) • Ductile (D) • Non-ductile (ND) • With tie rods/beams (WTB) • Without tie rods/beams (WoTB)	
Floor System (FS) • Rigid (R) • Flexible (F)	**Floor System Material (FSM)** • Reinforced concrete (RC) • Steel (S) • Timber (T)
Roof System (RS) • Peaked (P) • Flat (F) • Gable End Walls (G)	**Roof System Material (RSM)** • Timber (Ti) • Thatch (Th) • Corrugated Metal Sheet (CMS)
Height Level (HL) • Low-rise (1-3) (L) • Mid-rise (4-7) (M) • High-rise (8-19) (H) • Tall (20+)(Ta)	**Number of stories (NS)** [Here the number of stories is explicitly given, if known]
Code Level (CL) • None (NC) • Low (<0.1g) (LC) • Moderate (0.1-0.3g) (MC) • High (>0.3g) (HC)	

The analysed building classifications have different levels of detail. It is preferable to collect more information to better model the building stock that will conduct to the definition of building groups having similar damages and economic losses. For this reason, the SYNER-G classification seems to be the most complete one.

Starting from a CARTIS-like field survey, the buildings can be classified according to the SYNER-G taxonomy. Thus, a classification of the building stock is achieved and the following additional information would be available:

- Number of building for each building class
- Floor area of the buildings

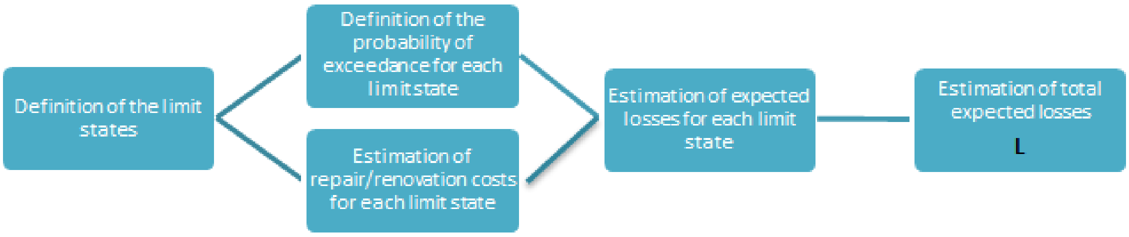
The latter information could be used also for energy performance assessment.

Once the building stock assessment is performed and the exposed buildings are classified into groups having similar characteristics, the evaluation of the expected losses can be achieved for each building group.

2.3.3 Expected earthquake losses evaluation

Expected earthquake losses evaluation is performed by following five steps: definition of limit states, definition of probability of exceedance, estimation of repair/replacement costs, estimation of expected losses for each limit state and estimation of total losses (Figure 34).

Figure 34. Flowchart for expected earthquake loss assessment



2.3.3.1 ***Definition of limit states***

The evaluation of the structural performance of buildings is necessary linked to the definition of the limit states. Four limit states (LS) are introduced for describing the building performances related to seismic actions.

Limit State 1: the first limit state corresponds to slight damage of the building. The building maintains its operability and no use interruptions and significant damages are involved.

Limit State 2: the second limit state corresponds to damage to non-structural elements. The building maintains its structural integrity but repairs on non-structural elements are necessary.

Limit State 3: the third limit state corresponds to heavy damage. The building exhibits serious damages and collapse of the non-structural elements and significant damages to structural elements. The structure maintains a safety margin against collapse.

Limit State 4: the fourth limit state corresponds to near collapse. The building exhibits serious damages and collapse of the non-structural elements and very serious damages to structural elements. For the sake of simplicity, if LS4 occurs, to demolish and rebuild a new building is considered.

2.3.3.2 ***Definition of probability of exceedance***

After defining the limit states, the probability that an event causing the over-mentioned damages for each limit state occurs during the building reference period has to be assessed. The probability that an event of low intensity occurs is higher than the probability that an event of high intensity occurs. Moreover, the return period of an event is directly proportional to its intensity: higher intensity events occur after higher number of years. The probability of exceedance for each limit state can be derived by national technical codes. Considering the Italian technical code [20], the probabilities of exceedance during building reference period (P_{VR}) are reported in Table 14.

Table 14. Probability of exceedance in the reference period for each limit state, according to Italian Technical Code [20]

LIMIT STATE	P_{VR}%
Operability Limit State	81%
Damage Limit State	63%
Life Safety Limit State	10%

Collapse Limit State	5%

2.3.3.3 *Estimation of repair/replacement costs*

The evaluation of the cost repair/replacement the buildings after a seismic event of a defined intensity is an ongoing research topic. Cost estimation is not only related to the seriousness of the building damages, but also to the economic value of the building components, which are related to the surrounding market. For this reason, it is hard to estimate a global value of repair/replacement costs.

Two ways can be taken for reaching this goal. As first option, a survey on existing post-earthquake costs data should be realised. A second option could be the analytical assessment, realised for building classes, according to the simplified performance based assessment procedure, described by Negro and Mola [19], and applied by Loli et al. [10].

Considering the first option, an example is presented herein. After L'Aquila earthquake, occurred in 2009 in Central Italy, a big amount of technical and economic data has been gathered. Starting from these data, techno-economic studies have been fulfilled to relate the structural characteristics of damaged buildings and their costs. Results from this study have been published in the "Libro Bianco", by ReLUIS, FINTECNA and CINEAS [89]. The book presents the costs related to the rehabilitation of 2245 Reinforced Concrete buildings and 1256 Masonry buildings, classified according to the usability classes. Usability classes are defined by the usability form, called AeDES [90], which, according to the step procedure reported in the form, allows understanding the gravity of the building damages related to the building functionality. According to the AeDES form, six usability categories are defined:

- **A**: the building is functional and usable
- **B**: the building is temporarily not usable, but it can reach the usability with small interventions
- **C**: the building is partially not usable
- **D**: the building is considered not usable, but a more in-deep examination is needed
- **E**: the building is not usable
- **F**: the building is not usable because of external risks (surrounding buildings create a risk for the considered building)

An approximated correlation between the building usability classes and the damage limit states can be realised as reported in Table 15. The fourth limit state has been correlated to the complete damage of the structure; this means that the related costs include the costs for building demolition and reconstruction, which can be obtained by national market.

Table 15. Correlation between the building usability classes by AeDES form [90] and the damage limit states

Usability class	Limit State
A	LS1
B-C	LS2
E	LS3
Demolition and reconstruction	LS4

According to what declared in the Libro Bianco, the repair/reinforcement costs listed in Table 16 can be used:

Table 16. Repair + reinforcement costs estimated after L'Aquila earthquake, considering structural materials, age of construction and number of floors, for B-C and E usability classes.

Building class	Usability Class	Number of buildings for building class	Repair + reinforcement cost [€/m^2]
Reinforced Concrete (RC)	**B-C**	**1598**	**217.76**
RC 1946-1961	B-C	40	269.18
RC 1962-1971	B-C	128	215.10
RC 1972-1981	B-C	359	228.47
RC 1982-1991	B-C	458	175.27
RC 1992-2001	B-C	273	169.28
RC >2001	B-C	202	155.31
RC 1 floor	B-C	51	164.88
RC 2 floors	B-C	220	173.91
RC 3 floors	B-C	532	161.55
RC 4 floors	B-C	394	204.02
RC 5 floors	B-C	142	249.36
RC 6 floors	B-C	87	240.17
RC 7 floors	B-C	29	264.35
RC 8 floors	B-C	5	134.97
Masonry (M)	**B-C**	**899**	**285.13**
M <1919	B-C	125	297.52
M 1919-1945	B-C	161	263.13
M 1946-1961	B-C	151	282.91
M 1962-1971	B-C	144	293.25
M 1972-1981	B-C	153	231.80
M 1982-1991	B-C	58	204.13
M 1992-2001	B-C	25	236.75
M >2001	B-C	13	240.55

M 1 floor	B-C	82	246.72
M 2 floors	B-C	376	277.41
M 3 floors	B-C	303	249.44
M 4 floors	B-C	67	251.24
M 5 floors	B-C	2	274.52
Reinforced Concrete	**E**	**447**	**925.80**
RC 1946-1961	E	20	978.94
RC 1962-1971	E	76	975.04
RC 1972-1981	E	140	962.99
RC 1982-1991	E	106	908.29
RC 1992-2001	E	55	941.52
RC >2001	E	29	847.95
RC 1 floor	E	2	665.99
RC 2 floors	E	33	896.45
RC 3 floors	E	97	906.77
RC 4 floors	E	118	934.54
RC 5 floors	E	84	986.82
RC 6 floors	E	63	1016.98
RC 7 floors	E	19	1016.98
RC 8 floors	E	10	1027.49
Masonry	E	313	837.28
M <1919	E	56	914.20
M 1919-1945	E	49	994.62
M 1946-1961	E	64	1001.03
M 1962-1971	E	54	928.87
M 1972-1981	E	44	915.43
M 1982-1991	E	14	884.79
M 1992-2001	E	7	941.10

M >2001	E	4	901.00
M 1 floor	E	14	800.53
M 2 floors	E	97	848.92
M 3 floors	E	125	856.09
M 4 floors	E	47	842.38
M 5 floors	E	6	879.43
M 6 floors	E	3	772.40

For limit state 1, corresponding to usability class "A", no data from techno-economic analysis of L'Aquila earthquake are available. For this class, market information about small repair activities (i.e. wall painting) can be used.

2.3.3.4 *Estimation of expected losses for each limit state*

Once the probability of exceedance and the repair/replacement costs are evaluated for each limit state, the estimation of the expected losses can be achieved by using the following expression:

$$L_i = C_i \cdot (P_i - P_{i+1}) \qquad (33)$$

where:

- L_i is the expected earthquake economic losses related to the *i*-th limit state
- C_i is the repair/replacement costs of the considered building, related to the *i*-th limit state
- P_i and P_{i+1} are, respectively, the probabilities of exceeding the *i*-th and the *i*+1-th limit state

2.3.3.5 *Estimation of total losses*

The total earthquake expected losses, related to the whole lifespan of the building, can be evaluated as the sum of the expected losses for each limit state:

$$L = \sum_{i=1} C_i \cdot (P_i - P_{i+1}) \qquad (8)$$

If yearly total loss is required, it can be obtained by dividing the total loss L by the building lifespan.

2.3.4 Initial costs

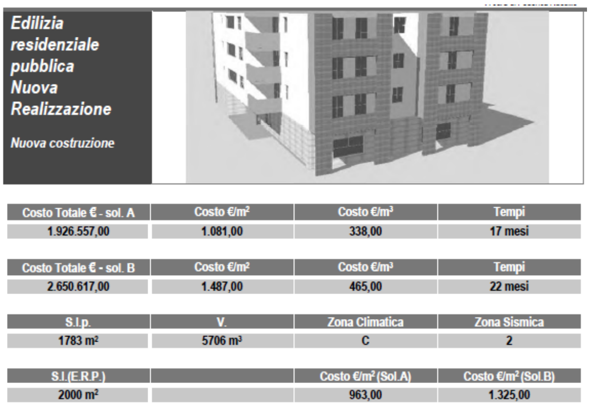
As reported at page 15, the cost related to the structural performances of the buildings (C_{TOT}) is the sum of building initial costs (I) and economic losses (L):

$$C_{TOT} = I + L \tag{9}$$

The building initial costs can be evaluated by means of the market information provided by each Member State.

As example, Italian Chamber of Commerce and the Construction Contractors Associations realise the price list of the construction typologies, for each building use, providing the €/m^2 value of a benchmark building. Some examples are the "Prezzario delle tipologie edilizie di Napoli" (Figure 35 [91]) and the "Prezzi Tipologie Edilizie" (Figure 36 [92]).

Figure 35. Initial construction cost for a new residential building in the Municipality and the Province of Napoli (IT) [91]



Edilizia residenziale pubblica Nuova Realizzazione

Nuova costruzione

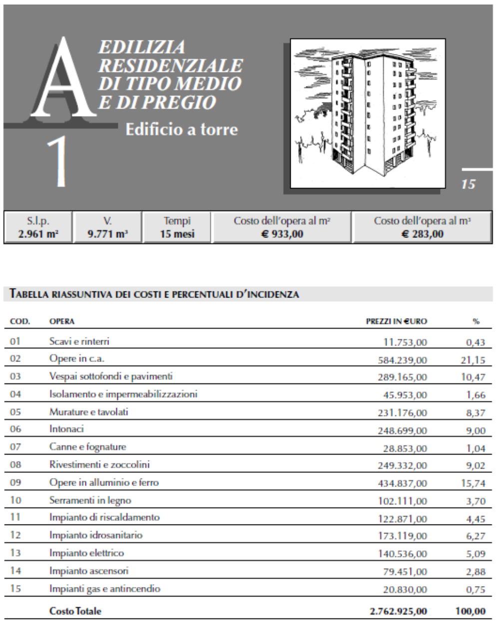
Costo Totale € - sol. A	Costo €/m²	Costo €/m³	Tempi
1.926.557,00	1.081,00	338,00	17 mesi

Costo Totale € - sol. B	Costo €/m²	Costo €/m³	Tempi
2.650.617,00	1.487,00	465,00	22 mesi

S.l.p.	V.	Zona Climatica	Zona Sismica
1783 m²	5706 m³	C	2

S.l.(E.R.P.)		Costo €/m² (Sol.A)	Costo €/m² (Sol.B)
2000 m²		963,00	1.325,00

Figure 36. Initial construction cost for a new residential building in the Municipality and the Province of Milan [92]



A

EDILIZIA RESIDENZIALE DI TIPO MEDIO E DI PREGIO

1

Edificio a torre

15

S.l.p.	V.	Tempi	Costo dell'opera al m²	Costo dell'opera al m³
2.961 m²	**9.771 m³**	**15 mesi**	**€ 933,00**	**€ 283,00**

TABELLA RIASSUNTIVA DEI COSTI E PERCENTUALI D'INCIDENZA

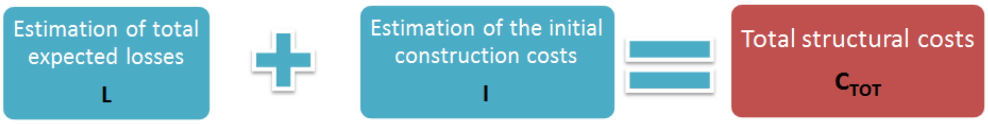
COD.	OPERA	PREZZI IN €URO	%
01	Scavi e rinterri	11.753,00	0,43
02	Opere in c.a.	584.239,00	21,15
03	Vespai sottofondi e pavimenti	289.165,00	10,47
04	Isolamento e impermeabilizzazioni	45.953,00	1,66
05	Murature e tavolati	231.176,00	8,37
06	Intonaci	248.699,00	9,00
07	Canne e fognature	28.853,00	1,04
08	Rivestimenti e zoccolini	249.332,00	9,02
09	Opere in alluminio e ferro	434.837,00	15,74
10	Serramenti in legno	102.111,00	3,70
11	Impianto di riscaldamento	122.871,00	4,45
12	Impianto idrosanitario	173.119,00	6,27
13	Impianto elettrico	140.536,00	5,09
14	Impianto ascensori	79.451,00	2,88
15	Impianti gas e antincendio	20.830,00	0,75
	Costo Totale	**2.762.925,00**	**100,00**

$$I = Construction\ costs\ per\ square\ meter \cdot building\ area\ \left[\frac{€}{m^2} \cdot m^2\right] \tag{34}$$

2.3.5 Total structural performance costs

The structural performance parameter C_{TOT} is evaluated by summing the total expected losses, L, and the initial construction costs, I (Figure 37. C_{TOT} is already provided in economic terms; for this reason no conversion is needed to evaluate the global assessment parameter R_{SSD}.

Figure 37. Evaluation of total structural performance costs



Focus on STEP III of SSD Methodology at national/regional/urban level: Structural

The third step of the SSD methodology is the safety performance assessment. Seismic safety is taken as an example.

For achieving the safety performance assessment of buildings, building stock survey cannot be avoided because the methodologies aiming at the evaluation of the expected economic losses are strictly dependent on structural and non-structural characteristics of buildings. Thus, step three needs a previous phase of identification and labelling of building groups having similar structural and non-structural characteristics. At this aim, Syner-G taxonomy applied at groups of buildings previously identified and analysed through a CARTIS-like field survey could be helping.

After the identification of buildings groups, the third phase of the SSD methodology at territorial level can be developed by evaluating the expected earthquake losses and the initial construction costs.

Earthquake loss assessment can be achieved by following five steps: 1) definition of limit states; 2) definition of probability of exceedance for each limit state; 3) estimation of the repair/replacement costs for each limit state; 4) estimation of expected losses for each limit state and 5) estimation of total losses. The first two steps of the loss assessment can be achieved with the help of national codes. The repair/replacement costs can be evaluated for each limit state in two different ways: a) by performing a survey on existing post-earthquake costs data or; b) by performing a loss assessment analysis on building classes prototypes, according to the simplified performance based assessment procedure. Expected economic losses for each limit state can be evaluated by multiplying the probability of exceedance by the repair/replacement costs and, finally, the total expected losses can be assessed by summing the expected losses referred to each limit state.

Initial construction costs are dependent on the market variables; thus, they can be evaluated by using the market information provided by each Member State.

Structural performance parameter, C_{TOT}, is the sum of total expected losses and initial construction costs.

2.3.6 Conclusions and Future developments of the safety performance assessment

According to the structural performance assessment described so far, it is clear that, in order to make the methodology directly available to the users, some activities should be realised.

Firstly, as already mentioned for the energy performance step, the evaluation of the building stock floor area at urban, regional and national levels has to be obtained.

A complete and accurate field survey on existing buildings at municipality/province level would be preferable; by aggregating the results at municipality/province levels, building stock information will be available also at regional and national levels. The total building stock can be classified into groups, according to the SYNER-G taxonomy.

For identifying the repair/replacement costs, a survey on existing post-earthquake costs data should be realised and a correlation among the limit states, the observed damages and the respective costs has to be addressed. Indeed, according to the available data on post-earthquake techno-economic analyses, a table, similar to Table 17, should be filled with the repair/replacement costs for each building stock class, which has been identified for the considered territory. At least, costs related to building classes including information about structural material, age (or code level) and number of floors should be considered (FRM1/FRMM1/X/X/X/X/X/X/HL-NS/CL).

Table 17. Repair/replacement costs per square meter table to be filled for each SYNER-G building class

Building class FRM1/FRMM1/X/X/X/X/X/X/HL-NS/CL	Repair/replacement costs per square meter €/m^2			
	LS1	LS2	LS3	LS4
MRF/C-RC/X/X/X/X/X/X/L-2/NC				
MRF/C-RC/X/X/X/X/X/X/L-2/LC				
MRF/C-RC/X/X/X/X/X/X/L-2/MC				
MRF/C-RC/X/X/X/X/X/X/L-2/HC				
MRF/C-RC/X/X/X/X/X/X/L-3/NC				
MRF/C-RC/X/X/X/X/X/X/L-3/LC				
MRF/C-RC/X/X/X/X/X/X/L-3/MC				
MRF/C-RC/X/X/X/X/X/X/L-3/HC				
MRF/C-RC/X/X/X/X/X/X/M-4/NC				
MRF/C-RC/X/X/X/X/X/X/M-4/LC				
MRF/C-RC/X/X/X/X/X/X/M-4/MC				
MRF/C-RC/X/X/X/X/X/X/M-4/HC				
…				
MRF/M-URM/X/X/X/X/X/X/L-2/NC				
MRF/M-URM/X/X/X/X/X/X/L-2/LC				
MRF/M-URM/X/X/X/X/X/X/L-2/MC				
MRF/M-URM/X/X/X/X/X/X/L-2/HC				
MRF/M-URM/X/X/X/X/X/X/L-3/NC				
MRF/M-URM/X/X/X/X/X/X/L-3/LC				
MRF/M-URM/X/X/X/X/X/X/L-3/MC				
MRF/M-URM/X/X/X/X/X/X/L-3/HC				
MRF/M-URM/X/X/X/X/X/X/M-4/NC				
MRF/M-URM/X/X/X/X/X/X/M-4/LC				
MRF/M-URM/X/X/X/X/X/X/M-4/MC				
MRF/M-URM/X/X/X/X/X/X/M-4/HC				
…				

If existing post-earthquake techno-economic analyses do not provide information about one (or more) building class(es), then the procedure described by Loli et al. [10] should be used for evaluating repair/replacement costs.

2.3.6.1 *A new safety performance assessment approach: the Italian seismic building certification*

Another future development of the safety performance assessment could be represented by the seismic building certification. In Italy, the frequent occurrence of seismic events and, consequently, the impacts they have generated on the national economy have driven the institutions to propose a seismic certification that each new building must have, in order to notify the buyer about the building's seismic performance. The seismic certification, which might be available in the near future, would be similar to the Energy Performance Certificate: a parameter describing the seismic performance would be evaluated for the building and a seismic class, labelled with a letter from A to F, would be attached to the building itself (Figure 38). The seismic parameter, according to which the seismic classification will be defined, could be the Expected Annual Loss (EAL). The seismic classification could be used for assessing the third phase of the SSD methodology at territorial level, simplifying the safety performance evaluation of buildings.

Figure 38. Preview of the Italian seismic certification of buildings

2.4 Global assessment parameter

As reported at § 1.4, global assessment parameter, R_{SSD}, is provided by the following expression:

$$R_{SSD} = R_{E(energy)} + R_{E(CO_2)} + C_{tot} \tag{12}$$

where:

— $R_{E(energy)} = Q_E * P_E$ represents the energy performance parameter;

— $R_{E(CO_2)} = Q_{CO_2} * P_{CO_2}$ represents the life-cycle performance parameter;

— $C_{tot} = L + I$ represents the structural performance parameter

3 Conclusions

The study herein performed derives from the sustainable structural design (SSD) methodology, an efficient and solid method aiming at guiding the sustainable construction sector toward a multi-performance approach, which jointly considers environmental and safety issues.

The described study demonstrates that the SSD methodology is applicable and can be realized at territorial level. A framework of the possible SSD methodology at national/regional/urban level has been presented by developing the four steps of the methodology itself. Precisely, the following phases have been developed: I) energy performance assessment; II) life-cycle assessment; III) safety performance assessment; IV) global assessment parameter evaluation. In the first step, buildings' energy consumptions have been analyzed considering two different approaches and data sources: international and European energy databases and energy performance certificates. Moreover, whereas some energy data are provided as energy consumption per square meter, a study on the available buildings' useful floor area has been realized. In the second step, life-cycle assessment of buildings is performed by using the data provided by the first step and the percentage values provided by the research community; thus, equivalent carbon dioxide emissions of groups of buildings are evaluated. Third step aims at the evaluation of safety performance of buildings, and seismic safety is taken as an example. Economic losses due to hazard events and initial buildings' costs are calculated. Buildings' data gathering and classification are essential to perform safety assessment, in order to treat groups of building having similar characteristics as a single building. Losses assessment is then performed on the basis of the performance-based assessment methodology and using repair/replacement costs provided by existing post-earthquake costs data. The fourth and last step consists in the assembly of the previous steps' results and the evaluation of the global assessment parameter, which includes in one value the buildings' environmental (energy consumptions and equivalent carbon dioxide emissions) and safety (economic losses and construction costs) issues, provided in economic terms.

The interest in developing this methodology derives from the powerful applications it could have. Indeed, if the methodology was applied to small areas, like districts, cities or regions, and to big areas, like nations, it could be a solid method for supporting the administrations in addressing the policy projects on the territory. If the building stock is classified into groups of buildings having similar structural and non-structural characteristics and the global assessment parameter is evaluated for each building group, the territory can be divided into areas having same R_{SSD} range. According to this classification, areas with highest values of R_{SSD} (resulting from high energy consumption, high CO_2 emissions and high expected losses, caused by earthquake or other events) will result as the ones where a structural and energy intervention is more necessary.

Nevertheless, the study herein presented has highlighted some critical aspects related to the methodology development. Firstly, no solid data on national and regional useful floor area of buildings are available. Consequently, it is hard to establish the correct value of energy consumption. A study on prices of all the energy components should be realized in order to provide a more complete value of energy performance parameter. Moreover, a field survey on buildings at regional/urban level is necessary in order to treat groups of buildings having similar characteristics as single building; the field survey should be finalized with a building group's labeling, according to Syner-G taxonomy. Another aspect to consider is the necessity of collecting techno-economic studies regarding repair/replacement costs from worldwide-occurred earthquakes.

Finally, a pilot study should be realised as application of the SSD Methodology at urban, regional and national levels, in order to show the methodology potentiality.

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List of abbreviations and definitions

AE: Agenzia delle Entrate (Italian Agency of Revenue)

BPIE: Buildings Performance Institute Europe

$CO_{2,D}$: CO_2 emissions generated during building dismissing phase

$CO_{2,E}$: Embodied Carbon

$CO_{2,LC}$: CO_2 emissions generated during each phase of the building life

$CO_{2,O}$: CO_2 emissions generated during building use-phase

C_{TOT}: Total Cost for structural performance assessment

DM: Damage Measure

DV: Decision Variable

E_D: Demolition energy

EDP: Energy Demand Parameter

E_E: Embodied energy

EEX: European Energy Exchange

E_{LC}: life-cycle energy incurred at each phase of the building life

E_O: Operational energy

$EP,_{gl,nren}$: non-renewable global energy performance index

$EP,_{H,nren}$: non-renewable energy index for winter space heating

$EP,_{W,nren}$: non-renewable energy index for water heating

EPBD: Energy Performance of the Buildings

EPC: Energy Performance Certificate

ES_BPIE: data referred to space heating consumption per square meter, evaluated dividing Eurostat consumption values for BPIE useful floor area

ES_ODYSSEE: data referred to space heating consumption per square meter, evaluated dividing Eurostat consumption values for ODYSSEE 1 useful floor area (i.e. number of dwellings * average floor area of dwelling)

EU ETS: European Union Emission Trading System

EU-27: European Union Member States before Croatia accession

EU-28: Actual 28 European Union Member States

EUA: European Emission Allowances

GHG emissions: GreenHouse Gas emissions

I: Initial Structural Costs

IDA: Incremental Dynamic Analysis

IDR: Inter-storey Drift

IEA: International Energy Agency

IEA_BPIE: data referred to space heating consumption per square meter, evaluated dividing IEA consumption values for BPIE useful floor area

IEA_ODYSSEE: data referred to space heating consumption per square meter, evaluated dividing IEA consumption values for ODYSSEE 1 useful floor area (i.e. number of dwellings * average floor area of dwelling)

IM: Intensity Measure

kOE: kg of Oil Equivalent

L: Expected economic Losses

L_B: life span of the building

LCA: Life Cycle Assessment

LCEA: Life Cycle Energy Assessment

LS: Limit State

$m^2_{\text{region/city}}$: useful area of buildings' groups in the considered region or city

MS: EU Member State

MTOE: Million Tonnes of Oil Equivalent

ODYSSEE 1: data referred to useful floor area, evaluated by dividing the total energy consumption for energy consumption related to 1 building's square meter

ODYSSEE 2: data referred to useful floor area, evaluated by multiplying the average building floor area by the number of dwellings

OECD: Organisation for Economic Co-operation and Development

PBA: Performance-Based Assessment

PBEE: Performance Based Earthquake Engineering

P_{CO2}: carbon dioxide price

P_E: energy price

PGA: Peak Ground Acceleration

P_{VR}: Probability of exceedance during building reference period (also called R_N)

Q_{CO2}: amount of equivalent CO_2

Q_E: amount of energy consumption

$R_{E(CO2)}$: CO_2 Performance Parameter

$R_{E(energy)}$: Energy Performance Parameter

R_N: probability of exceeding (also called P_{VR})

R_{SSD}: Global Assessment Parameter

sPBA: simplified Performance-Based Assessment

SSD: Sustainable Structural Design

STEP I.A: Energy Performance Assessment at national level

STEP I.B1: Energy Performance Assessment at regional/urban level - energy consumption provided by the European energy databases

STEP I.B2: Energy Performance Assessment at regional/urban level - energy consumption provided by the Energy Performance Certificates

TOE: Tonnes of Oil Equivalent

T_R: Return Period

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Annexes

Annex 1. Comparisons among total energy components for each end-uses declared in the databases

Table 18. Comparisons among energy components declared in the analysed databases – Solid Fuels

SOLID FUELS (2011)			
MTOE	**ODYSSEE** COAL	**Eurostat** SOLID FUEL	**IEA** Coal, peat and oil shale
European Union	10.370	10.370	
Austria	0.049	0.037	0.048
Belgium	0.098	0.098	0.098
Bulgaria	0.256	0.244	
Croatia	0.003	0.004	
Cyprus			
Czech Rep.	0.605	0.605	0.610
Denmark	0.001	0.001	0.011
Estonia	0.011	0.012	0.011
Finland	0.005	0.006	0.005
France	0.160	0.168	0.170
Germany	1.386	0.852	0.866
Greece	0.005	0.005	0.004
Hungary	0.172	0.172	0.172
Ireland	0.471	0.457	0.451
Italy	0.003	0.004	0.004
Latvia	0.023	0.023	
Lithuania	0.051	0.072	
Luxembourg	0.001	0.001	0.001
Malta			

Netherlands	0.004	0.002	0.004
Poland	6.805	6.810	6.806
Portugal			
Romania	0.009	0.019	
Slovakia	0.048	0.048	0.048
Slovenia		0.001	
Spain	0.122	0.122	0.122
Sweden			0.004
United Kingdom	0.690	0.609	0.627

Table 19. Comparisons among energy components declared in the analysed databases – Gas

GAS (2011)			
MTOE	**ODYSSEE** GAS	**Eurostat** GAS	**IEA** Natural Gas
European Union	101.714	101.714	
Austria	1.242	1.038	1.241
Belgium	3.114	3.114	2.789
Bulgaria	0.056	0.056	
Croatia	0.546	0.546	
Cyprus			
Czech Rep.	2.002	2.002	2.002
Denmark	0.649	0.649	0.638
Estonia	0.053	0.052	0.052
Finland	0.030	0.031	0.031
France	11.490	11.279	11.275
Germany	20.191	19.758	19.752
Greece	0.348	0.348	0.348
Hungary	2.966	2.966	2.966

Ireland	0.569	0.568	0.568
Italy	13.968	17.990	17.985
Latvia	0.107	0.107	
Lithuania	0.145	0.145	
Luxembourg	0.216	0.216	0.216
Malta			
Netherlands	7.030	7.547	7.029
Poland	3.237	3.237	3.235
Portugal	0.259	0.258	0.258
Romania	2.289	2.332	
Slovakia	1.173	1.173	1.172
Slovenia	0.113	0.113	0.113
Spain	3.411	3.412	3.411
Sweden	0.053	0.073	0.069
United Kingdom	22.705	22.705	22.699

Table 20. Comparisons among energy components declared in the analysed databases – Heat

HEAT (2011)			
MTOE	**ODYSSEE** HEAT	**Eurostat** DERIVED HEAT	**IEA** HEAT
European Union	21.708	21.708	
Austria	0.847	0.577	0.636
Belgium	0.013	0.013	0.013
Bulgaria	0.359	0.359	
Croatia	0.147	0.147	
Cyprus			
Czech Rep.	1.036	1.036	1.036
Denmark	1.612	1.612	1.612

Estonia	0.333	0.333	0.333
Finland	1.511	1.510	1.510
France	1.420	1.533	
Germany	3.925	3.925	3.925
Greece	0.054	0.054	0.054
Hungary	0.529	0.529	0.529
Ireland			
Italy	0.568	0.568	0.568
Latvia	0.367	0.367	
Lithuania	0.486	0.486	
Luxembourg	0.003		
Malta			
Netherlands	0.230	0.250	0.278
Poland	4.180	4.180	4.179
Portugal		0.006	0.006
Romania	1.120	1.121	
Slovakia	0.458	0.458	0.458
Slovenia	0.089	0.089	0.089
Spain			
Sweden	2.335	2.505	2.504
United Kingdom	0.052	0.052	0.052

Table 21. Comparisons among energy components declared in the analysed databases – Electricity

ELECTRICITY (2011)			
MTOE	**ODYSSEE** Electricity	**Eurostat** ELECTRICAL ENERGY	**IEA** ELECTRICITY
European Union	69.532	69.532	
Austria	1.442	1.539	1.499

Belgium	1.655	1.656	1.656
Bulgaria	0.938	0.938	
Croatia	0.561	0.561	
Cyprus	0.148	0.148	
Czech Rep.	1.221	1.221	1.221
Denmark	0.869	0.869	0.870
Estonia	0.166	0.166	0.166
Finland	1.842	1.842	1.842
France	12.860	12.079	12.081
Germany	11.746	11.746	11.748
Greece	1.516	1.516	1.516
Hungary	0.973	0.973	0.973
Ireland	0.712	0.712	0.712
Italy	6.031	6.031	6.032
Latvia	0.152	0.152	
Lithuania	0.225	0.225	
Luxembourg	0.073	0.073	0.073
Malta	0.046	0.051	
Netherlands	2.037	1.981	2.037
Poland	2.430	2.430	2.430
Portugal	1.183	1.183	1.183
Romania	0.996	0.995	
Slovakia	0.387	0.387	0.387
Slovenia	0.276	0.276	0.276
Spain	6.545	6.544	6.545
Sweden	3.611	3.642	3.133
United Kingdom	9.595	9.595	9.598

Table 22. Comparisons among energy components declared in the analysed databases – Petroleum Products

PETROLEUM PRODUCTS (2011)			
MTOE	**ODYSSEE** OIL	**Eurostat** Total petroleum products	**IEA** Oil Products
European Union	38.245	38.245	
Austria	1.246	1.091	1.238
Belgium	2.590	2.613	2.613
Bulgaria	0.028	0.027	
Croatia	0.207	0.208	
Cyprus	0.123	0.142	
Czech Rep.	0.004	0.004	0.004
Denmark	0.416	0.401	0.400
Estonia	0.009	0.009	0.009
Finland	0.410	0.417	0.406
France	6.170	6.641	6.605
Germany	11.869	12.367	12.287
Greece	2.583	2.600	2.583
Hungary	0.118	0.104	0.115
Ireland	1.035	0.997	0.973
Italy	3.113	3.079	3.079
Latvia	0.053	0.053	
Lithuania	0.053	0.053	
Luxembourg	0.172	0.150	0.151
Malta	0.022	0.013	
Netherlands	0.074	0.039	0.074
Poland	0.661	0.663	0.661

Portugal	0.587	0.587	0.587
Romania	0.181	0.234	
Slovakia	0.007	0.007	0.007
Slovenia	0.252	0.252	0.252
Spain	2.906	2.903	2.892
Sweden	0.135	0.052	0.052
United Kingdom	2.525	2.538	2.485

Table 23. Comparisons among energy components declared in the analysed databases – Renewable energies

RENEWABLE ENERGIES (2011)		
MTOE	**Eurostat** Renewable energies	**IEA** Renewables and Waste
European Union	39.546	
Austria	1.577	1.630
Belgium	0.443	0.442
Bulgaria	0.755	
Croatia	1.164	
Cyprus	0.062	
Czech Rep.	1.115	1.115
Denmark	0.867	0.867
Estonia	0.365	0.364
Finland	1.276	1.274
France	5.918	6.280
Germany	5.916	5.915
Greece	0.965	0.967
Hungary	0.730	0.730
Ireland	0.031	0.031

Italy	4.707	3.649
Latvia	0.624	
Lithuania	0.558	
Luxembourg	0.015	0.015
Malta	0.005	
Netherlands	0.433	0.327
Poland	2.764	2.764
Portugal	0.748	0.747
Romania	3.159	
Slovakia	0.049	0.049
Slovenia	0.531	0.477
Spain	2.646	2.646
Sweden	1.194	1.194
United Kingdom	0.929	0.351

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