D2.1: Report on EU implementation of nZEBs

COST REDUCTION AND MARKET ACCELERATION FOR VIABLE NEARLY ZERO-ENERGY BUILDINGS

Effective processes, robust solutions, new business models and reliable life cycle costs, supporting user engagement and investors' confidence towards net zero balance.

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D2.1: Report on EU implementation of nZEBs

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FOREWORD

Cost optimal and nearly zero-energy performance levels are principles initiated by the European Union's (EU) Energy Performance of Buildings Directive, which was recast in 2010. These will be significant drivers in the construction sector in the next few years because all new buildings in the EU from 2021 onwards are expected to be nearly zero-energy buildings (nZEB).

While nZEB realized so far have shown that the nearly-zero energy target can be achieved using existing technologies and practices, most experts agree that a broad-scale shift towards nearly-zero energy buildings requires significant adjustments to current building market structures. Cost-effective integration of efficient solution sets and renewable energy systems, in a form that fits with the development, manufacturing, and construction industry processes, as well as with planning, design, and procurement procedures, are the significant challenges.

CRAVEzero will focus on proven and new approaches to reduce the costs of nZEBs at all stages of the life cycle. The primary goal is to identify and eliminate the extra costs for nZEBs related to processes, technologies, building operation, and to promote innovative business models taking into account the cost-effectiveness for all the stakeholders.

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EXECUTIVE SUMMARY

The EPBD, as recast in 2010 (EPBD 2010/31/EU), together with the Energy Efficiency Directive (EED 2012/27/EU) and the Renewable Energy Directive (RED 2014/53/EU) represent the key regulatory framework adopted at EU level to promote and support the market uptake of nearly zero-energy buildings (nZEB) in Europe. The article 9 of the EPBD set the timeline for the implementation of the nZEB definition: all new public buildings starting from 1st January 2019 and all private buildings starting from 1st January 2021 must reach the nZEB target, according to the federal definition. Figure 1 summarises the main measures promoted by the three directives that affect the path towards nZEB in Europe.

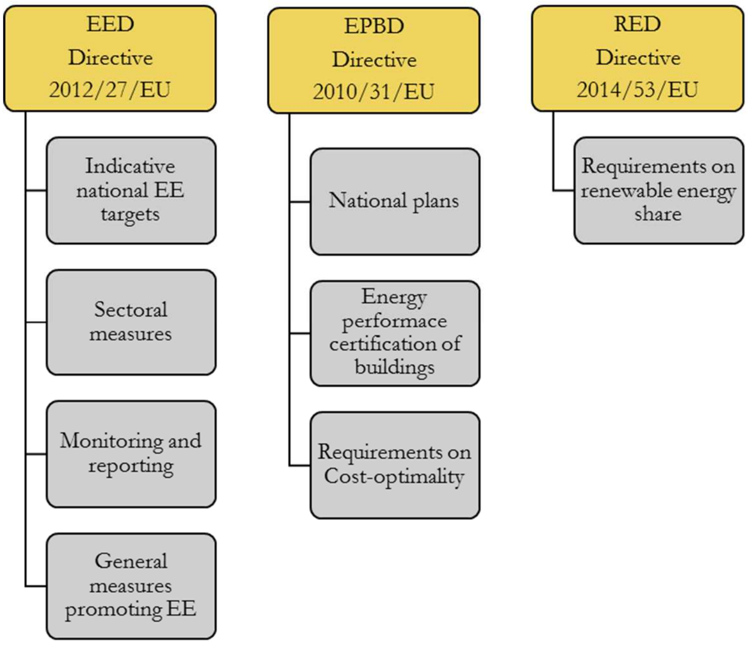

Figure 1: Key elements of European Directives (EED, EPBD, and RED)

The EPBD did not provide minimum or maximum harmonized requirements for nZEBs, but required only the implementation of very high energy performance, where the energy demand has to be covered to a very significant extent by energy from renewable sources. Therefore, the analysis of definitions and the fixed requirements shows how the countries chose different approaches to the matter, defining different system boundaries. In most of the cases, such as the CRAVEzero countries, the requirements are set at single building level and include in the definition of nZEB targets both new and renovated ones. At the same time, the definition is established for both private, and public buildings. Concerning the balance period for calulating the building energy performance and normalization factors, the Member States present a general homogeneity: in most countries, the balance period is one year, and the normalization factor is the conditioned area.

Cost-optimality

The EPBD stated that the achievement of high performances in nZEBs must go with the cost-optimality assessment. The idea is that the building design, from envelope to technical systems, has to take into account energy efficient solutions with minimal life cycle cost.

EU construction market

To understand better the field of application of the EPBD, an overview on construction market and the building sector in Europe is provided. The objective of CRAVEzero project is to identify and to propose solutions to reduce the extra costs associated with the nZEB construction (Figure 2).

As stated in the project ZEBRA 2020, the lack of structured financing schemes and the need of increase professional knowledge about best practices among designers and craftsmen are currently the main barriers for the transition to nZEB implementation.

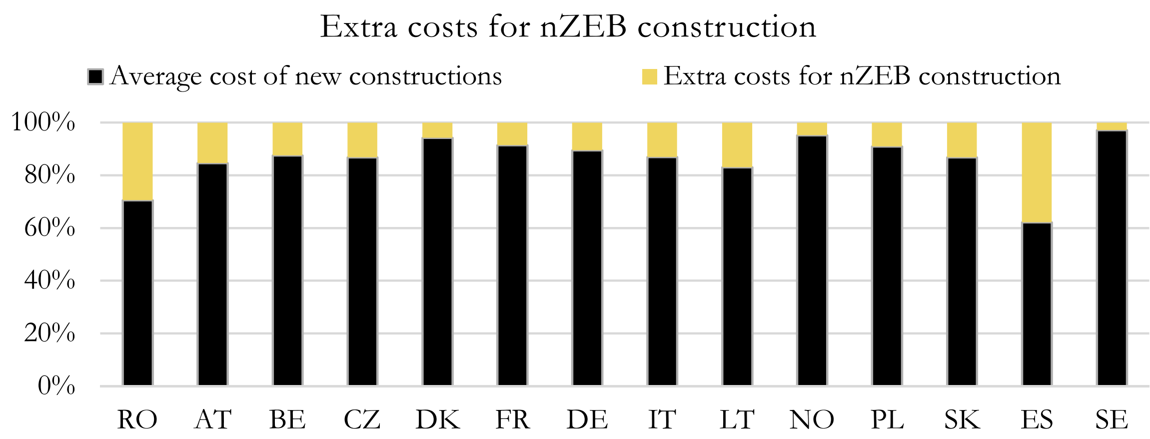

Figure 2: Extra costs for nZEBs construction versus average cost of new constructions (Pascual et al., 2016).

Focus at national level

To carry out a comparative analysis among countries, an analysis of regulatory framework at the national level is needed. This report focuses on CRAVEzero countries, Austria, Germany, France, Italy, and Sweden, were selected.

Austria - The document "national plan" included minimum standards for four energy indicators, which are used to define nZEBs: space heating demand, primary energy demand, CO_2 emissions and total energy efficiency factors. The OIB guideline 6 includes requirements for renewable energy share, for both new construction and major renovation of a building.

Germany - The current regulatory framework, which deals with energy efficiency and renewables in buildings, is structured in three parts: Energy Saving Act (EnEG), Energy Saving Ordinance (EnEV), Renewable Energy Heat Act (EEWärmeG). In several reports to the European Commission, the German federal government expressed the intention to define the future nZEB-level based on "KfW efficiency houses", a subsidies scheme for buildings that exceed current requirements. KfW standards for new buildings are not expressed by absolute values, but by comparing the performances with a corresponding reference building, calculated with the indicated maximum U-values.

France - The Thermal Regulation RT2012 expresses requirements for primary energy consumption. Total primary energy consumption is defined for heating, cooling, hot water production, lighting, ventilation, and any auxiliary systems. RT 2012 requires the use of a renewable energy source for individual houses. Five ways to meet this requirement are provided.

Italy - The decree D.M. 26 of June 2015 set the requirements for new construction and nZEB. Such as in the case of Germany, the decree introduced the reference building for defining the maximum limit of primary energy. The reference building is assumed as a building with the same geometry and specific values for the envelope thermal transmittance as well as HVAC system efficiency.

Sweden - The Swedish Building Code (BBR) is in charge to define building energy performance; currently, the BBR 25 (BFS 2017:5) is in force. The Swedish regulation set the requirements for building energy consumption, defining as an indicator the "specific energy use". The Swedish regulation does not indicate any requirement on a minimum renewable energy share.

Comparative analysis

The comparative analysis of the requirements for nZEBs among CRAVEzero countries, was carried out by simulating the performances of a reference building in PHPP (Passive House Planning Package). The reference building was modeled to calculate the nZEB requirements in Italy and Germany. It is a single-family house representative of the EU stock (FP7 project Inspire). As regards technical systems, different configurations have been adopted to show the effect of each technology on the primary energy demand, keeping constant the U-values (as indicated in the requirements). The four different cases simulated in PHPP are:

- **Case 1**: the building has a heat pump for heating and domestic hot water (COP=3), but no mechanical ventilation. We adopted an air change rate at pressurization test (n_{50}) of 4 volumes per hour. This is a standard value where no particular focus on airtightness level.
- **Case 2**: the building has mechanical ventilation with a heat recovery system.
- **Case 3**: same building with the maximum air change rate for Passive House Standard and high air tightness (0.6 1/h).
- **Case 4**: the same as case 2, whereas the heat pump is replaced by a gas condensing boiler.

In Figure 3Figure 17 primary energy requirements of Austria, France and Sweden are compared with those reached by Italy and Germany with their reference building in two configurations: case 2 (heat pump, ventilation with heat recovery) and case 4 (gas condensing boiler, ventilation with heat recovery). Figure 4 shows how the installation of a ventilation system results in a reduction of 10.1% of the primary energy demand. A building design with special attention to airtightness permits a further reduction of 9.8% of primary energy. The case number four represents a building with a gas condensing boiler and a ventilation system. The primary energy demand, in this case, is 28.7% higher than with a heat pump.

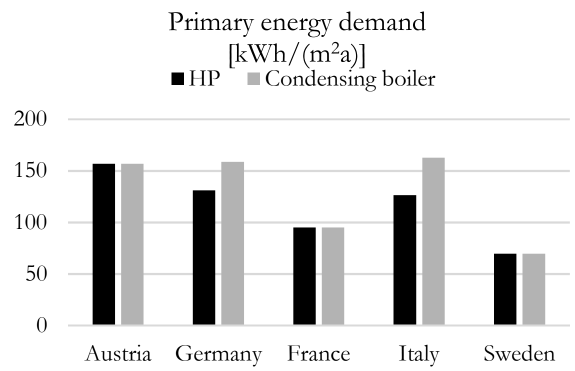

Figure 3: Primary energy demand for heat pump and gas condensing boiler in CRAVEzero countries.

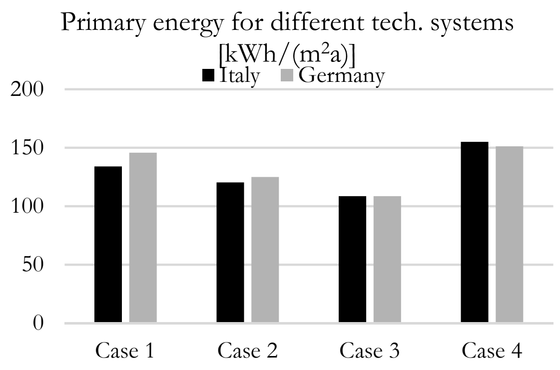

Figure 4: Primary energy demand for the reference building in Germany and in Italy with different tech. systems.

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1. INTRODUCTION

The Energy Performance of Building Directive (EPBD) 2010/31/EU introduced the nZEB concept as a target to be reached by all the new constructions from January 2019, in case of public buildings, and from January 2021 in case of private ones. Despite the established deadlines, the nZEB uptake is still far from the EPBD target, in case of both renovation and new construction. As demonstrated by the IEE project ZEBRA2020 and by the Concerted Action, the implementation of the EPBD at the national level is quite fragmented regarding both requirements and evaluation approach. Therefore, making a comparative analysis of the national standards, nZEB targets and features is quite difficult.

For the development of the activities within CRAVEzero, it is strategic to characterize the current nZEB situation across Europe, considering the national adoption of European Directives and impacts on the construction sector, with a special focus of the countries involved within the project.

In this regard, D2.1 aims to provide a general analysis of the implementation of nZEB across Europe, identifying the main information on the regulatory framework, policies, and impact on the construction sector.

As the first driver of the uptake of nZEB, the document focuses on the overview of the EU Directives and related activities (i.e., Concerted Action) identifying the general definition given by the European Commission and the indications to the Member States (MSs). Starting from the general framework, Section 2.1.2 reports an overview of the national implementation across EU, identifying the main aspects of the calculation approach (e.g., metrics, boundaries, normalization). Then, this deliverable reports in section 2.2 an overview of the EU construction market, organizing data from literature and previous projects.

A special focus is devoted at the national level for the countries involved, with a case study, within the project: Austria, Germany, France, Italy, and Sweden. This section describes the national regulatory policies and requirements regarding energy performance, the share of renewable energy sources, envelope insulation and technical systems performances. Each country has its characteristics, which are reflected in the different approaches towards the implementation of the EPBD. Eventually, in section 4 a comparative analysis of the requirements among the CRAVEzero countries involved in the consortium is proposed.

2. OVERVIEW AT EU LEVEL

The Energy Performance of Building Directive (EPBD 2010/31/EU) defines a nZEB as a building that has a very high-energy performance, as determined by Annex I, where a common general framework for the calculation of energy performance of buildings is introduced. The nearly zero-energy target should be covered, to a very significant extent, by energy from renewable sources, including energy produced on-site or nearby. Considering the differences among countries regarding the construction market, climate conditions and energy mix, the EPBD established the Member States to elaborate their nZEB definition and to set specific national requirements according to the context.

To better understand the regulatory framework developed in each country, this section will first give an overview of the main European directives that influence the building features. Section 2.1.2 reports the status of implementation at national level, analyzing the specificities and the main differences across the Member States, with a focus on new construction and nZEB implementation. One of the key concepts in the EPBD is cost-optimality. Therefore a closer look to this aspect has been devoted in section 2.1.3. In the end, forerunner projects, which tackled the issue of nZEB implementation in Europe, will be presented.

2.1. THE EUROPEAN POLICIES ON NZEBS

2.1.1.EU DIRECTIVES

The EPBD, as recast in 2010 (EPBD 2010/31/EU), together with the Energy Efficiency Directive (EED 2012/27/EU) and the Renewable Energy Directive (RED 2014/53/EU) represents the key regulatory framework adopted at EU level to promote an increase of energy efficiency and renewable energy production.

Energy Efficiency Directive (EED 2012/27/EU)
In October 2012, EU adopted the Energy Efficiency Directive 2012/27/EU. It established a set of measures for the promotion of energy efficiency, at all stages of the energy chain, starting from the production to final consumption. The aim is to achieve the target of 20% of energy savings by 2020. In November 2016, the European Commission proposed an update to this Directive, including a new 30% target by 2030.
The Directive applies minimum requirements and objectives, which are complementary to the indications of the EPBD 2010/31/EU; the Member States are allowed to set more tightening ones. Key measures to enhance the energy efficiency promoted by the directive are the followings:

① Energy saving efficiency targets for the Member States.
② Exemplary role of public buildings - article 5 sets binding renovation targets for public buildings.
③ Energy efficiency obligations - obligations related to the previous point are also imposed. For instance, every year starting from 2014, each MS shall refurbish 3% of the buildings owned or occupied by central government.
④ Energy audits and management - article 8 states that MS shall promote cost-effective, independent and high-quality energy audits for all final customers. Also, non-small and medium-sized enterprises shall implement energy or an environmental management system.
⑤ Metering and billing - good energy consumption management requires that the consumer can easily access to data through individual metering and billing information.
⑥ Qualification, accreditation and certification schemes, energy services and energy performance contracting, split incentives, online platform.

Although the abovementioned measures have a higher impact on existing buildings, the application can also improve the energy efficiency of new constructions. In particular, the improvement of monitoring and billing approach as well as a structured energy management of buildings can foster the proper operation of nZEBs and guarantee the energy performance targets.

The EED directive aims at reducing the energy consumption at EU level of 30%. To reach that target, each country has a specific objective. Table 1 reports the absolute level of energy consumption target in 2020 as indicated by the Member States to the European Commission, with a focus on the CRAVEzero countries.

STATE	PRIMARY ENERGY [MTOE]	PRIMARY ENERGY PER CAPITA [TOE]	FINAL ENERGY [MTOE]	FINAL ENERGY PER CAPITA [TOE]
Austria	31.5	3,6	25.1	2,9
Germany	276.6	3,4	194.3	2,4
France	219.9	3,3	131.4	2,0
Italy	158	2,6	124	2,0
Sweden	43.4	4,3	30.3	3,0

Table 1: Absolute level of energy consumption in 2020 as indicated from MSs (www.ec.europa.eu).

Energy Performance of Building Directive (EPBD 2010/31/EU)

The first version of the Directive was approved in December 2002 and recast in May 2010. This Directive established targets for the Member States to be fulfilled by all the new public buildings from January 2019 and all residential ones from 2021. As mentioned before, this Directive introduced the concept of nZEB and the main indications for implementation. It also added the concept of cost-optimality. Key elements of the directive are:

① Boosting the Member States to draw up National Plans towards nZEB, establishing definitions, requirements, and policies to reach the nZEB target.
② Encouraging the integration of renewable energy sources.
③ Cost-optimality - Article 2.14 defines the cost-optimal level as "the energy performance level which leads to the lowest cost during the estimated economic lifecycle".
④ Energy performance certificates, introduced in the EPBD 2002/31/EC, serve as an information tool for building owners, occupiers, and real estate actors.
⑤ Establishing regular inspections of heating and cooling systems.
⑥ Certification of buildings, which only qualified experts are accredited to carry out independently.

Renewable Energy Directive (RED 2014/53/EU)

The Directive 2014/53/EU established an overall policy for the promotion of the energy production from renewable sources. It requires the Member States to fulfill at least 20% of its total energy consumption with energy from renewables by 2020. Also, it requires that at least 10% of transport fuels come from renewable sources. The 20% target was updated in November 2016. The new target requires at least 27% of energy from renewable energy sources in the final energy consumption by 2030. Figure 1 summarises the main measures promoted by the three directives that affect the path towards nZEB in Europe.

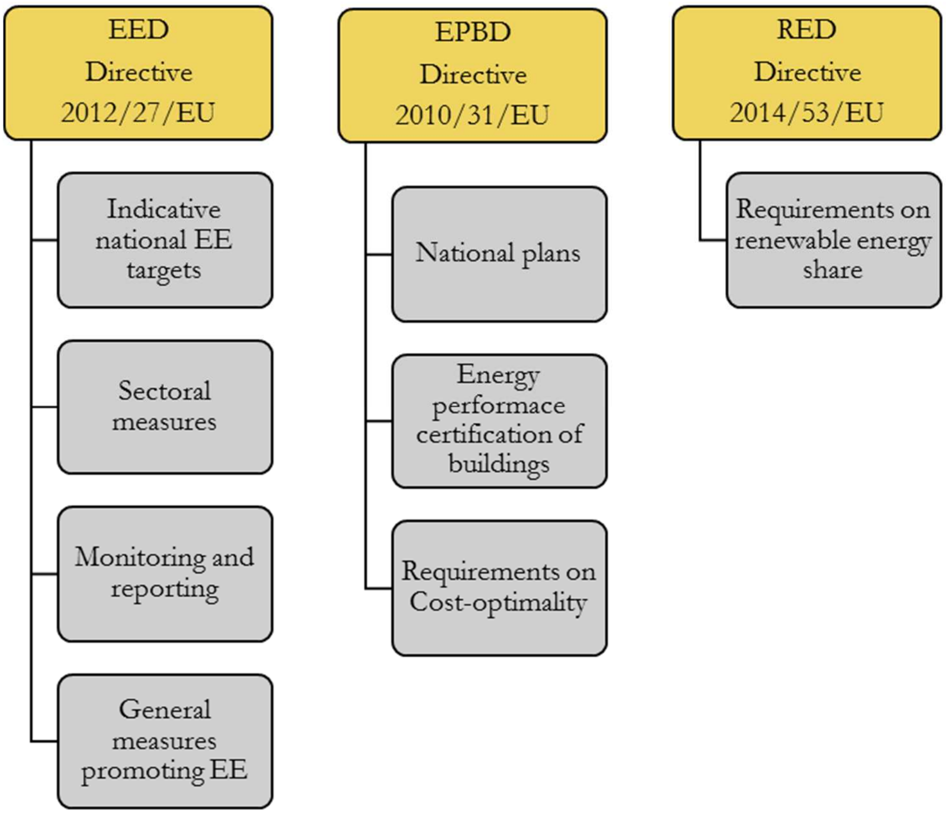


Figure 1: Key elements of European Directives (EED, EPBD, and RED).

2.1.2.OVERVIEW OF IMPLEMENTATION

The article 9 of the EPBD set the timeline for the implementation of the nZEB definition, as shown in Figure 2 (D'Agostino, 2015). All new public buildings starting from 1st January 2019 and all private buildings starting from 1st January 2021 must reach the nZEB target, according to the federal definition. To give an overview of implementation across Europe, we reviewed the latest issued reports, such as from the EPBD Concerted Action, from the IEE project ZEBRA2020 and the main relevant papers on the topic.

Following the indication of EPBD 2020/31/EU, in 2015 fifteen countries of the European Union had submitted a definition of nZEB, and four countries set both a definition with a numerical target with a specific requirement on renewable energy share. Figure 3 reports results of definition implementation across Europe from 2013 to 2015 (D'Agostino et al., 2016).

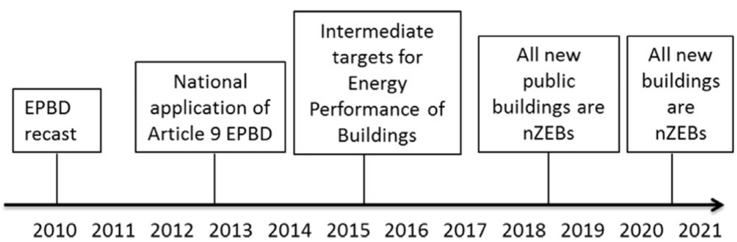


Figure 2: Timeline for nZEB implementation (D'Agostino, 2015).

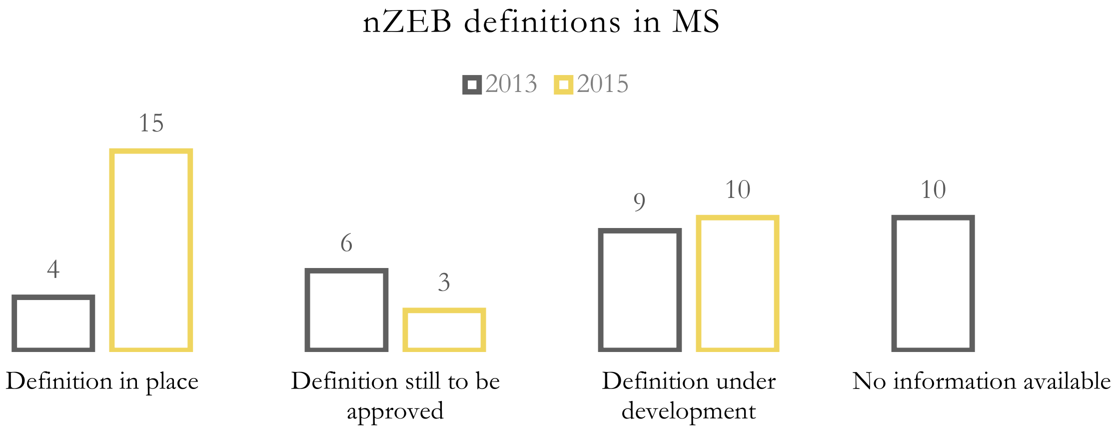


Figure 3: nZEB definitions in MSs, including Norway (BPIE, 2015).

The analysis of definitions and the fixed requirements shows how the countries chose different approaches to the matter, defining different system boundaries. Figure 4 summarizes the main differences and their distribution across the Member States. As stated in D'Agostino et al. (2016) as well as in the outcomes of Task 40, the boundaries of the energy balance are one of the most discussed issues, since they strongly affects the assessment of the renewable energy production that can contribute to the energy balance. Another critical point is the focus of the definition (that also affects the performance evaluation), which can refer to a single building or groups of buildings. In most of the cases, such as the CRAVEzero countries, the requirements are set for single buildings and include in the definition of nZEB targets both new and renovated ones. At the same time, the definition is established for both private, and public buildings. Concerning the balance period and normalization factors, MSs present a general homogeneity. In most countries, the balance period is one year, and the normalization factor is the conditioned area.

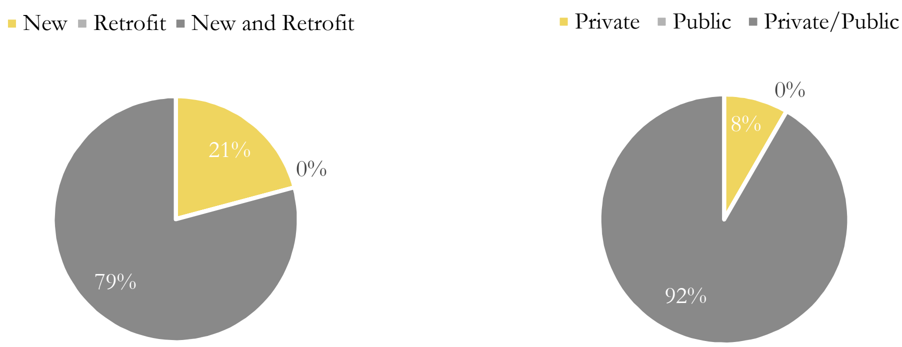


Figure 4: Building typology and building classification in nZEB MS definitions (D'Agostino et al., 2016).

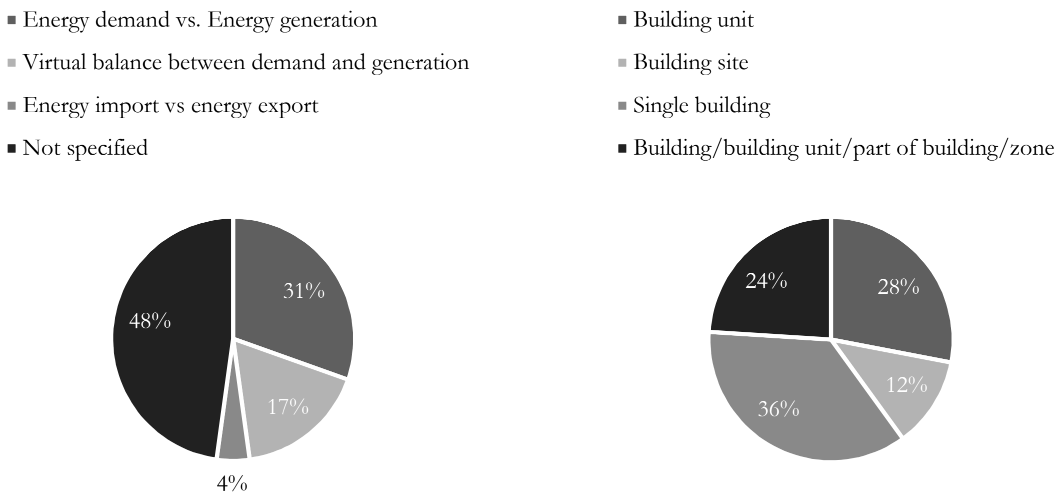


Figure 5: Energy balance and building physical boundary in nZEB MS definitions (D'Agostino et al., 2016).

Considering the generation from renewable energy sources, all countries include solar thermal, geothermal, heat recovery, and photovoltaics. Among the CRAVEzero partners, a minimum requirement for the renewable energy share is set in the case of Austria, Germany, Italy, and France, while the majority of MSs renewable energy share is not included in the primary energy requirement. An exception is France, where a certain amount of energy from photovoltaics can be accounted the primary energy consumption; this determines a higher requirement.

Drivers and barriers

To analyze major drivers and barriers in the nZEB market uptake in Europe the single country must be considered. However, the ZEBRA2020 project identified two common aspects, which go beyond national differences: financing schemes and professional knowledge.

On the one hand, there is a need for economic incentives and pilot programs as drivers of the market transition to nZEBs. On the other hand, a lack of professional knowledge and experience was identified. Most of the countries, examined in the project, pointed out that there are obstacles in the diffusion of innovative energy saving technical solutions among designers and craftsmen.

The objective of CRAVEzero is to tackle these issues, identifying and reducing the extra costs of nZEBs, so that the impact on financing policies can be reduced. Furthermore, one of the outcomes of the project is the CRAVEzero pinboard, an instrument where information, methodologies, tools and approaches defined within the project are collected. This instrument will support industry partners in the planning process to structure the specific business model.

2.1.3.COST-OPTIMALITY

The achievement of high performances in nZEBs must go with the cost-optimality assessment. The EPBD Directive stated that, MSs shall "take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost-optimal levels". Furthermore, the guidelines accompanying Commission Delegated Regulation (EU) 244/2012 supplementing the EPBD established "a comparative methodology framework for calculating cost-

optimal levels of minimum energy performance requirements for buildings and building elements."
Cost-optimality means that the building design, from envelope to technical systems, has to take into account energy efficient solutions with minimal life cycle cost. The investigated countries have adopted this aspect of the Directive as follows:

- Austria – OIB in March 2013 carried out studies on the cost-optimality of the energy performance requirements of nZEB 2020. The requirements, which have been defined in the OIB Guidelines 6, are based on those studies (Leutgöb, et al., 2012 and Mitterndorfer et al., 2012).
- Germany – Report on cost-optimality shows the calculations performed on a set of six representative model buildings, where different solutions were tested on new buildings. Results of the report show that the current requirements for all types of new buildings meet or exceed the cost-optimal level (Concerted Action, 2014).
- France – RT2012 states: "Regulatory requirements were developed starting from techno-economic studies. These made it possible to determine an optimum between the impact of the requirements on the cost of construction and the gain in energy consumption and comfort."
- Italy – Studies on cost-optimality were conducted in 2013 to define the requirements.
- Sweden – The national board of housing, building, and planning (Boverket), continuously monitors cost-optimality of the requirements. Several revisions have been carried out in the last years. A further one is planned in 2019/2020.

2.1.4.RELEVANT PROJECTS

There are several EU projects dealing with nZEB, and in this report, we adopted as a source of information for monitoring the nZEB implementation at European level three main references:

ZEBRA2020 - Nearly Zero-Energy Building Strategy 2020: the results of the project "are meant to reinforce the investors' confidence in the market transition and the long-term perspective of nZEB targets." The project carried out cross-country comparisons of barriers, drivers, and best practices, especially for economic aspects. Furthermore, online data tools, which provide data on the nZEB market, have been developed.
Relevant as starting point for CRAVEzero is the conclusion reached by ZEBRA2020 stating that "a quantitative comparison of national nZEB definitions is complex due to different system boundaries, calculation methodologies, applied factors, etc. However, the analysis indicates that a significant share of nZEB definitions does not meet the intent of the EU directive on energy efficient buildings (EPBD). Thus, a recast EPBD should require clear definitions of terms and thresholds, and gaps should be closed". Within this report, we tried to overcome the limits of this analysis, by comparing the required nZEB performances adopting a reference building and a unique calculation approach.

ASIEPI - Assessment and improvement of the EPBD Impact (for new buildings and building renovation): the objective was to support the Member States and the European Commission on the issues related to the implementation of the EPBD. The project carried out an instrument to compare the energy performance requirements in the Member States and proposed solutions for improving the national approaches to the implementation of EPBD. The comparison method is divided into five steps:

① Description of the cases: definition of the geometrical parameters of several case studies, together with the technical systems.

② National calculation of average insulation levels: for each country the average insulation level needed to fulfill the EP requirement is calculated.
③ Uniform calculated energy use: total primary energy for each case study is calculated. Results are compared, taking into account outcomes of point 2 and specific climate.
④ Climate severity index: a correction based on climate is needed to directly compare primary energy, therefore a climate severity index is introduced.

Qualitative evaluation: since this method presents several difficulties in the comparison, a qualitative evaluation was carried out.

ENTRANZE - Policies to enforce the transition to nearly zero-energy buildings in the EU-27: the project aims to support the development of those policy measures, which promote penetration of nZEB technologies. The project wanted to connect experts from European universities and research institutes with public decision-makers and stakeholders from the building sector, to promote a shared political action plan, with a focus on the refurbishment of existing buildings. Major outputs of the projects, also interesting for CRAVEzero framework, are:

- There is a massive lack of data regarding renovation activities and the energy performance of buildings. There is a need for a building data observatory, in particular for monitoring policy impacts.
- The EPBD (recast) was a first attempt to create a comparable framework for European countries. However, further enhancement of the legislation is necessary. Especially pointing out that cost-optimality has to represent the absolute minimum requirements for existing regulations in the building codes.
- The EPBD should also gradually increase the binding character of nZEB requirements for existing buildings. Thus, a precise definition of nZEB or deep renovation is also required.

EPBD Concerted Action (CA) – This project is a joint initiative between the Member States and the European Commission. Representatives of MSs plus Norway, who are in charge of preparing the technical, legal and administrative framework for the EPBD, take part in the project. The aim is to better share the information and progress about the adoption of the European directive.

IEA SHC TASK 40 – The activities of Task 40 had the aim of studying zero or near net energy buildings, aiming to develop a common understanding of a harmonized definitions framework, tools for the study of NZEBs (Net Zero Energy Building), innovative solutions and guidelines for industries. To accomplish this goal several case studies of both residential and non-residential buildings (new and existing) were documented and analyzed.

2.2. EU CONSTRUCTION MARKET

General overview

The building sector in Europe is responsible for approximately 40% of the total energy consumption. The percentage accounted for residential buildings amounts at 27% of the total. Hence, this sector has a key role in the path towards the enhancement of energy efficiency and reduction of greenhouse emissions at EU level. The EPBD, together with the Energy Efficiency Directive and the Renewable Energy Directive, established a set of measures with the aim to provide in Europe the conditions for significant and long-term improvements in the energy performance of the construction market.

In this section, an overview on construction market in Europe is provided, to better understand the current situation and trying to identify where the barriers on nZEB implementation identified by ZEBRA 2020 have a higher impact.

Figure 6 presents the share of residential buildings in European countries. This reaches 89% in Italy, while in Austria accounts 61.6%.

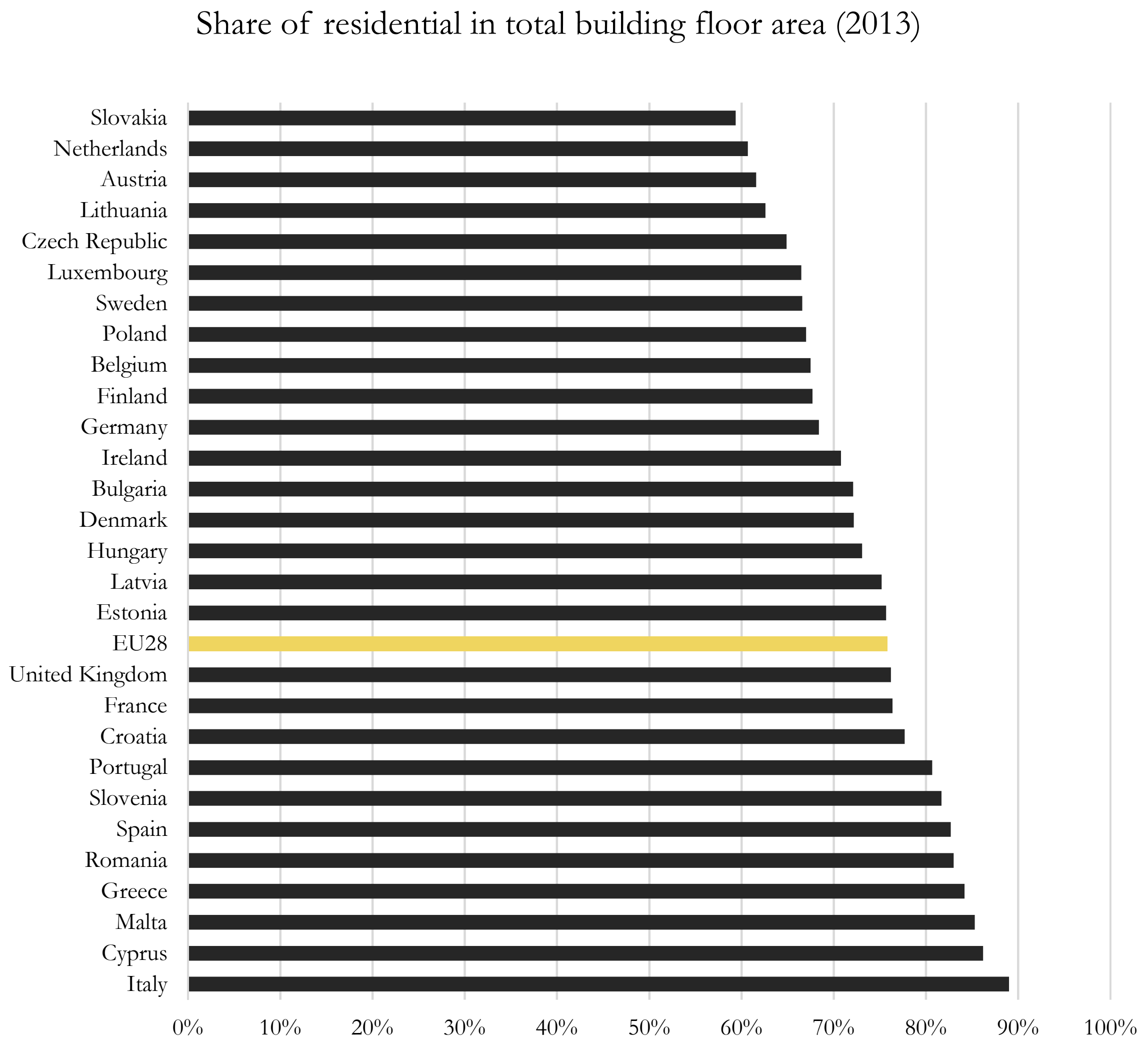


Figure 6: Share of residential in total building floor area across Europe (EU Buildings Observatory, 2013).

On average, the volume of housing development across Europe amounts 2.8 completed apartments per 1000 citizens (Figure 7). The number of households, at European level, is expected to increase by more than 15% by 2050 compared to the number measured in 2013.

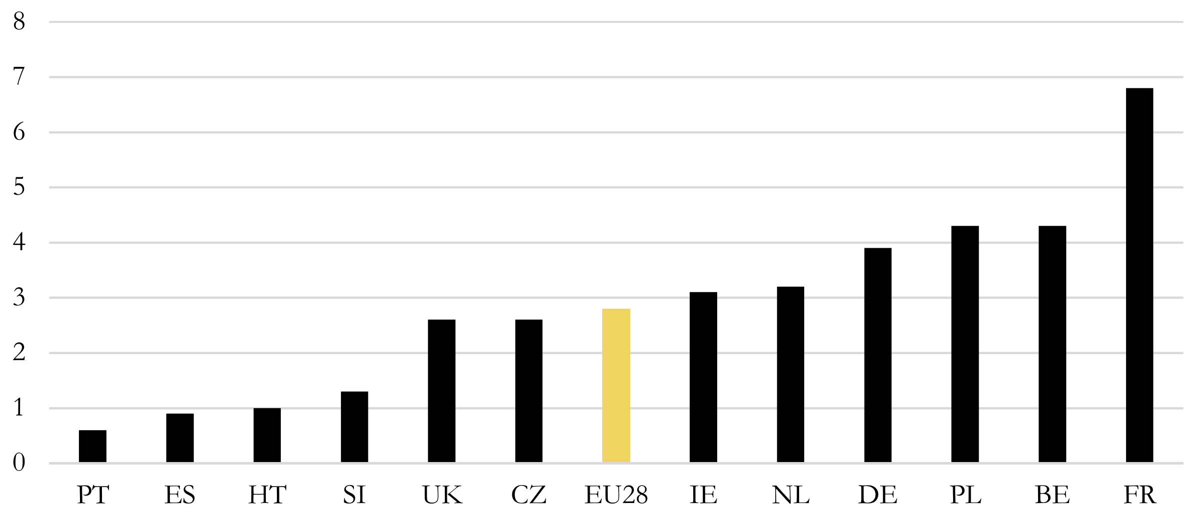


Figure 7: Number of completed dwellings per 1000 citizens (Deloitte, 2017).

Starting from 2021 (2019 for public buildings) all new buildings must be nZEB. Meanwhile, the project ZEBRA2020 carried out a picture of the new buildings in 2014. In Figure 8 and Figure 9, the distribution of respectively new residential and non-residential buildings is displayed according to the performance target. The scale starts from red, which indicates the share of new buildings fulfilling the minimum requirements of the building code, to green, where buildings with higher performance than nZEB definition are accounted. In this analysis, the level of ambition of the national target is not considered and so not directly comparable (e.g. in France, all the new buildings should reach the target nZEB, set at 65 kWh/m² of primary energy, thus there are no new constructions built below this limit).

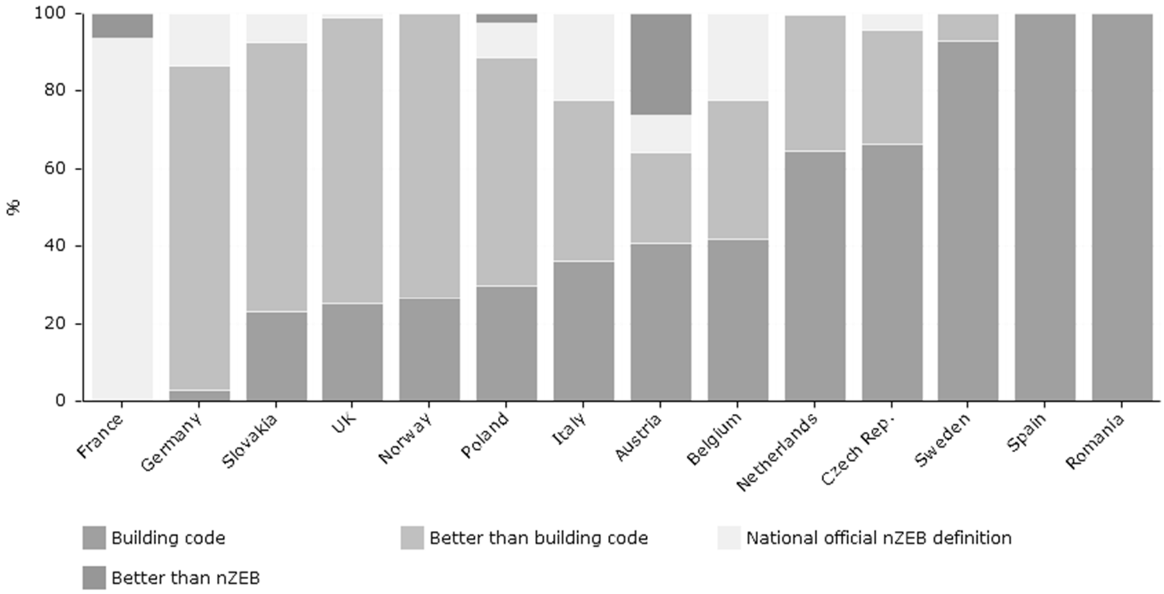


Figure 8: Distribution of new residential buildings according to the nZEB radar graph in 2014 (EU IEE ZEBRA2020 Data Tool).

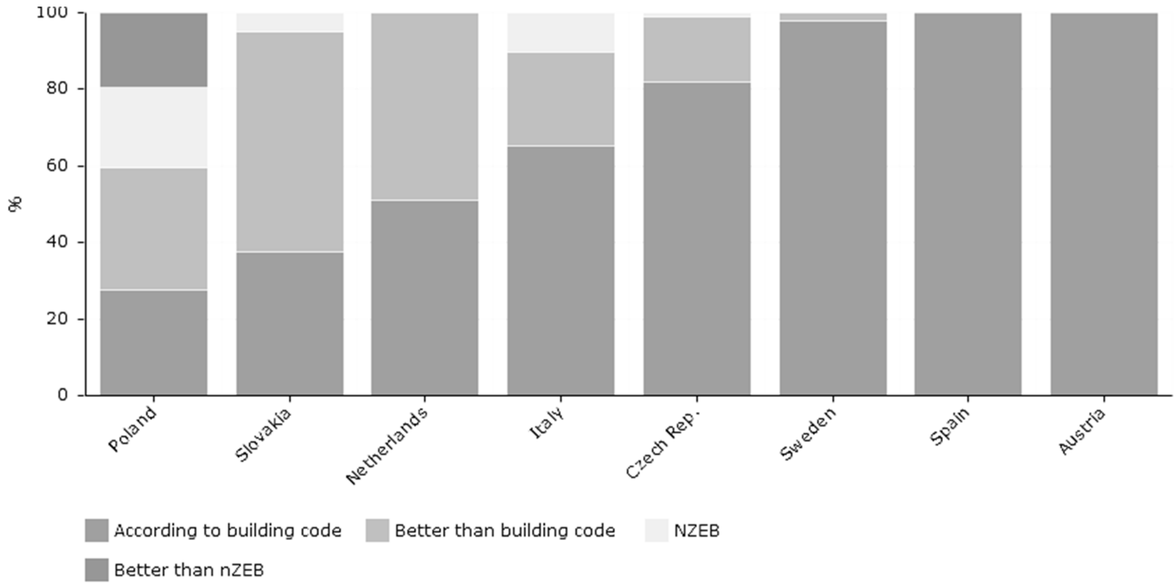


Figure 9: Distribution of new non-residential buildings according to the nZEB radar graph in 2014 (EU IEE ZEBRA2020 Data Tool).

Technologies

A cost-effective design and operation of technical systems play an important role in the final energy consumption of a building. As reported in Atanasiu et al. (2011), itis evident that technologies based on fossil fuel are not consistent with nZEB concept promoted by EPBD. Electric heat pump seems to be the most suitable technology, due to the expected increase of the renewable energy share in the national electricity mix and renewable on-site production. In addition to heat pumps also biomass micro-CHPs and district heating systems (with a renewable energy share of 50% at least) will be important in the future development of the nZEB market. Figure 10 shows the share of the most used heating systems, according to the climatic zone. In cold climate a sample of 234 buildings has been collected, in mild climate 160 and in warm climate 17. In cold climates the heat pump and the district heating occupy the first two positions of the most common heating technologies, whereas the heat pump has a lower penetration in comparison with mild climates (Paoletti et al., 2017). Other technological aspects whose improvement is necessary to push forward the market uptake of nZEB are efficient thermal insulation materials and windows, HVAC technologies. However, an analysis of BPIE showed how the actual markets related to these technologies must grow consistently to cover the future demand due to nZEBs. Table 2 shows that ventilation systems with heat recovery and triple glazed windows currently have a market about ten times smaller than the required one. The market of insulation materials, heat pumps, pellet boilers and solar thermal systems has to growth 2-3 times.

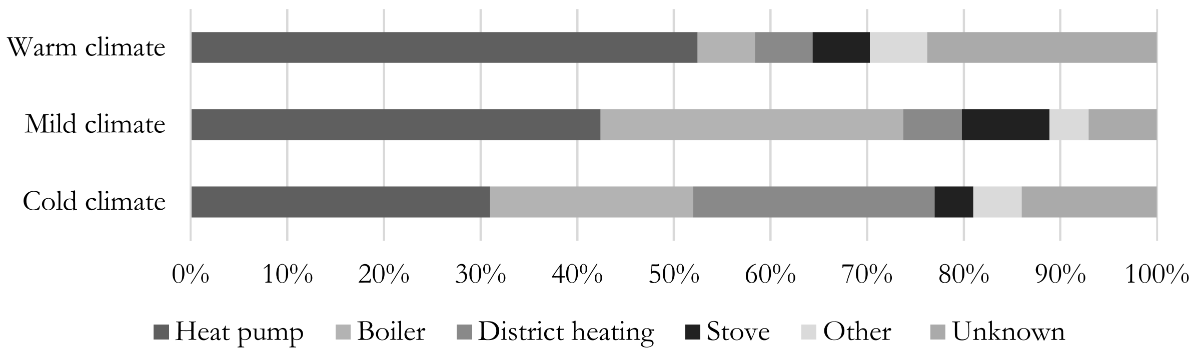


Figure 10: Share of heating systems according to climatic zones (Paoletti et al., 2017).

MARKETS	REQUIRED GROWTH FACTOR	CURRENT MARKET SIZE	UNIT
Insulation materials	2-3	2010	Mio €
Ventilation with HR	8-10	130.000	Units
Triple glazed windows	>10	1.500.000	m²
Heat pumps	2-3	185.000	Units
Pellet boilers	2-3	43.000	Units
Solar thermal systems	2-3	3.700.000	m²

Table 2: Overview of the factors actual markets should grow by to satisfy future demand (BPIE, 2011).

Data on average U-value of building envelope across Europe, as well as on the share of buildings with photovoltaic and solar thermal systems installed, are displayed in Figure 11 - 10 - 11.

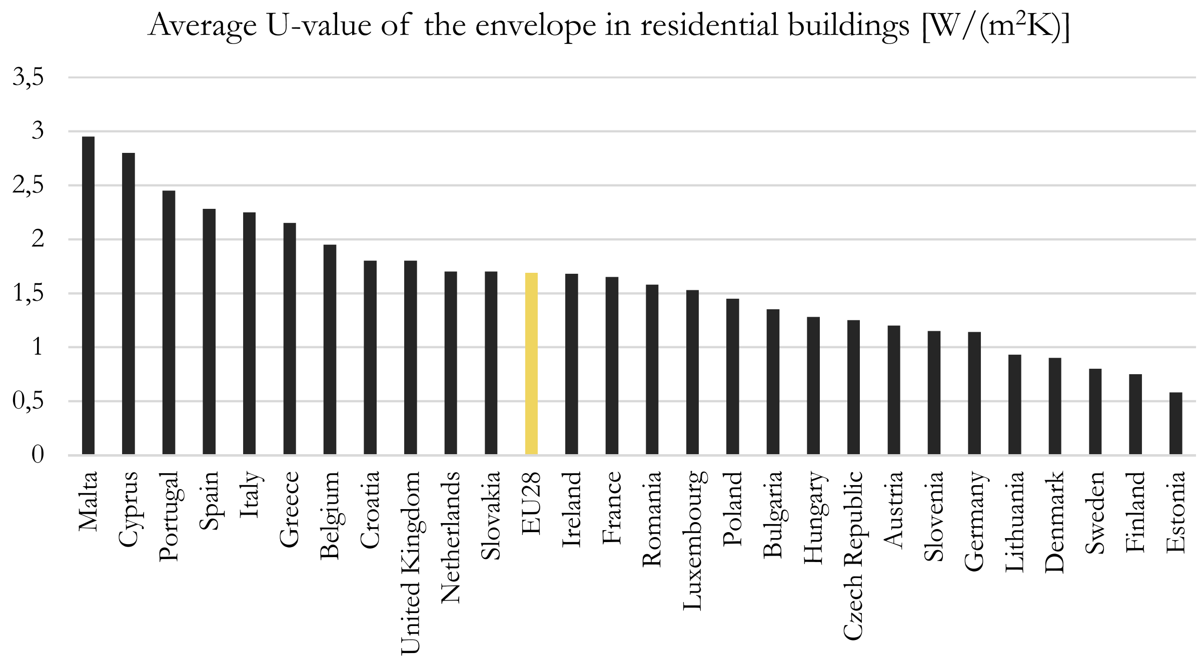


Figure 11: Average U-value of the envelope in residential buildings [W/(m²K)] (EU Buildings Observatory, 2014).

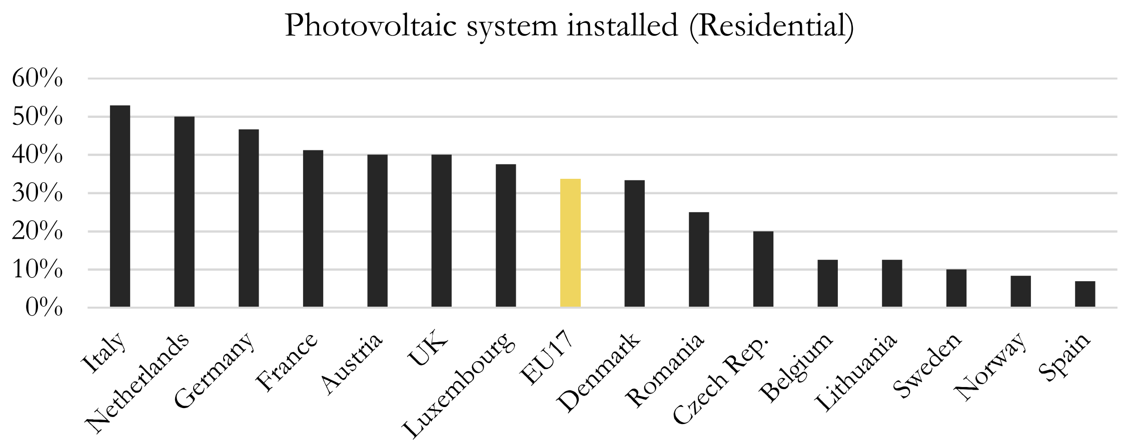


Figure 12: Share of buildings with photovoltaic systems across Europe (EU IEE ZEBRA2020 Data Tool).

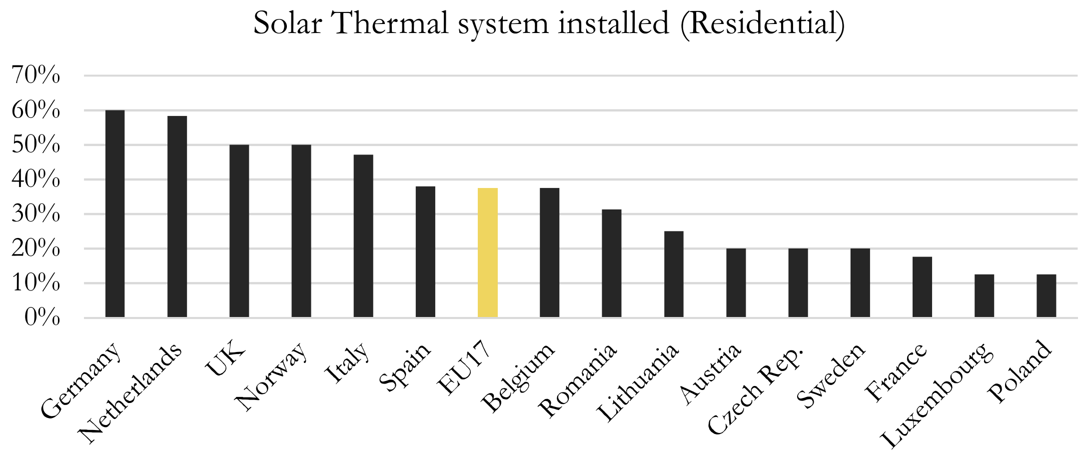


Figure 13: Share of buildings with solar thermal systems across Europe (EU IEE ZEBRA2020 Data Tool).

Finally, extra costs for nZEB construction are displayed in Figure 14. The objective of CRAVEzero project is to identify and to propose solutions to reduce these extra costs associated with the nZEB construction.

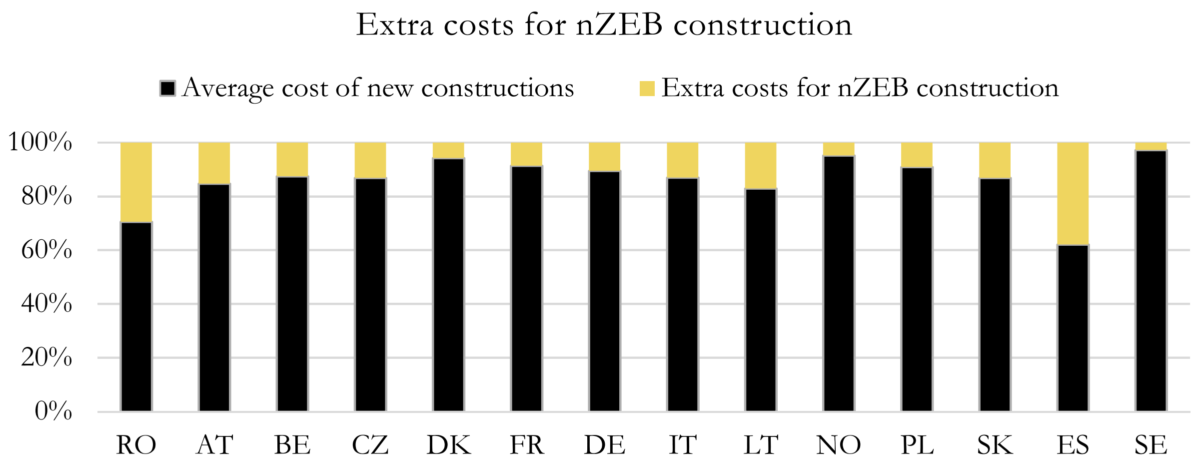


Figure 14: Extra costs for nZEBs construction versus average cost of new constructions (Pascual et al., 2016).

3. FOCUS AT NATIONAL LEVEL

The EPBD recognizes that each MS has its specific conditions regarding construction market, climate, and energy mix. Therefore, the Directive did not provide minimum or maximum harmonized requirements for nZEBs, but required only the implementation of very high energy performance, where the energy demand has to be covered to a very significant extent by energy from renewable sources. This, together with the absence of a common calculation methodology for energy performance, causes that the approaches of MSs are not readily comparable.
To carry out a comparative analysis among countries, an analysis of regulatory framework at the national level is needed. Due to the easy access to information and the possibility to receive direct feedback, we have selected the countries of the consortium CRAVEzero: Austria, Germany, France, Italy, and Sweden.

The focus is on the nZEB definitions of each country and the corresponding regulatory policies. We gave particular regard to minimum and maximum requirements, boundary conditions and renewable energy share. These indicators will permit, in chapter 4, to establish a comparison among countries that present significant differences in building stock typology, climate conditions, energy mix, etc.

COUNTRY	REGULATION	YEAR	REQUIREMENTS		
			PE	Envelope	Renewable energy
Austria	OIB-"Nationaler Plan", OIB-RL 6	2015	x	x	x
Germany	EnEV	2014	x		
	EEWärmeG	2011			x
	KfW	2015	x	x	
France	Réglementation Thermique (RT2012)	2012	x		x
	RT des bâtiments existants	2017	x	x	
Italy	Decreto ministeriale 26 giugno 2015	2015	x		
	Decreto legislativo 28/2011	2011			x
Sweden	BBR25	2017	x		

Table 3: Overview of the issued regulations for CRAVEzero countries.

In Table 3 national regulations of CRAVEzero members that are currently in force are displayed, together with the indication of which type or requirement is set: specific primary energy (PE), transmittance values for envelope elements and requirements on renewable energy share.
Each regulation has a different nZEB definition and thus different system boundaries, as pointed out in paragraph 2.1.2. However, the CRAVEzero countries show many approach similarities.
All take into account in their regulation both new and renovated buildings, as well as private and public buildings. In the same way, no one considers the balance at the building site level, but the physical boundaries are set on the building unit/single building. More differences can be found in the balance typology (which is related to how renewable energy is calculated in the energy balance), Austria and Germany consider energy demand and energy generation; Italy considers energy import and energy export. Finally, all regulations take into account both on-site and off-site generation.

COUNTRY	BUILDING TYPOLOGY	BUILDING CLASSIFICATION	ENERGY BALANCE	PHYSICAL BOUNDARY	GENERATION
Austria	new/retrofit	private and public	demand/ generation	single building	on-site/ off-site
Germany	new/retrofit	private and public	demand/ generation	single building	on-site/ off-site
France	new/retrofit	private and public	/	single building	/
Italy	new/retrofit	private and public	import/export	single building	on-site/ off-site
Sweden	new/retrofit	private and public	/	single building	on-site/ off-site

Table 4: Main characteristics of the national regulations.

3.1. AUSTRIA

3.1.1.DEFINITION AND REGULATORY POLICY

The Austrian Institute of construction engineering carried out the "National Plan". This contains minimum energy performance requirements for buildings, by EPBD. In 2015 the new OIB Guideline 6 (OIB-RL 6) "Energy saving and heat protection" was published, where the definition of nZEB and the regulation of energy savings for both residential and non-residential buildings are contained. This guideline deals with heating and cooling demand and final energy demand related to space heating and DHW of new buildings or those, which are under a deep renovation process.

3.1.2.EP AND ENVELOPE FEATURES

The document "national plan" includes minimum standards for four energy indicators, which are used to define nZEBs: space heating demand, primary energy demand, CO_2 emissions and total energy efficiency factors. The provided requirements are tightened stepwise towards 2020 (in 2014, 2016, 2018, and 2020). Furthermore, the guideline provides as a second, additional requirement on U-values for all buildings, which need an energy performance certificate (Table 6). The requirements are related to the Austrian reference climate (3400 HDD).

REQUIREMENTS FOR 2020	HEATING DEMAND	PE_{MAX} [KWH/(M²A)]	CO_2 [KG/(M²A)]
New residential buildings	$10*(1+3.0/l_c)$ [kWh/(m²a)]	160	24
New non-residential buildings	$3.33*(1+3.0/l_c)$ [kWh/(m³a)]	170	27
Existing residential buildings	$17*(1+2.5/l_c)$ [kWh/(m²a)]	200	32
Existing non-residential buildings	$5.67*(1+2.5/l_c)$ [kWh/(m³a)]	250	39

Table 5: Requirements for residential and non-residential buildings, as well as for new and existing buildings.

U-VALUES [W/(M²K)]	
Wall	0.35
Roof	0.20
Floor	0.40
Window	1.4

Table 6: Additional requirements on U-values.

Specific limits of energy demand are set. Thus the building envelope should ensure minimum performance levels (calculated without the heat recovery of the mechanical ventilation system). The overall performance of the building is evaluated regarding the requirements shown in Table 5, and the contribution of energy from renewable sources is partly included in the energy balance.

3.1.3.RENEWABLE ENERGY SOURCES

The OIB guideline 6 includes requirements for renewable energy share, for both new construction and major renovation of a building. Requirements are fulfilled in at least one of the following cases:

a) Use of renewable sources outside the system boundaries "Building": 50% of the required heat demand for space heating and hot water must be covered by one the following renewable energy sources: biomass, heat pump, district heating from renewable energy, district heating from high-efficiency cogeneration and waste heat.

b) Use of renewable sources by generation on-site or nearby:

- 10% of the final energy demand for DHW by solar thermal.
- 10% of the final energy demand for household electricity by photovoltaics.
- 10% of the final energy demand for space heating by heat recovery.
- Equivalent to the three abovementioned options, the reduction of the maximum permissible final energy demand or the maximum permissible total energy efficiency factor (fGEE) by at least 5% by any combination of measures of solar thermal energy, photovoltaics, heat recovery or efficiency increase.

3.1.4. OTHER REQUIREMENTS

- Heat Recovery: in case of first installation or major renovation, the air-conditioning and exhaust air system have to be equipped with a heat recovery system.
- Air tightness: if there is no mechanical ventilation system installed, the maximum value from the blower door test n_{50} is three h^{-1}. If there is a mechanical ventilation system, the requirement for the maximum airtightness is 1.5 h^{-1}. The air change rate is assumed as a constant value of 0.4 h^{-1}. This requirement are valid for both residential and public buildings.

3.2. GERMANY

3.2.1. DEFINITION AND REGULATORY POLICY

An official definition of nZEBs is still under development. However, in several reports to the European Commission, the German federal government expressed the intention to define the future nZEB-level based on "KfW efficiency houses." BBSR (Bundesinstitut für Bau-, Stadt- und Raumforschung) adds that nZEB-standard will be following the requirements for KfW Efficiency Homes 55 level related to the German Energy Saving Ordinance (EnEV) 2009, that set the minimum performance requirements in case of new construction.

The KfW funding bank (Kreditanstalt für Wiederaufbau), on behalf of the federal government, provides subsidies for buildings that exceed current requirements. Recently, more than 50% of new residential buildings got such subsidies. In these cases, the energy demand was 30% below the required value (EnEV), and around 10% of these buildings present a demand 45% below the value required. For these reasons, we selected the requirements of KfW 55 as German nZEb target for the comparison with the other countries.

The current regulatory framework, which deals with energy efficiency and renewables in buildings, is structured in three parts:

- Energy Saving Act (EnEG): currently the version EnEG 2013 is in force. Among other things, the law stipulates a minimum energy standard for new buildings and the insulation of existing ones.
- Energy Saving Ordinance (EnEV): is in force since May 2014. This ordinance specifies the requirements buildings have to meet. No further tightening is expected. The KfW requirements are based on the EnEV.
- Renewable Energy Heat Act (EEWärmeG): it came into force on 1 January 2009 and aimed to promote renewable energies in heating and cooling systems in buildings. The act introduces national requirements for renewable energy in case of new buildings.

In 2018 the federal government planned to issue the Building Energy Act. This one should contain and update the three above-mentioned regulations, providing the official nZEB definition.

3.2.2.EP AND ENVELOPE FEATURES

Requirements for new buildings are not expressed by absolute values, but by comparing the performances with a corresponding reference building. It has the same geometry, but its components and its technical systems implement the requirements fixed by the ordinance. Accordingly, the requirement for primary energy consumption is calculated.

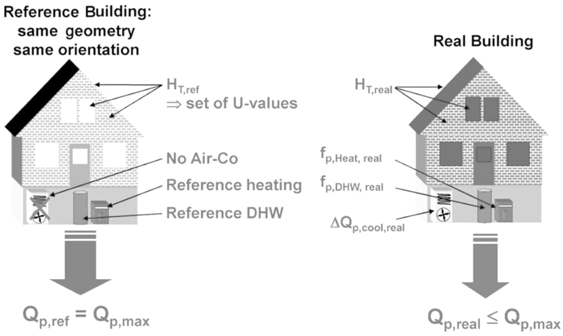


Figure 15: Reference building used to calculate the requirement on primary energy consumption (Concerted Action, 2014).

U-VALUES [W/(M²K)]	ENEV 2014	KFW NEW
Wall	0.28	0.20
Roof	0.20	0.14
Floor	0.35	0.25
Window	1.3	0.9

Table 7: U-values comparison for new buildings between EnEV2014 and KfW.

3.2.3.RENEWABLE ENERGY SOURCES

The EEWärmeG, which came into force on 1 January 2009 and was amended in 2011, set minimum targets, depending on the energy source, for primary energy (associated to heating and cooling) to be covered with renewable energy by 2020. Specific requirements are:

SHARE OF RES	EEWÄRMEG
Solar radiation	15% of $PE_{heating}$ and $PE_{cooling}$
Biogas	30% of $PE_{heating}$ and $PE_{cooling}$
Biomass	50% of $PE_{heating}$ and $PE_{cooling}$
Geothermic or ambient	50% of $PE_{heating}$ and $PE_{cooling}$

Table 8: Share of renewable energy sources according to EEWärmeG.

3.2.4.OTHER REQUIREMENTS

As concerns technical systems, the KfW set the requirements to reach the standard KfW55. The heat generator must be within the thermal building envelope and, in case of a multi-family building, the new construction must have a central domestic hot water generation. Also, one of the six following technical concepts has to be implemented:

- Condensing boiler, solar DHW production, and central ventilation system with heat recovery (efficiency ≥ 80%).
- District heating with certified primary energy factor ≤ 0.7, central ventilation system with heat recovery (efficiency ≥ 80%).
- Central biomass heating system based on wood pellets, wood chips or firewood, central exhaust air system.
- Geothermal heat pump with surface heating system, central exhaust air system.
- Water-to-water heat pump with surface heating system, central exhaust air system.
- Air-to-water heat pump with surface heating system, central ventilation system with heat recovery (efficiency ≥ 80%).

3.3. FRANCE

3.3.1.DEFINITION AND REGULATORY POLICY

The Thermal Regulation RT2012 (Réglementation Thermique 2012), like the RT2005, expresses requirements for primary energy consumption. This regulation considers that the nZEB definition matches its requirements. Therefore, all new constructions, since January 2013, are considered nZEB in France. A new version of the Thermal Regulation is planned for 2020 (RT2020), and its goal is to promote the construction of positive energy buildings.

3.3.2.EP AND ENVELOPE FEATURES

In the RT2102 total primary energy consumption is defined for heating, cooling, hot water production, lighting, ventilation, and any auxiliary systems. For new residential buildings the regulation set maximum primary energy consumption of 50 kWh/(m^2a) and 70 kWh/(m^2a) for new non-residential buildings without cooling systems and 110 kWh/(m^2a) for buildings with cooling systems. The required consumption levels are subject to variations, depending on geographical areas and altitudes.

The RT 2012 is structured around three performance indicators:

- BBio: this index characterizes the impact of bioclimatic design on the building energy performance and limits the energy demand (heating, cooling, and lighting) based on the bioclimatic design (B_{biomax}) of the project.
- Cep: this index characterizes primary energy consumption. It includes heating, cooling, domestic hot water, lighting, and auxiliaries. Permanent production must not exceed a maximum threshold, Cep_{max}. This requirement is calculated as a sum of the previews elements minus photovoltaic production (limited to 12 $kWh_{EP}/(m^2a)$).
- Tic: this index sets the conventional indoor temperature for summer comfort, where the ambient indoor temperature of the building, reached after the five hottest days of the year (T_{ic}), cannot exceed the requirement.

France is an example of different system boundaries, in comparison to the other examined countries, since photovoltaic production on site can be accounted in the energy balance to assume a higher primary energy requirement for nZEBs.

REQUIREMENTS	PE_{MAX} [KWH/(M²A)]
New residential buildings	40-65
New non-residential buildings	70-110
Existing residential buildings	80
Existing non-residential buildings	60% PE

Table 9: Requirements on primary energy for residential and non-residential buildings, as well as for new and existing buildings in France.

3.3.3.RENEWABLE ENERGY SOURCES

RT 2012 requires the use of a renewable energy source or an alternative solution for individual houses. There are five ways to meet this requirement:

- The contribution of renewable energies to the “Cep” superior or equal to 5 $kWh/(m^2a)$].
- Production of domestic hot water from a solar thermal panel with a minimum surface area of $2m^2$.
- Production of domestic hot water from a heat pump, with minimum COP of 2.
- Connection to a heating network supplied more than 50% by renewable energy sources.
- Production of heating and domestic hot water provided by a micro-cogeneration boiler with liquid or gaseous fuel, allowing the production of electricity in addition to heating.

3.4. ITALY

3.4.1.DEFINITION AND REGULATORY POLICY

The decree D.M. 26 of June 2015, which came into force in October 2015, set the requirements for new construction and nZEB. The decree introduced the reference building for defining the maximum limit of primary energy for heating, cooling, ventilation, hot water production and, in case of non-residential buildings, lighting and movement for new constructions and nZEBs. The reference building is assumed as a building with the same geometry and specific values for the envelope thermal transmittance as well as HVAC system efficiency. In case of nZEBs, the values to be applied are referred to 2019/2020.

The decree also updated the classification scale of the energy performance of buildings, now consisting of 10 classes: A4, A3, A2, A1, B, C, D, E, F, G.

3.4.2.EP AND ENVELOPE FEATURES

Stated the different climate conditions across Italy, the decree set transmittance values for six zones, from A (0-600 HDD) to F (+3000 HDD), and in two steps: 2015 and 2019/2021. In Table 10 U-values for new and existing buildings in zone E are displayed, since 53% of Italian municipalities are in zone that climate zone. These U-values, implemented in the reference building, permit to calculate the primary energy consumption. This will be the requirement for the real case. The maximum primary energy consumption is expressed in kWh/(m^2a) for residential buildings and in kWh/(m^3a) for non-residential ones.

U-VALUES ZONE E [W/(M²K)]	2019/2021 NEW	2019/2021 EXISTING
Wall	0.26	0.28
Roof	0.22	0.24
Floor	0.26	0.29
Window	1.4	1.4

Table 10: U-values for new and existing buildings in the climate zone E to define the reference building.

3.4.3.RENEWABLE ENERGY SOURCES

With the Legislative Decree 28/2011, transposing the Renewable Energy Directive, the requirements regarding the share of renewable energy for new buildings and major renovations were increased. The decree established to cover 35% of primary energy consumption for thermal uses from renewable sources, which will become 50% from 1 January 2018.

3.5. SWEDEN

3.5.1.DEFINITION AND REGULATORY POLICY

Sweden has developed a nZEB strategy, based on the EPBD, adapting previous regulations for energy performances. The Swedish Building Code (BBR) is in charge to define building energy performance; currently, the BBR 25 (BFS 2017:5) is in force. The Swedish National Board of Housing (Boverket) proposed the system boundary "purchased/delivered energy" for evaluating nZEBs.

3.5.2.EP AND ENVELOPE FEATURES

The Swedish regulation set the requirements for building energy consumption, defining as an indicator the "specific energy use." This is defined as the "energy which, in normal use during a reference year, needs to be supplied to a building (often referred to as purchased energy) for heating (E_{uppv}), comfort cooling (E_{kyl}), hot tap water (E_{tvv}) and the building's property energy (E_f)". Requirements are set for single-family homes, multi-apartment buildings, and non-residential buildings and divided into 4 climate zones. Moreover, the requirements are divided for electrically heated and non-electrically heated buildings. The first ones also include heat pump systems. The regulation set requirements on U-values only in case of small buildings. Table 11 reports the requirements on specific energy use for a new building in the climate zone 3 (Stockholm) both in case of residential and non-residential.

REQUIREMENTS	SPECIFIC ENERGY USE$_{MAX}$ [KWH/(M²A)]	
	Electrically heated	Non-electrically heated
New residential buildings	55	90
New non-residential buildings	50	70

Table 11: Requirements on specific energy use for residential and non-residential buildings in Sweden (zone 3).

3.5.3.RENEWABLE ENERGY SOURCES

The Swedish regulation does not indicate any requirement on a minimum renewable energy share. The reason can be identified observing the national target on renewable energy. The target to reach at least 50% of renewable energy of the total energy use by 2020 was exceeded already in 2014 (53%). However, to promote the use of renewable energy sources on-site, energy freely available transformed into heat or comfort cooling shall not be counted, in the verification of the energy performance requirement (Martinac, I., 2016).

3.5.4.OTHER REQUIREMENTS

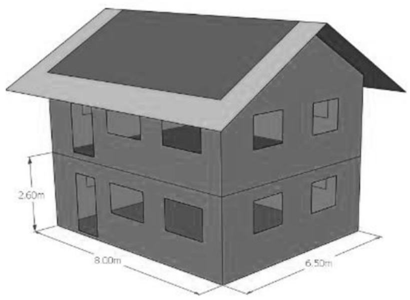
The BBR provides general recommendations for HVAC systems. Heating and cooling systems should provide adequate efficiency during normal operation, implementing control and regulation systems. Specific fan power requirements are set for different ventilation systems.

4. COMPARATIVE ANALYSIS

One of the objectives of this deliverable is to provide a comparison among CRAVEzero countries on the nZEB requirements set by each national regulation. The previous sections showed how the requirements are defined in different ways. In fact, while Austria, France, and Sweden define a fixed value for the energy consumption, Italy and Germany adopt the methodology of the reference building. For the comparison between these two approaches, PHPP (Passive House Planning Package) was adopted to model the reference building and to calculate the nZEB performance requirements in Italy and Germany. PHPP is an energy efficiency planning tool developed by the Passive House Institute, where a building can be modeled (structure and technical systems) to calculate key performance indicators.
After displaying geometrical and technical features adopted in the building modeling, we carried out a comparative analysis of different configurations.

4.1. REFERENCE BUILDING

The reference building selected has been introduced within the FP7 project Inspire as single family house representative of the EU stock. It is composed of two stories with a total of 100m². The following glazing ratio characterizes the building: on the south side, it amounts to 25%, in the north side around 14% and the east and west side around 22%. Main geometrical features are reported in Table 12, while U-values of the building elements have been selected depending on the country's minimum nZEB requirements, changing the insulation thickness.



GEOMETRICAL FEATURES

	Windows surface [m²]	Surface (opaque) [m²]	Total surface [m²]	Glazing ratio
Facade North	6,15	38,65	44,8	14%
Facade South	11,1	33,7	44,8	25%
Facade East	8	28,4	36,4	22%
Facade West	8	28,4	36,4	22%
Ground floor			52	
Roof			52	

Table 12: Geometrical features of the reference building.

As regards technical systems, we adopted different configurations to show the effect of each choice on the primary energy demand, keeping constant the U-values (as indicated in the requirements). In Table 13 we displayed the four different cases we have simulated in PHPP:

- **Case 1**: the building has a heat pump for heating and domestic hot water (COP=3), but no mechanical ventilation. An air change rate at pressurization test (n_{50}) of 4 volumes per hour was set. This is a standard value where no particular focus to airtightness has been devoted in the design phase.
- **Case 2**: the building has mechanical ventilation with a heat recovery system.
- **Case 3**: the same as case 2, but with the maximum air change rate for Passive House Standard (0.6 1/h).
- **Case 4**: the same as case 2, whereas the heat pump is replaced by a gas condensing boiler.

TECHNICAL FEATURES	CASE 1	CASE 2	CASE 3	CASE 4
	Heat pump	Heat pump + Mech. ventilation	Heat pump + Mech. Ventilation + Airtightness	Gas Condensing boiler + mech. ven-tilation
Ventilation + HR (eff.: 85%)	/	Yes	Yes	Yes
Air change rate (n_{50}) [1/h]	4	4	0,6	4

Table 13: Summary of the four cases modeled in PHPP.

4.2. RESULTS

The comparative analysis starts with the energy demand for heating of the reference building, calculated regarding primary energy. In the case of France and Sweden, this was not possible, since the French and Swedish regulations indicate only a requirement on total energy consumption and not on the heating demand.
The heating demand was calculated in representative cities in Germany and Italy (Munich and Milan), implementing the configuration of case 2, showed in Table 13. For Austria, the reference climate was adopted, since the requirements of the OIB Guideline are based on this. The results were normalized using the average heating degrees of the three cases. Figure 16 shows the results: first, on the left, the heating demand in terms of final energy (downstream of the generator), and then the corresponding primary energy associated with the only heating demand in case of a boiler supplied by natural gas, solid biomass or coal, and a heat pump supplied by electricity from the grid. It can be observed that the primary energy associated with a heat pump is considerably lower than the one related to a boiler.

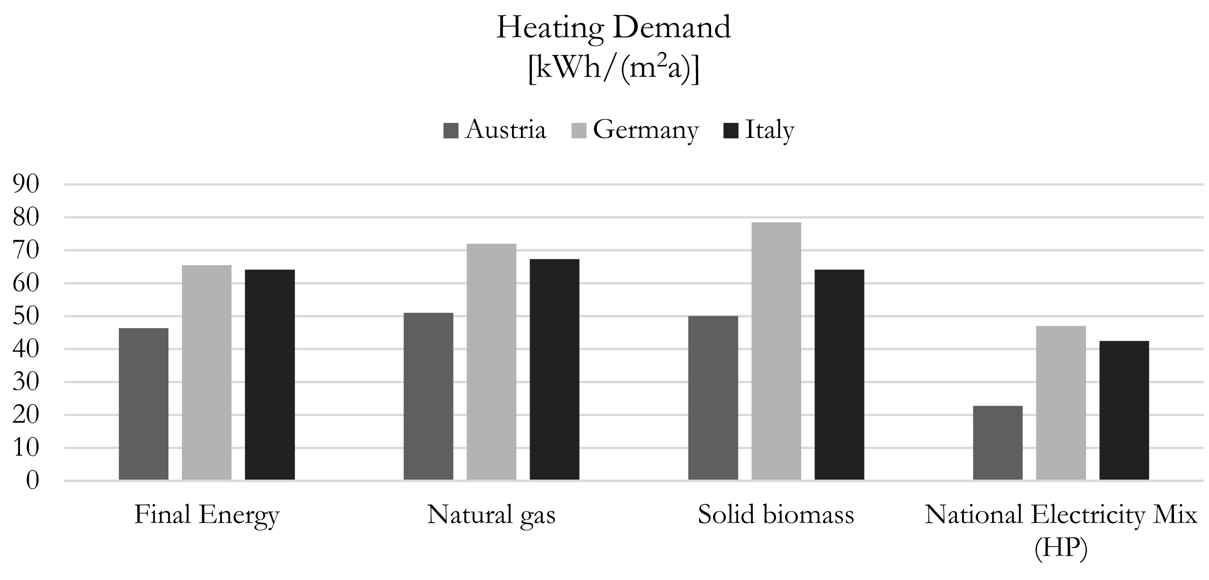


Figure 16: Comparison of final and primary energy (boiler supplied by natural gas or solid biomass and an electric heat pump) associated with the only heating demand among Austria, Germany and Italy.

In Figure 17 the primary energy requirements of Austria, France and Sweden have been compared with those reached by Italy and Germany with their reference building in two configurations: case 2 (heat pump, ventilation with heat recovery) and case 4 (gas condensing boiler, ventilation with heat recovery). Primary energy demand refers to the sum of heating demand, domestic hot water generation and household electricity. The case of Sweden displays the primary energy demand, calculated starting from the values of "specific energy use" for climate zone 3 (Stockholm area). In the case of France, correction factors have been applied, to obtain the requirement for the city of Paris. Finally, the results have been normalized, using the heating degree-days.

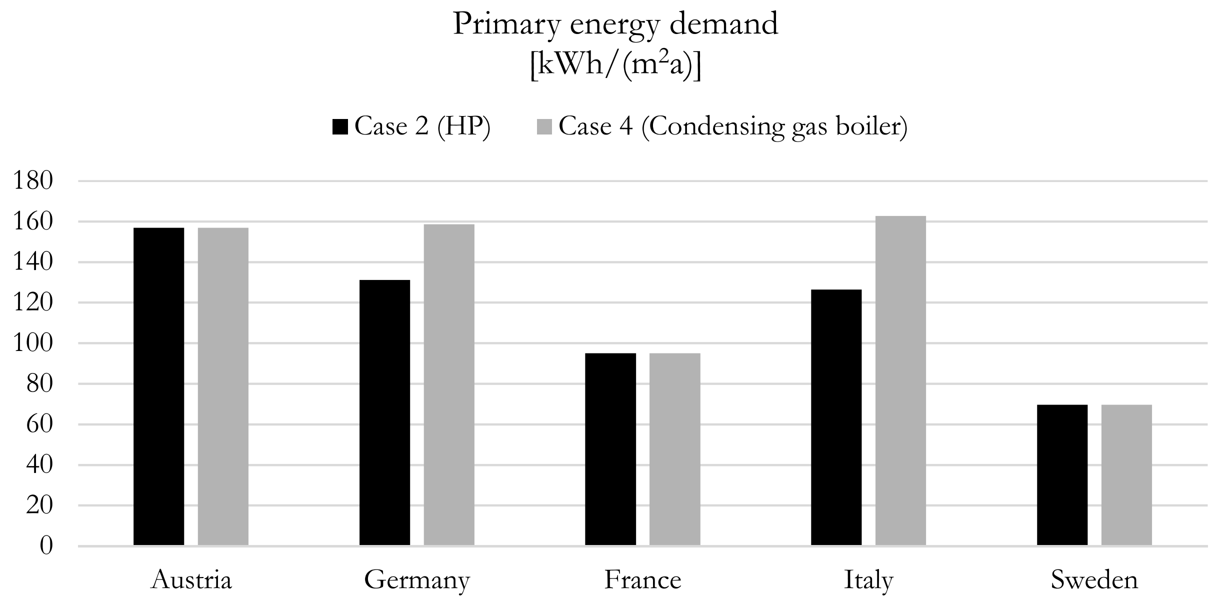


Figure 17: Primary energy demand for heat pump and gas condensing boiler.

Furthermore, a comparative analysis of the four configurations presented in Table 13 is proposed, to better understand the effects on the primary energy of design choices. Figure 18 the results. The installation of a ventilation system reduce of 10.1% the primary energy demand. A building design with special attention to airtightness permits a further reduction of 9.8%. The case number four represents a building with a gas condensing boiler and a ventilation system. The primary energy demand, in this case, is 28.7% higher than the case with a heat pump (case 2).

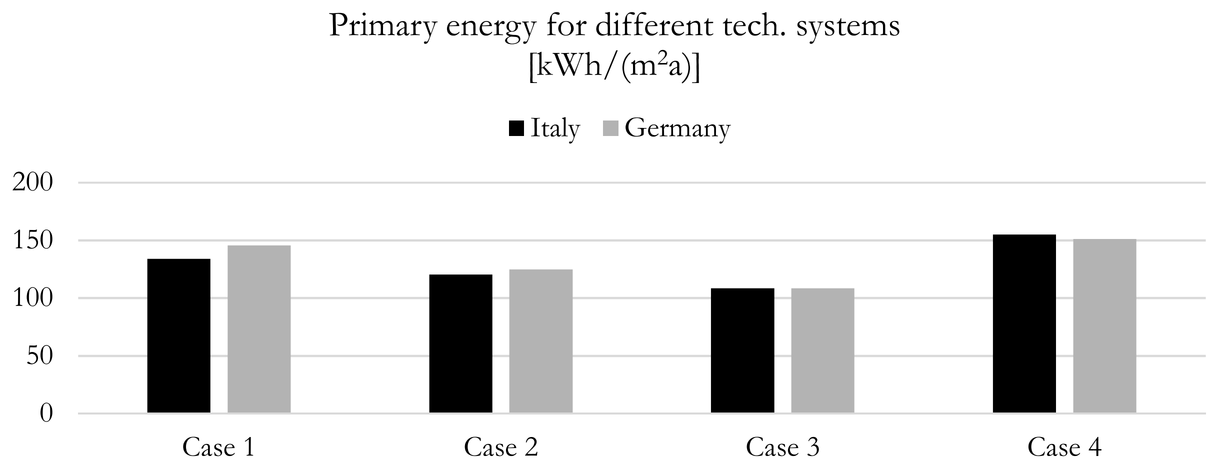


Figure 18: Primary energy demand for the reference building in Germany and in Italy with different tech. systems.

Other aspects of technical systems design can positively influence the building energy consumption. Tackling these aspects with a cost-effective approach, on the other way round, permit to better fulfill the fixed requirements on energy demand such as in the case of France, Sweden, and Austria. Two of these aspects are provided:

- Results of PHPP calculation showed how an essential role in the energy consumption in a nZEB building is played by the total energy demand of domestic hot water, in particular, the losses due to the distribution system. As Clarke and Grant (2010) stated, "these losses are independent of actual consumption, but they are strongly influenced by house layout and hot water system design." A good system design, for example reducing the length of distribution pipes, can play an important role in reducing the total energy consumption of the building.
- Another source of energy consumption is the heat loss of the hot water storage tank. We took from the literature a heat loss rate of 4,1 W/K for a storage tank in combination with a heat pump (Glembin, Büttner, Steinweg, & Rockendorf, 2015).

To complete the comparative analysis, in Table 14 an overview of requirements for U-values is displayed. However, in the Austrian regulation, the U-values are considered a second requirement, in combination with requirements on primary energy. In France, there is no specific indications about U-values, and in Sweden, the U-values are defined only in case of small buildings. Table 15 shows a comparison of the primary energy factors. The differences reflect those in the national energy mix and the political decisions of each country. In fact, since the requirements are in most cases, defined using primary energy, this can incentive the implementation of those technologies, which energy supply comes from a source with a low primary energy factor.

U-VALUES [W/(M²K)]	AUSTRIA	GERMANY	FRANCE	ITALY	SWEDEN
Sources	OIB-RL 6	KfW	RT2012	D.M. 26/06/2015	BBR 25
Wall	0.35	0.20	-	0.26	0.18
Roof	0.2	0.14	-	0.22	0.13
Floor	0.4	0.25	-	0.26	0.15
Window	1.4	0.9	-	1.4	1.3

Table 14: U-values requirements comparison in the consortium countries.

ENERGY VECTORS	AUSTRIA			GERMANY		
	$PEF_{non-re.}$	$PEF_{re.}$	PEF_{global}	$PEF_{non-re.}$	$PEF_{re.}$	PEF_{global}
Oil	1.23	0.01	1.23	1.1	0	1.1
Natural Gas	1.16	0	1.17	1.1	0	1.1
Liquefied Petroleum Gas (LPG)	1.1			1.1	0	1.1
Coal	1.46	0	1.46	1.2	0	1.2
Solid biomass	0.06	1.02	1.08	0.2	1	1.2
Liquid and gas biomass				0.5	1	1.5
Liquid biomass				0.5	1	1.5
National Electricity-Mix	1.32	0.59	1.91	2.4	0.2	2.8

ENERGY VECTORS	FRANCE	ITALY			SWEDEN
	PEF_{global}	$PEF_{non\text{-}re.}$	$PEF_{re.}$	PEF_{global}	PEF_{global}
Oil	1	1.07	0	1.07	1
Natural Gas	1	1.05	0	1.05	1
Liquefied Petroleum Gas (LPG)	1	1.05	0	1.05	1
Coal	1	1.1	0	1.1	1
Solid biomass	1	0.2	0.8	1	1
Liquid and gas biomass	1	0.4	0.6	1	1
Liquid biomass	1	0.4	0.6	1	1
National Electricity-Mix	2.58	1.95	0.47	2.42	1.6

Table 15: Primary energy factors comparison in CRAVEzero countries.

5. CONCLUSIONS

The objective of this deliverable was to give a better understanding of the European regulatory framework, of the national regulations and their mechanisms, together with an analysis of nZEB construction market. This overview represents the starting point and the base knowledge for defining and implementing the activities and results CRAVEzero project.

Nearly zero-energy performance levels and cost-optimality are principles included in the Energy Performance of Buildings Directive recast (EPBD 2010/31/EU) as key aspects influencing the new constructions in Europe. These principles, adopted from the Member States, will strongly influence the construction sector in the next years. As presented in this deliverable, there are many approaches to the nZEB definition, which reflect the differences and specificities of the Member States. The focus on CRAVEzero countries allows to identify common patterns in the structure of the national regulatory policies. All of them include the same building typology, building classification and physical boundaries of the construction. However, it is evident that primary energy values present differences because they reflect different calculation methodologies and different approaches to primary energy factors. Major discrepancies have been detected in the system boundaries, renewable energy uses and approaches to HVAC systems analysis.

Nevertheless, national energy policies seem to be under constant development, both with the entry into force of the steps defined in current legislation and with new legislation and methodologies introduced. In Austria, the OIB-"Nationaler Plan" defined a progressive tightening of the requirements every two years from 2014 until 2020. By 2020, Germany is planning to unify and update the three regulations, carrying out in 2020 the Building Energy Act and France planned the new version of Thermal Regulation. Italy set requirements first for 2015 and then for 2019/2021 and Sweden update every year the Swedish building code. For these reasons, by 2020 the regulatory framework of MSs will approximate the concept that inspired Europeandirectives. Nevertheless, at the moment there are still important barriers to the full implementation of the nZEB concept, and the current rate of new nZEB construction is still quite low. In this regards, the deep analysis of the current nZEB technologies, processes and business models, the identification of the main difficulties and threats as well as the proposals of improvements promoted by the project CRAVEzero will foster a positive impact.

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6. REFERENCES

Recast, E.P.B.D. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Off. J. Eur. Union 2010, 18, 21.

Atanasiu, B., & Attia, S. (2011). Principles for nearly zero-energy buildings: Paving the way for effective implementation of policy requirements. *Principles for nearly Zero-energy Buildings: Paving the way for effective implementation of policy requirements*, 124.

BPIE. (2015). Factsheet Nearly Zero Energy Buildings Definitions across Europe.

Concerted Action EPBD, 2014. Concerted Action | Energy Performance of Buildings Directive. Intelligent Energy Europe. Available online: http://www.epbd-ca.eu/ [Accessed in March, 2018].

D'Agostino, D. (2015). Assessment of the progress towards the establishment of definitions of Nearly Zero Energy Buildings (nZEBs) in the European Member States. *Journal of Building Engineering*, *1*, 20–32.

EU Buildings Observatory. (2013). European construction market.

EU IEE ZEBRA2020 Data Tool. Available online: http://www.zebra-monitoring.enerdata.eu/ [Accessed in March 2018].

Eurostat, Final energy consumption by sector, 2014. Available online: http://epp. eurostat.ec.europa.eu/portal/page/portal/statistics/search_database [Accessed in March, 2018].

Glembin, J., Büttner, C., Steinweg, J., & Rockendorf, G. (2015). Thermal storage tanks in high efficiency heat pump systems–optimized installation and operation parameters. *Energy Procedia*, *73*, 331–340.

Isaac, M., Pana Tronca, L., & Gajsak, M. (2016). D 8.1 Report: Market analysis of trends in the construction of residential highly energy performing buildings.

Leutgöb, K., Jörg, B., Rammerstorfer, J., Amann, C., & Hofer, G. (2012). Analyse des kostenoptimalen Anforderungsniveaus für Wohnungsneubauten. *E7 Marktanalyse GmbH Wien.*

Leutgöb, K., Rammerstorfer, J. (2012). Implementing the cost optimal methodology in EU countries. Case study Austria. *E7 Marktanalyse GmbH Wien.*

Linhart, M., Hána, Petr., Petrík, V., Marek, D. (2017). Property Index: Overview of European Residential Markets. *Deloitte.*

Martinac, I. (2016). Experiences of implementation of EPBD in Sweden – Towards NZEB. *Rakennustenenergiaseminaari, Helsinki.*

Mitterndorfer, M., Mair am Tinkhof, O., & Simader, G. (2012). Berechnung von kostenoptimalen Mindestanforderungen an die Gesamtenergieeffizienz von Gebäuden (gemäß EPBD Art. 5). *Österreichische Energieagentur–Austrian Energy Agency, Wien.*

Paduos, S., & Corrado, V. (2017). Cost-optimal approach to transform the public buildings into nZEBs: an European cross-country comparison. *Energy Procedia*, *140*, 314-324.

Paoletti, G., Pascual Pascuas, R., Pernetti, R., & Lollini, R. (2017). Nearly Zero Energy Buildings: An Overview of the Main Construction Features across Europe. *Buildings*, *7*(2), 43.

Pascual, R.; Paoletti, G. (2016). Deliverable 5.1: Nearly Zero-Energy Building (nZEB) Technology Solutions, Cost Assessment and Performance. Available online: http://zebra2020.eu/publications/nzeb-technology-solutions-cost-assessment-and-performance/