The Primary Energy Factors play a central role in European 2020 targets achievement

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ABSTRACT: The primary energy factors are numerical coefficients that weigh the different energy carriers, comparing them to the corresponding energy sources. The 2010/31/EU Directive establishes that the building energy performance should be expressed by a primary energy index. The analysis of the values currently employed in the European Countries shows that the performance assessment results are highly dependent from these values. The aim of the paper is to show that primary energy factors can play a central role for leading the building sector towards the European 2020 targets achievement. Starting from their determination it is possible to direct the choice among different energy carriers, as well as to rule the competition between renewable and fossil energy sources. Moreover the PEF values diversification for the imported or exported energy allows to advantage the distributed generation compared with the power generation, and the on-site produced energy consume compared with the input to grid.

1 INTRODUCTION

The “20-20-20” strategy for smart, sustainable and inclusive growth defines the energy and environmental targets that the European Union is committed to achieve by 2020 (EC 2012). The targets are: a 20% reduction of EU greenhouse gases emissions compared to the 1990 levels; the reaching of a 20% share of EU gross final energy consumption supplied from renewable energy sources; a 20% improvement in the EU energy efficiency through a 20% reduction of primary energy consumption. The Eurostat statistical data currently available (Eurostat 2012) indicate that in 2010 the levels reached for the three targets are respectively 15.0%, 12.5%, 5.4%. The target of a 20% reduction of primary energy consumption is the most far from reach.

The building sector accounts for 40% of total energy consumption in the European Union (EEA 2012). So the 2020 targets achievement is directly dependent on the energy efficiency efforts in this sector. The energy saving potential to 2020 is 27% for the residential building sector and 30% for the services building sector (European Commission 2006). The CO_2 emission reduction potential for the residential and services building sector is 20% in the reference scenario and 25% in the alternative efficient technology scenarios (European Commission 2011a). In 2010 the EPBD Directive (European Union 2002) has been recasted, in order to lead the building sector toward European 2020 targets achievement. The EPBD recast Directive (European Union 2010) establishes that the building energy performance should be expressed by a primary energy index based on Primary Energy Factors (PEF) per energy carrier, which can be derived from national or regional annual average.

The aim of the paper is to show that the PEF can play a central role for leading the building sector towards the European 2020 targets achievement. The results of the building energy performance assessment are directly dependent on the PEF values. Therefore they can direct the choices among different energy carriers used to meet the building energy needs.

2 RELATION BETWEEN PRIMARY ENERGY FACTORS AND ENERGY PERFORMANCE

2.1 *Energy Performance*

According to EN/TR 15615 (CEN 2008), the energy performance of a building is the sum of the weighted net delivered energy used to meet the building energy needs. The building energy performance assessment has a double purpose. The first is to check the minimal energy performance requirements for the new and existing buildings. The second is to express through an energy certificate the building energy value. The energy certification can be related to the energy classification. The energy certification and the energy classification should drive the real estate market, attributing a higher economic value to those building which have a higher energy performance. Currently the real estate market pushes towards high energy performance buildings. The higher prices of sale or rent allow to compensate the higher construction/refurbishment initial investment costs, compared to the Building As Usual prices and costs, and make suitable push the building energy performance beyond the minimal requirements.

Currently in European Countries three different indices are employed in the building energy performance assessment: primary energy, CO_2 emissions, final energy (EPBD-CA 2010). If the final energy index is employed, the building energy performance depends only on the building features. If the primary energy index or the CO_2 emission index is employed, the building energy performance depends also on the conversion or emission factors values. The primary energy index is already employed in most Member States, and its employment is expected also in the Countries where is not yet applied, in compliance with the EPBD recast Directive.

In the real estate market the economic value of a building increases when its energy performance increases. At the same building energy needs, the energy performance of a building increases when the PEF values decrease. The purpose of the PEF is to weigh the energy carriers. The PEF are able to direct the choices among different energy carriers because, at the same building energy efficiency and initial investment costs, the energy and economic overall building value depends on their values.

2.2 *Primary Energy Factors*

According to EN/TR 15615 (CEN 2008), the primary energy is defined as energy that has not been subjected to any conversion or transformation process. For example the fossil fuels. The secondary energy originates from the primary energy, through conversion or transformation processes. For example the electricity. The purpose of the PEF is to weigh the energy carriers, comparing them to the corresponding energy sources. The PEF are numerical coefficients determined as the inverse of the ratio between one unit of energy delivered to the building and n units of primary energy expended to deliver it. The PEF take into account the energy expenditure for energy carriers distribution and transmission, and also it take into account the efficiency of conversion or transformation processes from primary to secondary energy. So, employing the primary energy index, the energy performance of a building depends not only on the building features, but also on the energy supply chain features.

Currently in the European Union a shared methodology for the PEF values calculation lacks. An average European reference value of the electricity PEF, 2.50, is given in the 2006/32/EC Directive (European Union 2006). The PEF calculation is carried out at national or regional level, according to technical or political criteria. If technical criteria are employed, the PEF values are dependent on the energy supply chain efficiency, and are derived from the ratio between final energy consumption and primary energy consumption. An example of technical PEF value calculation is described in a report published by the Sustainable Energy Authority of Ireland (SEAI 2012). If political criteria are employed, the PEF values are dependent on the national or regional energy policy, which advantages some energy carriers and disadvantages others.

In the following paragraphs is shown that in the building sector the PEF can direct the choices among different energy carriers: 1) the choice among different fossil fuels; 2) the choice between fossil fuels and electricity; 3) the choice between fossil fuels and renewable fuels. Furthermore the PEF can direct the choices on electricity: 1) the choice between power generation and on-site generation; 2) the choice between consumption and input in grid of the electricity produced from on-site generation.

3 ROLE OF THE PEF IN BUILDING SECTOR RELATED TO THE CHOICE AMONG DIFFERENT ENERGY CARRIERS

3.1 *Choice among different fossil fuels and between fossil fuels and electricity*

The European decarbonisation energy roadmap is based on three different strategies (European Commission 2011b): energy end-uses electrification; increase in the renewable energy source share in the electricity power generation; CO_2 capture and storage. The building sector is directly involved from the first strategy and indirectly involved from the second strategy. The “Odyssee” report on the energy efficiency indicators in Europe (Odyssee 2012) shows that currently the European energy end-uses are supplied for 25% from electricity and for 57% from fossil fuels in the household building sector, and for 43% and for 48% respectively in the tertiary building sector. The share of fossil fuels is composed for 68% from gas and for 26% from oil in the household sector, and for 68% and for 29% respectively in the tertiary sector. There are different strategies for leading the building sector towards the CO_2 emissions reduction. One is the fuel switching from oil to gas. Another is the fuel switching from fossil fuels to electricity.

According to Sustainable Energy Action Plan “SEAP” data (SEAP 2012), the gas has a lower CO_2 emission factor than the oil. The energy efficiency of a fuel fired boiler is approximately equal if it is fuelled from gas or oil. At the same building energy needs, a lower PEF value for the gas rather than the oil leads to a higher building energy performance if a gas-fired boiler is used. In this case the PEF values are able to direct the choice towards that fuel which has lower CO_2 emission factor. The PEF values, indicated as $f_{P,x}$, currently employed for fossil fuels in several European Countries are given in (Sartori et. al. (in press)). In some Countries, as in Spain, they are different for gas and oil, respectively 1.07 and 1.12. In other, as in Germany, they are equal for all fossil fuels, 1.10. In the Countries where different PEF values are employed, the differentiation facilitates the fuel switching from oil to gas and leads towards CO_2 emissions reduction.

According to “SEAP”, the electricity has a higher CO_2 emission factor than the fossil fuels. However the electricity is a suitable energy carrier, because the positive impact due to the high energy end-uses efficiency is greater than the negative impact due to the high CO_2 emission factor. Currently the average European renewable energy source share in the electricity power generation is 19.0% (European Commission 2009). The trends show that in 2020 it will be 32.6%. So progressively the electricity suitability among different energy carriers will increase because the electricity CO_2 emission factor will decrease, instead the fossil fuels CO_2 emission factors will remain unchanged.

The heating energy use is the main energy end-use in the building sector (Odyssee 2012). The heat pump technology is more efficient than the fuel fired boiler technology to fuel the heating plants. The efficiency is defined as the ratio between thermal energy delivered to the building and energy carriers expended to deliver it. The RES Directive (European Union 2009) establishes that the aerothermal, idrothermal and geothermal energy are renewable energy sources. The fuel switching from fossil fuels to electricity leads towards CO_2 emissions reduction, end-uses efficiency increase and renewable share increase in gross final energy consumption.

At the same building energy needs, applying the primary energy index, the energy performance of a building depends on the heating plant fuelling technology efficiency and on the PEF values of the energy carriers used to fuel it. The heat pump technology is suitable if the ratio between the Coefficient Of Performance (COP) and the boiler efficiency is greater than the ratio between $f_{P,el}$ and $f_{P,x}$. The RES Directive establishes that should be take into account only those heat pumps which have a high efficiency compared to the primary energy consumption. That is in the case of electric heat pumps, only those which have a high COP compared to the electricity PEF value. The PEF values, indicated as $f_{P,el}$, currently employed for electricity in several European Countries are given in (Sartori et. al. (in press)). We calculated the ratio between $f_{P,el}$ and $f_{P,x}$ for gas, based on these PEF values. The results are given in Figure 1. The PEF values employed in Austria have the smallest ratio, 1.70, and the PEF values employed in Germany have the largest ratio, 2.72. If this ratio decreases, the heat pump technology suitability increases. According to the Ecofys PEF report (Molenbroek et al. 2011), the increase of the average European renewable energy source share in the electricity power generation will change the average European electricity PEF from the current value, 2.50, to the expected value, 2.00, in 2020. So progressively the electricity suitability among different energy carriers will increase.

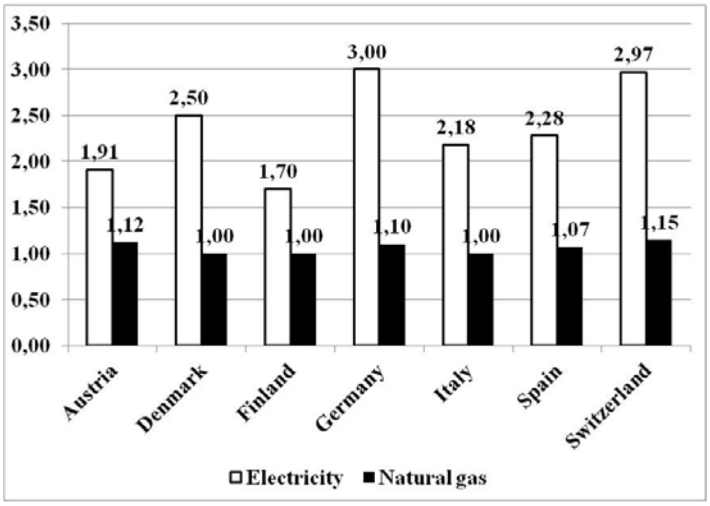

Figure 1. Ratio between $f_{P,el}$ and $f_{P,x}$ in several European Countries.

3.2 *Case-study*

We applied to a case-study the topics described in the previous paragraph.

We modeled a single family residential building (two floor dwelling) through an hourly numerical simulation, assuming a conventional user profile and a weather profile from Test Reference Year (Florence – Italy). The main building data are given in Table 1. The heating plant maintains the indoor temperature at 20 °C setpoint during the winter season (1 November – 15 April). The heating seasonal thermal energy need is 23,750 kWh, calculated downstream of the thermal generation system.

Table 1. Data for the case study building.

Conditioned area	200	m^2
Conditioned volume	800	m^3
Shape factor	0.45	
Wall mean U-value	1.5	W/m^2K
Window mean U-value	3.0	W/m^2K
Glazing factor	0.15	

We modeled three different thermal generation systems which fuel the heating plant: the first is an oil-fired boiler, which has 0.95 average seasonal efficiency; the second is a gas-fired boiler, which has 0.95 average seasonal efficiency; the third is an electric air heat pump, which has 3.50 average seasonal COP. The energy carriers expenditure is: 1956 kg of oil, 1908 kg of gas and 6785 kWh of electricity. The lower heating values, derived from the 2006/32/EC Directive (European Commission 2006), are 12.778 kWh/kg for oil and 13.10 kWh/kg for gas. The CO_2 emission factors, derived from (SEAP 2012), are 0.267 kg(CO_2)/kWh for oil, 0.202 kg(CO_2)/kWh for gas, and 0.46 kg(CO_2)/kWh for electricity.

For the three systems we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in Italy, Switzerland and Austria, derived from (Sartori et. al. (in press)). The results are given in Table 2.

Table 2. Energy Performance and CO_2 emissions for the case study building.

Reference	Oil fired boiler		Gas fired boiler		Electric air heat pump	
	PEF	Pr. En. Index kWh/m²anno	PEF	Pr. En. index kWh/m²anno	PEF	Pr. En. Index kWh/m²anno
Italy	1	131.6	1	131.6	2.18	77.9
Switzerland	1.15	151.3	1.24	163.2	2.97	106.1
Austria	1.12	147.4	1.13	148.7	1.91	68.2
emissions kg(CO_2)		6675		5050		3121

The calculation results explain the topics described in the previous paragraph.

The overall building CO_2 emissions are lower if the gas-fired boiler is used rather than if the oil-fired boiler is used (-24%). If the PEF values for gas and oil are equal, as in Italy, also the building energy performance is equal. In this case the PEF are unable to direct the choice among different fuels. Instead if the PEF value for gas is lower than for oil, as in Switzerland, the building energy performance is higher if gas is used than if oil is used. In this case the PEF are able to direct the choice towards that fuel which causes lower overall building CO_2 emissions.

The overall building CO_2 emissions are lower if the electric heat pump is used than if fuel fired boiler is used (-53% and -38%). Moreover the heat pump allows a higher end-uses efficiency and an about 70% renewable share (aerothermal energy) in gross final energy consumption. The building energy performance using the heat pump is higher than using the fired boiler in all three Countries. The heat pump suitability, dependent on the PEF values, is higher in Austria, where the ratio between $f_{P,el}$ and $f_{P,x}$ for gas is 1.69, than in Switzerland, where the ratio is 2.39.

3.3 *Choice between fossil fuels and renewable fuels*

The CO_2 emitted during combustion from a wood renewable fuel, that is wood pieces or wood pellets, is equal to the CO_2 absorbed during growth from the tree from which the wood was originated. According to "SEAP" a wood fuel has a CO_2 emission factor equal to 0 if wood is harvested in a sustainable manner. The fuel switching from fossil fuels to wood fuels leads towards the CO_2 emissions reduction and the renewable share increase in gross final energy consumption. The energy efficiency of a wood fuel fired boiler is lower compared to that of a fossil fuel fired boiler, however they are approximately similar. At the same building energy needs, applying the primary energy index, the building energy performance depends on the PEF values and on the choice between total PEF and non-renewable-PEF.

According to EN/TR 15615 (CEN 2008) there are two criteria about the PEF. Non-renewable PEF, which take into account only the non-renewable part of primary energy; total PEF, which take into account also the renewable part of primary energy. A fossil fuel has the total PEF value equal to the non-renewable PEF value. A wood fuel has the total PEF value equal to the sum of the non-renewable PEF value and 1. 1 is the PEF value conventionally attributed to the renewable energy sources. The PEF values currently employed for wood fuels in several European Countries are given in (Sartori et. al. (in press)). In some Countries, as in Sweden, the wood fuels total PEF values are equal to the fossil fuels total PEF values, 1.20. In others, as in Germany, they are similar, respectively 1.10 for fossil fuels and 1.20 for wood fuels.

If the primary energy index is calculated applying the total PEF, the energy performance of a building heated from a wood fuel fired boiler is approximately similar to that of a building heated from a fossil fuel fired boiler. The small EP differences possibly resulting from different heating-fuels are due to small energy efficiency differences of boilers and/or to small total PEF values differences. In this case the PEF are unable to direct the choice among different fuels. Instead if the primary energy index is calculated applying the non-renewable PEF, the energy performance of a building heated from a wood fuel fired boiler is higher to that of a building heated from a fossil fuel fired boiler. In this case the PEF are able to direct the choice towards that fuel which allows a lower CO_2 emission and a higher renewable share in gross final energy consumption.

3.4 *Case-study*

We applied to the previous case-study the topics described in the previous paragraph.

We modeled two different thermal generation systems which fuel the heating plant: the first is a wood pieces fired boiler, which has 0.90 average seasonal efficiency; the second is a gas fired boiler, which has 0.95 average seasonal efficiency. The energy carriers expenditure is: 5654 kg of wood pieces and 1908 kg of gas. The lower heating values, derived from the 2006/32/EC Directive (European Commission 2006), are 4.667 kWh/kg for wood pieces and 13.10 kWh/kg for gas. The CO_2 emission factors, derived from "SEAP", are 0 kg(CO_2)/kg for wood pieces and 0,202 kg(CO_2)/kWh for gas.

For the two systems we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in Austria and Germany, derived from (Sartori et. al. (in press)). The results are given in Table 3.

Table 3. Energy Performance and CO_2 emissions for the case study building.

Reference	Wood pieces fired boiler		Gas fired boiler	
	PEF	Pr. En. index kWh/m²anno	PEF	Pr. En. index kWh/m²anno
PEF total, Germany	1.20	166.7	1.10	144.7
PEF non-ren., Germany	0.20	27.8	1.10	144.7
PEF total, Austria	1.01	140.3	1.12	147.4
PEF non-ren. Austria	0.01	1.4	1.12	147.4
emissions kg(CO_2)		0		5050

The calculation results explain the topics described in the previous paragraph.

The building overall CO_2 emissions are 0 if wood pieces boiler is used. Moreover the wood pieces fired boiler allows a very high renewable share in gross final energy consumption. If the primary energy index is calculated applying the total PEF, the building energy performance when the heating plant is fuelled from the wood pieces fired boiler is approximately similar to the one when it is fuelled from the gas fired boiler. In this case the PEF are unable to direct the choice among different fuels. If the primary energy index is calculated applying the non-renewable PEF, the building energy performance when the heating plant is fuelled from the wood pieces fired boiler is much higher than when it is fuelled from the gas fired boiler. In this case the PEF are able to direct the choice towards that fuel, wood pieces, which causes lower overall building CO_2 emissions and allows a very high renewable share in gross final energy consumption. These results occur both for the Austrian PEF and for Germany PEF.

4 ROLE OF THE PEF IN BUILDING SECTOR RELATED TO THE CHOICE ABOUT THE ELECTRICAL ENERGY CARRIER

4.1 *Choice between power generation and on-site generation and between consume and input in the grid*

An on-grid building interacts with the electric grid through the system boundary. If there are on-site electric generation devices based on renewable energy sources, as the sun or the wind, the building imports electricity from power generation and exports electricity from on-site generation. The on-site generation based on renewable energy sources contributes to reach the 2020 target of a 20% renewable share in gross final energy consumption. The grid electricity PEF value affects the competition between power generation and on-site generation. At the same building electric energy need, a high grid electricity PEF value pushes towards the installation of on-site electric generation devices. Instead a low grid electricity PEF value pushes towards the electric taking from the grid.

The mismatch between users consumption profiles and on-site generation profiles makes necessary to take electricity from the grid when the on-site generation is smaller than the users consumption and to input electricity in grid when the users consumption is larger than the on-site generation. The on-site generated electricity amount consumed from the users is deducted from the grid electricity amount taken from the grid. The deduction implicitly affects the building energy performance assessment because in this case the on-site generated electricity has virtually the same PEF value of the grid electricity.

If the PEF values for the imported and exported energy are equal, the users consumption and the input in grid affect the building energy performance assessment in the same way. If the PEF value for the delivered electricity is higher than the one for exported electricity, the users consumption is advantaged compared to the input in grid, because the amount of on-site generation that is input in grid affects the building energy performance assessment less than the one that is consumed. Instead if the PEF value for the delivered electricity is lower than the one for imported electricity, the input in grid is advantaged compared to the users consumption, because the amount of on-site generation that is consumed affects the building energy performance assessment more than the one that is input in grid.

4.2 *Case study*

We applied to a case-study the topics described in the previous paragraph.

We modeled a single family residential building (two floor dwelling) through an hourly numerical simulation, assuming a conventional user profile and a weather profile from Test Reference Year (Florence – Italy). The building main data are equal to the previous case-study. The heating plant maintains the indoor temperature at 20 °C setpoint during the winter season (1 November – 15 April) and the cooling plant maintains the indoor temperature at 26 °C setpoint during the summer season (1 June – 31 August). The seasonal thermal energy needs are 23,750 kWh for heating and 12,250 kWh for cooling, calculated downstream of the thermal generation system. The heating and cooling plants are fueled from an electric air heat pump, which has average seasonal COP 3.50 and average seasonal Energy Efficiency Ratio (EER) 2.50. The seasonal building electric energy needs are 6785 kWh for heating and 4900 kWh for cooling, calculated upstream of the thermal generation system.

We modeled also a photovoltaic system integrated on the building roof (Building Integrated Photo Voltaic – BIPV) composed of polycrystalline silicon modules. The BIPV system features are: surface 90 m^2; electric peak power 9 kW_p; annual overall producibility 9933 kWh. The BIPV system production is used to fuel the heat pump during the heating and cooling seasons, and is input in grid otherwise.

We simulated two different configurations of the BIPV system. The first without on-site electric storage devices: in this case the amounts of delivered and exported energy depend only on the users consumption profile and on the on-site generation profile. The second with on-site electric storage devices: in this case the amounts of delivered and exported energy depend also on the storage devices capacity. The energy amounts for the two configuration with BIPV and for that one without BIPV are given in Table 4.

For the two configuration with BIPV and for the one without BIPV we calculated the overall building CO_2 emissions and the building primary energy index, using the PEF values currently employed in the Netherland, where the PEF value for exported energy, 2.00, is lower than that the one for the delivered energy, 2.56, and in United Kingdom, where the PEF value for exported and delivered energy are equal, 2.92, derived from (Sartori et. al. (in press)). The results are given in Table 5. The CO_2 emission factors are 0,46 kg(CO_2)/kWh for the delivered electricity, derived from “SEAP”, and 0 kg(CO_2)/kWh for the exported electricity, because it is produced from devices based on renewable energy sources, namely the sun.

Table 4. Energy amounts for the case study building.

System	Without BIPV	With BIPV without storage	With BIPV with storage
	kWh	kWh	kWh
Delivered energy	11.685	8107	4529
Exported energy	0	6356	2778
Consumed energy	11.685	11.685	11.685
Produced energy	0	9934	9934

Table 5. Energy Performance and CO_2 emissions for the case study building.

Reference	Without BIPV	With BIPV without storage	With BIPV with storage
	Pr. En. Index kWh/m²anno	Pr. En. index kWh/m²anno	Pr. En. Index kWh/m²anno
PEF the Netherland	149.57	40.21	30.19
PEF United Kingdom	170.6	25.56	25.56
emissions kg(CO_2)	5375	3729	2083

The calculation results explain the topics described in the previous paragraph.

If the PEF values for the imported and exported energy are equal, as in United Kingdom, the energy performance results are equal in both BIPV system configuration. If the PEF value for delivered electricity is higher than the one for exported electricity, as in the Netherland, the energy performance in the configuration with storage is higher than in the one without storage (+25%). In this case the users consumption is advantaged compared to the input in grid, and the PEF values lead towards the configuration which has the lower overall building CO_2 emissions.

5 CONCLUSIONS

The topics discussed in the paper show that the primary energy factors can play a central role for leading the building sector towards the European 2020 targets achievement. The PEF are a very important means for the energy policy in the building sector at national or regional level. They are able to direct the choice among different energy carriers used to meet the building energy needs, because the building energy performance assessment results depend directly on their values. The cases-study show that the PEF can lead to CO_2 emission reduction, end-uses energy efficiency increase and renewable share increase in gross final energy consumption.

An overall European energy policy strategy about the PEF lacks. This is a missed opportunity to make the PEF a central element in “20-20-20” strategy. However the PEF values currently employed in some European Countries are already suitable for leading the building sector towards the European 2020 targets achievement. Instead those currently employed in other should be redetermined, according to technical or political criteria, in order to facilitate the fuel switching from oil to gas, from fossil fuels to electricity and from fossil fuels to renewable fuels. Alternatively should be established a shared methodology for the PEF values calculation, so as to obtain an overall effective impact at European level.

REFERENCES

CEN 2008. EN/TR 15615. Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) – Umbrella Document.

EC 2012 http://ec.europa.eu/clima/policies/package/index_en.htm

EEA 2012. http://www.eea.europa.eu/

EPBD-CA 2010. *Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2010*. Brussels: European Union.

European Commission 2006. COM (2006) 545 final. Communication from the Commission – Action Plan for Energy Efficiency: Realising the Potential.

European Commission 2009. EU Energy Trends to 2030 – Update 2009.

European Commission 2011a. SEC (2011) 288 final. Commission staff working document impact assessment accompanying document to the Communication from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the Regions – A roadmap for moving to a competitive low carbon economy in 2050.

European Commission 2011b. COM(2011) 112 final. Communication from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the Regions – A Roadmap for moving to a competitive low carbon economy in 2050.

European Union 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

European Union 2006. Directive 2006/32/EC of the European Parliament and of the council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC.

European Union 2009. Directive 2009/28/EC of the European Parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

European Union 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 may 2010 on the energy performance of buildings (recast).

Eurostat 2012. http://epp.eurostat.ec.europa.eu/

Molenbroek et al. 2011. Primary *energy factors for electricity in buildings – Toward a flexible electricity supply*. Utrecht: Ecofys.

Odyssee 2012. *Energy Efficiency Trends in Buildings in the EU – Lessons from the ODYSSEE MURE project*. Grenoble: Enerdata.

Sartori et al. (in press). Net zero Energy buildings: A consistent definition framework. *Energy and Buildings*.

SEAI 2012. Derivation of Primary Energy and CO_2 Factors for Electricity in DEAP. http://www.seai.ie/

SEAP 2012. Technical annex to the SEAP template instructions document: The Emission Factors. http://www.eumayors.eu/