CHAPTER 10

Benefits from the Use of Pellet Boilers in the Energy Rating of Buildings

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Abstract

Using renewable energy contributes to reducing CO₂ emissions and improves energy ratings. The building sector is responsible for a significant portion of global CO₂ emissions. European Directive 2002/91/EC on the Energy Performance of Buildings, and the recast in Directive 2010/31/EU, configures the legislative framework of the European Union with respect to the energy rating of buildings in Member States.

This chapter summarizes the different transpositions regarding energy ratings and renewable energy sources, and more specifically it examines the CO₂ emissions and the energy rating using pellet boilers with different climatic conditions, based on real cases. It is concluded that replacing gasoil by wood pellets can lead to reductions in CO₂ emissions that range from 82.91% to 95.28%. Such a substantial reduction of CO₂ emissions directly affects the final energy rating, improving it as much as four levels on a scale of seven levels. Meanwhile, the economic savings from using wood pellets instead of gasoil may reach 68.82%.

Keywords: Energy certification, energy rating, wood pellets, buildings, CO₂ emissions.

1 Introduction

Global warming is directly linked with the emission of greenhouse gases, which include CO₂, CH₄ and N₂O. In recent years, their emissions have grown exponentially, leading to important environmental problems [1], and underlining the need to control their impact [2].

Buildings dedicated to living quarters are responsible for 40% of the energy consumed and 36% of the CO₂ emissions to the atmosphere in Europe [3,4].

Therefore, normative regulations – Directive 2002/91/CE [3], recast in the Directive 2010/31/EU [4] – were necessary to reduce the environmental impact generated by the building sector. The energy rating of buildings and their systems of heating and cooling, from the final users' standpoint, set energy requirements for a comfortable interior temperature, reduced emissions of CO₂ to the atmosphere and economic savings. In addition, governmental energy strategies include provisions for future grants for those residences that have optimal energy ratings.

The European Union, through its Directive 2002/91/CE [3], later recast in Directive 2010/31/EU [4], introduced energy performance certification for newly constructed buildings. This is one of the initiatives of the European Union against climate change deriving from the Kyoto Protocol [2], intended to reduce the environmental burden of emissions from the use of fossil fuels [1,2]. Directive 2002/91/CE replaces previous Directive 92/42/CEE regarding boilers, Directive 89/106/CEE regarding the products of construction and the provisions related with buildings corresponding to the program SAVE [5,6]. Each country is responsible for incorporating the guidelines specified in Directive 2002/91/CE and recast in Directive 2010/31/EU into the domestic legislative framework. The Directives formulate minimum requirements on energy performance and introduce a system of energy performance certification for buildings. They also call for developing plans for low or zero carbon buildings, with the public sector leading the way.

However, little attention was paid during their design or construction to the thermal performance of buildings, meaning that a very significant percentage would fail current energy examinations. For instance, over 50% of installed boilers run on fossil fuels [7]. Given the need to reduce the CO₂ emissions, the use of renewable fuels such as biomass should be encouraged. At present, 80% of the world energy is supplied by fossil fuels and 14% comes from renewable sources, with 9.6% thereof coming from traditional biomass [8]. This is an economically favourable alternative [9,10], which makes it possible to obtain beneficial energy ratings for existing buildings.

This chapter focuses on the impact of using pellet boilers on the energy rating and CO₂ emissions of residential buildings. Related studies using thermal simulations have been conducted in a number of countries under diverse conditions. For example, Pisello *et al.* [11] evaluated the influence of the climatic zone on the energy rating of buildings. Buratti *et al.* [12] concluded that building orientation and glazing systems improve thermal comfort and reduce the energy demand up to 67% in non-residential buildings. Studies in China [13], Spain [14] and the United Kingdom [14] have examined the energy efficiency performance of buildings using renewable energy sources for heating and domestic hot water (DHW), including biomass [13,14] and solar DHW [15]. Wang *et al.* [15] applied passive design methods and advanced façade designs to minimize the load requirements for heating and cooling purposes through building energy simulations, and analysed the local climate data. All these studies looked at factors affecting energy efficiency separately. The chapter at hand compares different parameters, including different climatic

zones, and conventional and renewable fuels, such as wood pellets, for heating and DHW in different types of dwellings, with regard to: (1) energy demand; (2) environmental effects; (3) economic effects and (4) energy rating.

Given this background, and based on data reported previously [16], our main objective at this time is to determine the environmental and economic advantages of using wood pellets in systems for heating and DHW (as opposed to conventional energy sources), with reference to the energy rating of residential buildings. The methodology used, furthermore, makes it possible to determine the variables that bear the greatest influence on the energy rating of a building, and how the use of wood pellet biomass can contribute to an improved rating.

2 Legal Framework

The energy rating of a building is determined by theoretical thermal simulations that depend on the characteristics of the building and the classification of the climatic zone where it is located.

In general, the method of calculation is very similar in all European countries, taking the annual energy demand of the building to calculate the energy rating [17]. In the case of Sweden, calculation is based on the real quantity of energy used [18–20]; and other countries use a combination of the two methods for building energy ratings [17].

Calculating the energy rating according to the annual energy demand of the building requires great precision in the definition of the building envelope, materials, thermal bridges, heating and cooling, DHW, etc. This method is based on prediction [17]. Thus, it has the advantage of determining how the building will work before its actual use under normal conditions. In turn, calculating the real amount of energy used implies measurements that may vary among identical buildings in the same climate zone, because the human factor is involved in the calculation method [21], although a more individualized result for each dwelling is obtained.

According to the transposition of Directive 2002/91/CE [3], and the subsequent Directive 2010/31/EU [4], the calculation is to be carried out in the project phase. The objective of these Directives is to promote improvement of the energy performance of buildings (EPBD), taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

Not all European Union countries have adopted the same scale. There are scales with seven levels (used by Bulgaria [22], Cyprus [23], Czech Republic [24], France [25], Malta [26–28], Romania [29], Sweden [18–20], United Kingdom [30–34] and Norway [35]), to scales of up to 17 levels (e.g. Belgium – Brussels Capital Region [36]). Still other countries or regions have adopted a continuous scale (Belgium – Flemish Region [37], Germany [38,39], Latvia [40] and Portugal [41–43]).

The scale used in this chapter is the one most commonly used in Europe and comprises seven levels. The most efficient level is denoted by A, and the least efficient one designated by G (Fig. 1).

Figure 1: Energy rating label. Scale of seven levels.

Table 1 shows the EPBD transpositions to the different European countries. Some countries have a single regulation, whereas others have several additional transpositions.

3 Calculation Method in the Energy Rating

3.1 Climatic zoning

The climatic zone is defined as an area for which common external conditions for calculating the energy demand are defined using a few parameters [70]. The assignment of a correct climate zone is crucial, because the building faces different requirements depending on the climate zone, which affect the final energy rating. The classification of climatic zones chosen for use in this chapter to study the benefits of pellet boilers in the energy rating is a variation of the Köppen classification [71]. It involves the assignment of five different climatic zones for winter and four different climatic zones for summer [70]. The winter climates are designated by a letter (A, B, C, D and E) corresponding to the winter climate severity (WCS), whereas a number (1, 2, 3 and 4) represents the summer climate severity (SCS). As

Table 1: EPBD transpositions [17].

Country	EPBD transposition
Austria (AT)	Energy Performance Certificate Law (EAVG) [44]
Belgium – Brussels Capital Region (BE BR)	Brussels Air, Climate and Energy Code (BE) [36]
Belgium – Flemish Region (BE FR)	Execution Order of May 11, 2005, adopted in 2009 [37]
Belgium – Walloon Region (BE WR)	Calculation Procedures and Minimum Requirements for New and Existing Buildings [45], Certification of New Buildings [46], Certification of Existing Residential Buildings [47] and Certification of Existing Non-Residential Buildings [48]
Bulgaria (BG)	Energy Efficiency Act 2013 [22]
Croatia (HR)	Physical Planning and Building Act [49] and Energy Efficiency Act [50]
Cyprus (CY)	Law for the Regulation of the Energy Performance of Buildings [23]
Czech Republic (CZ)	Regulation on Energy Performance of Buildings [24]
Denmark (DK)	Danish Building Regulations (BR10) [51]
Estonia (EE)	Minimum Energy Performance Requirements [52]
Finland (FI)	National Building Code [53]
France (FR)	Energy Performance Diagnosis (DPE) [25]
Germany (DE)	Energy Saving Ordinance (EnEV) [39] and Renewable Heating Law (EEWärmeG) [38]
Greece (EL)	Law 3361 [54], KENAK (Regulation for Energy Performance of Buildings) [55], Presidential Decree 100/NG177 [56]
Hungary (HU)	Ministerial Decree on the Establishment of Energy Characteristics of Buildings [57] and Decree of Minister about Determination of Energy Efficiency of Buildings [58]
Ireland (IE)	Dwelling Energy Assessment Procedure (DEAP) and Non- Dwelling Energy Assessment Procedure (NEAP) [59]
Italy (IT)	Decree on the Promotion of the Use of Energy from Renewable Sources [60]
Latvia (LV)	Law on the Energy Performance of Buildings (LEPB) [40]
Lithuania (LT)	Law Energy Performance of Buildings [61]
Luxembourg (LU)	Grand-Ducal Regulation on the energy performance of buildings. Memorial and Functional [62]

(Continued)

Table 1: EPBD transpositions [17].

Country	EPBD transposition
Malta (MT)	Legal Notice of Minimum Requirements on the Energy Performance of Buildings [26], Legal Notice of Energy Performance of Buildings Regulations [27] and Legal of Energy Performance of Buildings Regulations [28]
Netherlands (NL)	Decree on Energy Performance of Buildings (BEG) [63] and Regulation on Energy Performance of Buildings (REG) [64]
Poland (PL)	Construction Act Journal [65]
Portugal (PT)	System of Energy Certification (SCE) [43], Regulation of Energy Systems and Climatization of Buildings (RSECE) [42] and Regulation of the Characteristics of Thermal Conduct of Buildings (RCCTE) [41]
Romania (RO)	Law of Energy Performance of Buildings [29].
Slovak Republic (SK)	Act on the Energy Performance of Buildings and on Amendment and Supplements to Certain Acts [66]
Slovenia (SI)	Regulation on Energy Performance [67]
Spain (ES)	Basic Procedure for Certification of Energy Efficiency of Buildings [68], Regulation of Thermal Installations in Buildings (RITE) [69] and Technical Code of Edification (CTE) [70]
Sweden (SE)	Law on Energy Declaration of Buildings [19], Performance Certificates for Buildings Ordinance [18] and Regulations by the National Board of Housing, Building and Planning [20]
United Kingdom – England and Wales (UK – EW)	Building Regulations (amendments) Regulations [30] Energy Performance of Buildings [31]
United Kingdom – Northern Ireland (UK – NI)	Building Regulations [32] and Energy Performance of Buildings (Certificates and Inspections) [33]
United Kingdom – Scotland (UK – S)	Building Act 2003, Building Regulations 2004, Building Procedure and Forms 2007, Energy Performance of Buildings Regulations 2008 [34]
Norway (NO)	Criteria for Passive Houses and Low Energy Buildings [35]

Table 2: Climatic zones [70].

		Summer Climate Severity (SCS)			
		1	2	3	4
		$SCS \leq 0.6$	$0.6 < SCS \leq 0.9$	$0.9 < SCS \leq 1.25$	$SCS > 1.25$
Winter Climate Severity (WCS)	A	A1	A2	A3	A4
	$WCS \leq 0.3$				
	B	B1	B2	B3	B4
	$0.3 < WCS \leq 0.6$				
	C	C1	C2	C3	C4
	$0.6 < WCS \leq 0.95$				
	D	D1	D2	D3	D4
	$0.95 < WCS \leq 1.3$				
	E	E1	E2	E3	E4
	$WCS > 1.3$				

shown in Table 2, the different combinations of these intervals amount to a total of 20 possible climatic zones. Yet, some are hardly feasible and could not be identified in Europe – for instance, an Antarctic climate or a Sahara desert climate [70]. Table 2 shows the thresholds of WCS and SCS.

3.2 Energy efficiency indicators method

The estimation of the energy necessary to comply with the demands of a building under normal conditions of occupancy and functioning is known as the Energy Efficiency Rating. By comparing a number of indicators of the mean energy use in model buildings of reference, a real building can be qualified and certified on an energy scale established for this purpose [68,72].

The Energy Efficiency Indicators (EEI) in residential buildings are: (1) EEI heating demand; (2) EEI cooling demand; (3) EEI of heating emissions; (4) EEI of cooling emissions; (5) EEI of emissions for DHW; and (6) EEI of total emissions.

3.2.1 Energy efficiency indicator heating demand

It is the ratio between the heating demand of the studied building and the reference heating demand. For residential buildings, the heating demand is the reference corresponding to the average value of similar new buildings that conform with the regulations of a given year (in this case 2006).

This mean value depends on the locality in which the building is located. It is different for single-family houses and residential buildings.

3.2.2 Energy efficiency indicator cooling demand

This is the ratio between the cooling demand of the studied building and the reference cooling demand. In the case of residential buildings, the cooling demand is the reference corresponding to the average value of similar new buildings in conformity with the regulations in a given year (in this case 2006).

This mean value depends on the locality in which the building is located, and it is also different for single-family houses and residential buildings.

3.2.3 Energy efficiency indicator of heating emissions

It is the ratio of CO₂ emissions due to heating service in the studied building and CO₂ emissions of reference for the heating service.

3.2.4 Energy efficiency indicator of cooling emission

It is the ratio of CO₂ emissions due to cooling service in the studied building and CO₂ emissions of reference for the cooling service.

3.2.5 Energy efficiency indicator emission for DHW

This is the ratio of CO₂ emissions due to DHW service in the studied building with respect to CO₂ emissions of reference for the DHW service.

3.2.6 Energy efficiency indicator of total emissions

It is the ratio between the total CO₂ emissions caused by all the services considered in the building object and total CO₂ emissions of reference for the same services. Total CO₂ emissions of the building as well as the building object reference are obtained by adding the CO₂ emissions for each service considered.

3.3 Method for obtaining efficiency classes

The rate of energy rating, C1, is obtained from the value of the indicator of energy efficiency (IEE) by

$$C_1 = \frac{(IEE \times R) - 1}{2 \times (R - 1)} + 0.6$$

where R is the ratio between the value of the indicator for the percentile 50% and the percentile 10% of new residential buildings of 2006 according to the housing census.

Table 3 shows the values of R (dispersion of the IEE, to use in total emissions).

The limits of the scale are expressed through the energy rating index C1, based on Table 4.

This scale comprises seven levels, the most efficient one denoted by A, and the least efficient one designated by G. No new buildings would have levels F or G, as these are used only for renovated structures [74].

Table 3: Values of R [73].

		Summer climate zone			
		1	2	3	4
Winter climate zone	A			1.60	1.60
	B			1.60	1.55
	C	1.50	1.50	1.55	1.55
	D	1.45	1.50	1.50	
	E	1.45			

Table 4: Limits of efficiency classes [73].

Level	Limits	
A	C1	<0.15
B	$0.15 \leq C1$	<0.50
C	$0.50 \leq C1$	<1.00
D	$1.00 \leq C1$	<1.75
E	C1	>1.75

3.4 Simulation software

The use of software designed for calculating the energy rating began in the 1980s [75]. It originally involved theoretical thermal simulations, and eventually sophisticated tools arose, including exhaustive climate records, libraries of materials with different constructive solutions and complete CAD integration.

The various programs available nowadays differ in terms of how the characteristics of the building are introduced as input, and in the output provided [76]. The software chosen for this study was CERMA [77], which works on the scale of seven levels.

4 Case Study

4.1 Characteristics

4.1.1 Fuel characteristics

Biomass is defined as ‘all biological materials excluding those that were included in geological formations suffering a mineralization process’ [78]. Accordingly, coal, oil and natural gas are excluded. For the purposes of this study, wood pellets were selected as the fuel [79], and for comparison with fossil fuels, we chose natural gas and gasoil. Table 5 shows the lower heating value (LHV), density and price of fuels used for the study.

Table 5: Fuel characteristics.

Fuel	LHV	Density	Price
Gasoil [80]	11.89 kWh/kg	850 kg/m ³	1.100 €/l–0.109 €/kWh
Natural gas [81]	11.63 kWh/m ³	<i>n/n</i>	0.059 €/kWh
Wood pellet [82]	5.01 kWh/kg	<i>n/n</i>	0.034 €/kWh

n/n, not necessary for this study.

The present chapter focuses on heating and DHW since this system uses fuel directly (gasoil, natural gas or wood pellet). Because the energy rating procedure calls for choosing a system of refrigeration as well, also considered is an electrical based refrigeration system, which would be the most commonly used system in residential buildings.

4.1.2 Construction characteristics

Two types of buildings were selected: (1) a single-family house and (2) a multi-family residential building, placed among other constructions.

The single-family dwelling consists of three floors with total usable area 261.99 m²: a basement (108.73 m²), a ground floor (117.01 m²) and a first floor (36.25 m²). The house is located on a gentle slope, which means that the basement is completely underground on one side, yet above the ground on the other side of the house.

The multi-family dwelling has five stories with total usable area 861.71 m²: a ground floor (267.10 m²), a first (267.10 m²), a second (267.10 m²), a third floor (267.10 m²) and a tower (18.96 m²). In this case, the building is a rectangle on a corner so that the north and east sides of it are fully in contact with other constructions, while the south and west façades are exposed.

The most important materials in the thermal enclosure and thermal transmittance limit (*U*) used were: roof (0.48 W/m²k), uninhabitable area roof (0.75 W/m²k), external wall (0.54 W/m²k), ground floor (0.65 W/m²k), wood door (2.20 W/m²k), garage door (3.20 W/m²k) and windows (2.47 W/m²k). The main façade was facing south in all cases. Continuous insulation implies junctions with framework slab, and constant closure to the line of the doorjamb, lintel or windowsill, due to the thermal bridges, given their role in heat loss. For instance, inadequate execution of exterior closures of a double brick wall can mean 30% more thermal losses [83].

For the thermal simulation of each building and climatic zone, boilers with similar characteristics – able to fire gasoil, natural gas or wood pellet – were chosen. The thermal load selected for each boiler was set to 24 kW. For the single-family house, just one boiler (24 kW) was considered, whereas for the multi-family dwelling three boilers were installed (total boiler load of 72 kW). For all boilers, the thermal efficiency value adopted was 90%, with an outlet water temperature of

50°C for DHW and 80°C for heating. The flow rate of DHW in the single-family house was 235.80 L/day, and in the multi-family dwelling 568.72 L/day. Both types of residence featured an accumulator; specifically, it had a capacity of 200 L in the single-family house and 500 L in the multi-family dwelling. In both cases, the water temperature varied between 60°C and 80°C, and the global heat transfer coefficient ($U \times A$) being 1 W/K.

4.1.3 Climatic zones

For this study, the most common climatic zones were selected, including extremes zones (the warmest, A4 and B3; the coldest, D2 and E1) and intermediate zones (C4 and C3). Table 2 shows the different climatic zones.

4.1.4 Indoor temperature

The indoor temperature of the residences is determined by the climate, season and the heating/cooling system used. The colder climate zones show fairly even temperatures in all months of the year, except during summer, revealing that heating systems provide a very stable indoor temperature in winter (between 17°C and 20°C). During summer, temperatures are somewhat irregular since there is no need for cooling, with a mean temperature of 21°C and a maximum of 24°C. The lowest temperatures, in May and June, can be attributed to an interruption in the use of heating together with outdoor temperatures generally lower than 17°C. In contrast, the dwellings situated in the warm climate zones show very irregular temperature during winter: the outdoor temperature often reaches 22°C to 23°C, meaning that heating is not required, whereas during summer the indoor temperatures are regulated by the usual use of a cooling system.

4.2 Results

4.2.1 Energy demand

Table 6 shows the energy demand in the buildings and different climatic zones. The energy demand data obtained through simulations of ideal and equivalent situations indicate the objectives to attain in the blueprint stage. Once a residence is occupied, the 'user factor' can significantly affect the results, depending on the residents' particular habits, and their maintenance and use of the home. For example, two adjacent and identical dwellings may show up to 40% variability in their heating expenses due to excessive ventilation [21]. This implies that real data may vary from 50% to 150% with regard to the theoretical calculations [84].

All the houses studied share the same essential features, so that the only factor influencing the energy demand is the climatic zone, which has a great impact on the results. Table 6 reveals that the total energy demand ranges from 55.7 kWh/m² year in A4 to 164.1 kWh/m² year in B1 for single-family houses, and from 44.7 kWh/m² year in A4 to 136.5 kWh/m² year in B1 for multi-family residences. The variations are particularly high in the case of cities with harsher climates, where the heating demand is greater [10,15].

Table 6: Energy demand (kWh/m² year).

Climatic zone	Single-family house					
	A4	B3	C4	C3	D2	E1
Heating	13.7	32.5	47.2	62.3	76.5	143.7
Cooling	23.8	12.9	18.3	11.5	9.9	
DHW	18.2	18.7	18.8	18.8	19.2	20.4
Total	55.7	64.1	84.3	92.6	105.6	164.1

Climatic zone	Residential building					
	A4	B3	C4	C3	D2	E1
Heating	17.1	35.5	46.8	60.9	72.0	121.2
Cooling	14.0	7.9	9.3	6.8	6.2	
DHW	13.6	14.0	14.1	14.0	14.4	15.3
Total	44.7	57.4	70.2	81.7	92.6	136.5

It is also observed that the single-family house uses 20.22%–24.61% more energy than the multi-family house, depending on the climatic zone. In fact, the enclosure of a building (m²) and its volume (m³) are 26% greater for the single-family residence, which means larger exposure to the elements.

There is a progressive increase in energy demand from warmer to colder areas. The heating demand in B1 is 1048.9% greater than that in A4 for a single-family house, and 708.8% greater for a multi-family house. It may be concluded that energy demand for heating is inversely proportional to the winter outdoor temperatures.

In the case of cooling, A4 is the climatic zone with the greatest demand, requiring 204.4% more energy than the single-family residence in D2, and 225.8% more than the multi-family house. B1 was not included in this aspect of the study since it does not need cooling in the summer, when the outdoor temperature remains within the comfort zone. Hence, there is a progressive increase in the energy demand for cooling related to higher temperatures.

Finally, regarding DHW, the demand appears to depend largely upon the area of the living quarters. The influence of the climatic zone is minimal, giving differences between the two cities with extreme climates of 12.1% for the single-family unit and 12.5% for the multi-family unit.

4.2.2 CO₂ emissions

Table 7 also shows the CO₂ emissions, expressed in kg CO₂/m² year, released to the atmosphere by the residential units as a consequence of the energy demands. The emissions due to the heating systems are much higher for climatic zone E1, regardless of the type of house. The values range from 0.5 kg CO₂/m² year using wood pellets in the single-family house in A4 to 51.1 kg CO₂/m² year for the single-family house in E1 using gasoil. The single-family house shows an increase

Table 7: CO₂ emissions (kg CO₂/m² year).

Fuel	Climatic zone	Single-family house						Residential building					
		A4	B3	C4	C3	D2	E1	A4	B3	C4	C3	D2	E1
Gasoil	Heating	4.6	10.7	16.1	22.0	26.3	51.1	5.7	11.8	15.6	20.3	24.2	41.8
	Cooling	9.1	4.9	7.0	4.4	3.8	–	5.3	3.0	3.5	2.6	2.4	–
	DHW	6.0	6.1	6.2	6.1	6.3	6.6	4.5	4.6	4.6	4.6	4.7	5.0
	Total	19.7	21.7	29.3	32.5	36.4	57.7	15.5	19.4	23.7	27.5	31.3	46.8
Natural gas	Heating	3.4	7.9	12.1	16.6	19.8	38.9	4.3	8.9	11.8	15.3	18.4	32.1
	Cooling	9.1	4.9	7.0	4.4	3.8	–	5.3	3.0	3.5	2.6	2.4	–
	DHW	4.2	4.4	4.4	4.4	4.5	4.7	3.2	3.3	3.3	3.3	3.3	3.5
	Total	16.7	17.2	23.5	25.4	28.1	43.6	12.8	15.2	18.6	21.2	24.1	35.6
Wood pellet	Heating	0.5	1.0	2.1	3.4	3.6	8.8	0.9	1.9	2.4	3.2	4.1	8.0
	Cooling	9.1	4.9	7.0	4.4	3.8	–	5.3	3.0	3.5	2.0	2.4	–
	DHW	0	0	0	0	0	0	0	0	0	0	0	0
	Total	9.6	5.9	9.1	7.8	7.4	8.8	6.2	4.9	5.9	5.2	6.5	8.0

of CO₂ emissions of 1760.0% with wood pellets as opposed to gasoil; in the multi-family residential building, the increase comes to 888.8%.

Gasoil is the fuel that releases more CO₂ during its combustion for the purpose of heating and DHW [10], while wood pellets prove to be the most favourable fuel from the standpoint of CO₂ emissions [10,85,86].

Table 8 compares the CO₂ emissions from systems using gasoil and wood pellets. It is seen that replacing gasoil by wood pellets leads to reductions in the CO₂ emissions that range from 82.91% to 95.28%. Similar results were obtained by Pardo and Thiel [10], who report reductions of around 95% in CO₂ emissions using biomass for Southern Europe when compared with conventional fossil fuel fired systems.

The present chapter reveals that the replacement of gasoil by any other fuel for heating and DHW purposes reduces the CO₂ emissions, although the use of wood pellets is the most favourable.

It is noteworthy that the differences in CO₂ emissions from one climatic zone to another depend not only on the energy demand but also on the fuel type and the dwelling area.

An increase in household size tends to decrease the energy consumption per unit area, i.e. the CO₂ emission density or CO₂ emission per unit area, which is commonly used worldwide to determine the building energy efficiency rating [87]. In summary, the smaller the dwelling area is, the lower the building energy efficiency rating can be set. Meanwhile, the larger the dwelling area is, the higher the energy efficiency rating can be set [87].

4.2.3 Energy rating

Based on existing legislation, the rating interval determined for the buildings under consideration is based on a calculation with respect to a model building and other

Table 8: CO₂ emission savings: pellet versus gasoil.

Climatic zone	Single-family house					
	A4	B3	C4	C3	D2	E1
Heating	89.13%	90.65%	86.96%	84.55%	86.31%	82.78%
H + DHW	95.28%	94.05%	90.58%	87.90%	88.96%	84.75%
H + DHW + cooling	51.27%	72.81%	68.94%	76.00%	79.67%	84.75%
Climatic zone	Residential building					
	A4	B3	C4	C3	D2	E1
Heating	84.21%	83.90%	84.62%	84.24%	83.06%	80.86%
H + DHW	91.18%	88.41%	88.12%	87.15%	85.81%	82.91%
H + DHW + cooling	60.00%	74.74%	75.11%	81.09%	79.23%	82.91%

H, Heating; DHW, domestic hot water.

Table 9: Energy rating in the buildings and climatic zones studied.

Climatic zone	Single-family house					
	A4	B3	C4	C3	D2	E1
Gasoil	D	D	D	D	D	D
Natural gas	D	D	D	D	D	D
Wood pellet	C	B	B	A	A	A

Climatic zone	Residential building					
	A4	B3	C4	C3	D2	E1
Gasoil	E	E	E	E	E	E
Natural gas	D	D	D	D	D	D
Wood pellet	C	B	B	B	A	A

references. Table 9 shows the energy rating for the buildings and climatic zones studied. The threshold limits of the levels of energy ratings are seen to depend on the type of residence, climatic zone and fuels used.

Improvement in the energy rating of a building is directly related to the fuel type. Gasoil and natural gas imply the assignment of rating D for single-family dwellings, and E for multi-family units in the six climatic zones studied here. In the case of pellets, as well as for all biomass, the rating depends on climate, but is independent of the housing type, with improvements associated with the lower winter mean temperatures, which may result in upgrading of up to four levels, that is, C would be the rating in the case of the hottest city, A in the coldest three cities and B for the remaining cases.

4.2.4 Economy

To determine the costs involved in using the heating systems with the different fuels, an economic analysis was carried out. Bearing in mind the fuel costs (Table 5) and the energy demand (Table 6), costs were evaluated for heating and DHW together. Table 10 summarizes the results of this analysis. Costs were found to be directly related to the energy demand.

Regarding the most economical climatic zone, A4, the following results were obtained, regardless of the fuel used: (1) for single-family unit, costs in C4 were 60.50% higher, in B3 106.90%, in C3 154.30%, in D2 300.00% and in E1 414.42% higher and (2) for the multi-family unit, costs in B3 were 61.24% higher, C4 98.37%, C3 143.97%, D2 181.43% and E1 344.62% higher. It should be stressed that savings of 68.82% are achieved by changing from gasoil to wood pellets. The use of natural gas instead of gasoil yields savings of 54.21%. Therefore, it may be concluded that the most economic fuel is generally the wood pellet. Other studies arrived at savings of $\approx 95\%$ in Central and Northern Europe and $\approx 75\%$ in the case of Southern European regions in comparison with conventional systems [10].

Table 10: Economic cost: heating + DHW.

Climatic zone	Single-family house					
	A4	B3	C4	C3	D2	E1
Gasoil	838 €	1,345 €	1,734 €	2,130 €	2,514 €	4,310 €
Natural gas	454 €	729 €	940 €	1,155 €	1,363 €	2,336 €
Wood pellet	261 €	419 €	540 €	664 €	783 €	1,344 €

Climatic zone	Residential building					
	A4	B3	C4	C3	D2	E1
Gasoil	2,487 €	4,011 €	4,934 €	6,069 €	7,000 €	11,060 €
Natural gas	1,348 €	2,174 €	2,675 €	3,290 €	3,795 €	5,995 €
Wood pellet	775 €	1250.36 €	1538.32 €	1891.96 €	2182.44 €	3,448 €

5 Conclusions

The transposition of the European framework to each country has given rise to a series of regulations with a common origin that are nonetheless not uniform or homogeneous among them.

In view of the current transpositions, it is impossible to compare the energy efficiency of two identical buildings in different countries, even when the same climatic conditions prevail, because the energy scales are different, as are the calculation methods (energy demand, real consumption or both).

Based on the most commonly applied method in Europe, for an energy rating with a scale of seven levels, this chapter may conclude that the use of wood pellets in heating and DHW residential systems presents three important advantages: (1) the environmental costs are reduced, since significantly less CO₂ is released; (2) a very favourable energy rating is ensured and (3) important economic savings are provided.

The CO₂ emissions depend directly on the climatic zone where the house is located, in addition to the fuel used. Gasoil was found to yield higher CO₂ emissions regardless of the housing type. However, the use of pellets instead of gasoil or natural gas was found to bring about an important reduction of the CO₂ emissions in all cases. Specifically, if gasoil is replaced by pellets, reductions in CO₂ emissions as high as 95.25% for single-family units, and 91.18% for multi-family units, are achieved. Bearing in mind that 40% of the energy consumed in Europe and 36% of the CO₂ emissions to the atmosphere are produced by buildings dedicated to living quarters, the choice of fuel stands as a significant factor in evaluating emissions derived from heating and DHW.

Using wood pellets for heating purposes enhances the energy rating of the housing units in all cases. In the best case scenario, improvements are of four points on

the scale of residential energy performance, which would put the unit into the top category, A. In comparison, with the use of fossil fuels, the best rating is D for the single-family residence and E for the multi-family one.

Cost-effectiveness is another important area where savings by means of wood pellets are noteworthy. In comparison with gasoil, the use of pellets can lead to economic savings of as much as 70%.

In short, the use of pellets is advantageous in all respects, providing for environmental and economic benefits, while leading to a better energy rating.

References

- [1] Petit, J.R., Jouzel, J. & Raynaud, D., Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, **399**, pp. 429–436, 1999.
- [2] United Nations, Kyoto protocol to the United Nations framework convention on climate change, 1997.
- [3] European Parliament and of the Council, Directive 2002/91/EC of the European Parliament and of the Council of 16 December on the energy performance of buildings. *DOUE*, **1**, pp. 65–71, 2003.
- [4] European Parliament and of the Council, Directive 2010/31/EU of the European Parliament and of the Council of 19 May on the energy performance of buildings. *DOUE*, **153**, pp. 13–35, 2010.
- [5] European Parliament and of the Council, Multiannual programme for the promotion of energy efficiency (SAVE) (1998 to 2002). Decision 647/2000/-EC of 28 February. *DOUE*, **79**, pp. 6–9, 2000.
- [6] European Parliament and of the Council, Multiannual programme for the promotion of energy efficiency in the Community (SAVE II). Decision 96/737/EC of 16 December, Annual report, 1996.
- [7] Eurostat European Commission, Ministerio de Industria Energía y Turismo, Government of Spain, Instituto para la Diversificación y Ahorro de la Energía. Proyecto SECH-SPAHOUSEC. Analisis del consumo energético del sector residencial en España. Final ed., Madrid, 2011.
- [8] Khan, A.A., de Jong, W., Jansens, P.J. & Spliethoff, H., Biomass combustion in fluidized bed boilers: potential problems and remedies. *Fuel Processing Technology*, **90**, pp. 21–50, 2009.
- [9] Abulfotuh, F., Energy efficiency and renewable technologies: the way to sustainable energy future. *Desalination*, **209**, pp. 275–282, 2007.
- [10] Pardo, N. & Thiel, C., Evaluation of several measures to improve the energy efficiency and CO₂ emission in the European single-family houses. *Energy and Buildings*, **49**, pp. 619–630, 2012.
- [11] Pisello, A.L., Goretti, M. & Cotana, F., A method for assessing buildings' energy efficiency by dynamic simulation and experimental activity. *Applied Energy*, **97**, pp. 419–429, 2012.

- [12] Buratti, C., Moretti, E., Belloni, E. & Cotana, F., Unsteady simulation of energy performance and thermal comfort in non-residential buildings. *Building and Environment*, **59**, pp. 482–491, 2013.
- [13] Cao, G., Jokisalo, J., Feng, G., Duanmu, L., Vuolle, M. & Kurnitski, J., Simulation of the heating performance of the Kang system in one Chinese detached house using biomass. *Energy and Buildings*, **43**, pp. 189–199, 2011.
- [14] Ruiz, M.C. & Romero, E., Energy saving in the conventional design of a Spanish house using thermal simulation. *Energy and Buildings*, **43**, pp. 3226–3235, 2011.
- [15] Wang, L., Gwilliam, J. & Jones, P., Case study of zero energy house design in UK. *Energy and Buildings*, **41**, pp. 1215–1222, 2009.
- [16] Carpio, M., Zamorano, M. & Costa, M., Impact of using biomass boilers on the energy rating and CO₂ emissions of Iberian Peninsula residential buildings. *Energy and Buildings*, **66**, pp. 732–744, 2013.
- [17] Carpio, M., García-Maraver, A., Ruiz, D.P., Martínez, A. & Zamorano, M., Energy rating for green buildings in Europe. *WIT Transactions on Ecology and the Environment*, **190(1)**, pp. 381–394, 2014.
- [18] Ministry of Enterprise, Energy and Communications, Government of Sweden, Performance Certificates for Buildings Ordinance. *Ordinance* 2006:1592, 2006.
- [19] Ministry of Enterprise, Energy and Communications, Government of Sweden, Law on Energy Declaration of Buildings. *Law* (2006:685), 2006.
- [20] Ministry of Enterprise, Energy and Communications, Government of Sweden, National Board of Housing, Building and Planning, 2012.
- [21] Zabalza, I., Díaz, S. & Aranda, A., *Manual práctico de certificación energética de edificios*. Universidad de Zaragoza: Zaragoza, 2009.
- [22] Ministry of Economy and Energy, Government of Bulgaria, Energy Efficiency Act SG24/12 03 2013.
- [23] Ministry of Energy, Commerce, Industry and Tourism, Government of Cyprus, Law for the Regulation of the Energy Performance of Buildings. L142(I)/2006, 2006.
- [24] Ministry of Industry and Trade, Government of Czech Republic, Regulation on Energy Performance of Buildings. Regulation 148/2007, 2007.
- [25] Ministry of Ecology and Sustainable Development Energy, Government of France, Diagnostic de Performance Énergétique (DPE). *décret no.* 2011-413 du 13 avril, JORF 0092, p. 6840, 2011.
- [26] Ministry for Resources and Rural Affairs, Government of Malta, Minimum Requirements on the Energy Performance of Buildings. Legal Notice 238 of 2006.
- [27] Ministry for Resources and Rural Affairs, Government of Malta, Energy Performance of Buildings Regulations. Legal Notice 261 of 2008.
- [28] Ministry for Resources and Rural Affairs, Government of Malta, Energy Performance of Buildings Regulations. Legal Notice 376 of 2012.
- [29] Ministry of Regional Development and Public Administration, Government of Romania, Law of energy performance of buildings. Law 372/2005, 2005.

- [30] Welsh Government, Building Regulations (amendments) Regulations. Statutory Instrument 2012/3119, 2012.
- [31] Welsh Government, Energy Performance of Buildings. Statutory Instrument 2012/3118, 2012.
- [32] Department of Finance and Personnel Northern Ireland (DFPNI), Building Regulations. Statutory Rule 2012 No. 192, 2012.
- [33] Department of Finance and Personnel Northern Ireland (DFPNI), Energy Performance of Buildings (Certificates and Inspections). Statutory Rule 2008 No. 170, 2008.
- [34] Directorate for the Built Environment, Government of Scotland, Energy Performance of Buildings Regulations, 2008.
- [35] Water Resources and Energy Directorate (NVE), Government of Norway, Criteria for passive houses and low energy buildings. NS 3701, 2012.
- [36] Regional Ministry of Energy, Government of the Brussels Capital Region, Brussels Air, Climate and Energy Code. BE on 19 April 2013.
- [37] Flemish Energy Agency (VEA), Government of Belgium, Execution Order of May 11, 2005, adopted in 2009.
- [38] Federal Ministry for Environment, Nature Conservation and Nuclear Safety, Government of Germany, Erneuerbaren-Energien-Wärmegegesetz (EEWärmeG), 2009.
- [39] Federal Ministry of Transport, Building and Urban Development, Government of Germany, Energieeinsparverordnung für Gebäude (EnEV), 2009.
- [40] Ministry of Economy, Government of Latvia, Ēku energoefektivitātes likums. Law on the Energy Performance of Buildings (LEPB), 2008.
- [41] Ministério das Obras Públicas, Transportes e Comunicações, Government of Portugal, Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE). Decreto-Lei no. 80/2006 de 4 de Abril, DR 67, pp. 2468–2513, 2006.
- [42] Ministério das Obras Públicas, Transportes e Comunicações, Government of Portugal, Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios (RSECE). Decreto-Lei no. 79/2006 de 4 de Abril, DR 67, pp. 2416–2468, 2006.
- [43] Ministério da Economia e da Inovação, Government of Portugal, Sistema de certificação energética (SCE). Decreto-Lei no. 78/2006 de 4 de Abril, DR 67, pp. 2411–2415, 2006.
- [44] Austrian Institute of Construction Engineering (OIB), Energieausweis-Vorlage-Gesetz (Energy Performance Certificate Law). EAVG, 2012.
- [45] Department of Energy and Sustainable Buildings, Government of Belgium, Calculation procedures and minimum requirements for new and existing buildings. MB du 22/06/2012, p. 34014, 2012.
- [46] Department of Energy and Sustainable Buildings, Government of Belgium, Certification of new buildings. MB du 05/09/2011, p. 56370, 2011.
- [47] Department of Energy and Sustainable Buildings, Government of Belgium, Certification of existing residential buildings. MB du 07/06/2010, p. 35958, 2010.

- [48] Department of Energy and Sustainable Buildings, Government of Belgium, Certification of existing non-residential buildings. MB du 03/11/2011, p. 65830, 2011.
- [49] Ministry of Construction and Physical Planning, Government of Croatia, Physical Planning and Building Act. Official Gazette No.76, 2007.
- [50] Ministry of Construction and Physical Planning, Government of Croatia, Energy Efficiency Act. Official Gazette No. 152, 2008.
- [51] Ministry of Business and Growth, Government of Denmark, Danish Building Regulations, BR10, 2010.
- [52] Ministry of Economic Affairs and Communications, Government of Estonia, Minimum Requirements for Energy Efficiency. Decree nr. 258, 2009.
- [53] Ministry of Environment, Government of Finland, National Building Code. NBD 2013, 2013.
- [54] Ministry of Environment, Energy and Climate Change, Government of Greece, Transposition of the EPBD. Law 3661 (18 May 2008), 2008.
- [55] Ministry of Environment, Energy and Climate Change, Government of Greece, KENAK (Regulation for Energy Performance of Buildings). Ministerial decision D6/B/5825, National Gazette 407, 2010.
- [56] Ministry of Environment, Energy and Climate Change, Government of Greece, Presidential Decree 100/NG177. National Gazette 6th October, 2010.
- [57] Ministry of Interior, Government of Hungary, Ministerial Decree on the establishment of energy characteristics of buildings. MD TNM 7/2006, 24, 2006.
- [58] Ministry of Interior, Government of Hungary, Decree of Minister without Portfolio About Determination of Energy Efficiency of Buildings. Hungarian Decree 40/2012, 13, 2012.
- [59] Department of the Environment, Community and Local Government (DECLG), Government of Ireland, Dwelling Energy Assessment Procedure (DEAP) and Non-Dwelling Energy Assessment Procedure (NEAP). SI 243 of 2012, 2012.
- [60] Ministry for Economic Development, Government of Italy, Fourth Conto Energia. Decree 28/2011, 2011.
- [61] Ministry of Energy, Government of Lithuania, Law on Energy, Energy Performance of Buildings. STR 2 01 09, 2005.
- [62] Ministry of Economy and Foreign Trade, Government of Luxembourg, Règlement grand-ducal modifié du 31 août 2010 concernant la performance énergétique des bâtiments fonctionnels. A No. 173 de 2010, 2010.
- [63] Ministry of the Interior and Kingdom Relations, Government of the Netherlands, Decree on Energy Performance of Buildings (BEG), 2006.
- [64] Ministry of the Interior and Kingdom Relations, Government of the Netherlands, Energy Performance of Buildings (REG), 2009.
- [65] Ministry of Infrastructure, Government of Poland, Construction Act Journal Laws No. 191, 1373, 2009.

- [66] Ministry of Construction and Regional Development, Government of Slovakia, Energy Performance of Buildings and on Amendment and Supplements to Certain Acts. Act 555/2005, 2005.
- [67] Ministry of the Economy, Energy and Mining Inspectorate, Government of Slovenia, Regulation on Energy Performance, 2010.
- [68] Ministerio de la Presidencia, Government of Spain, Procedimiento básico para la certificación de la eficiencia energética de los edificios. Real Decreto 235/2013, de 5 de Abril, BOE 89, pp. 27548–27562, 2013.
- [69] Ministerio de Industria, Turismo y Comercio, Government of Spain, Ministerio de la Vivienda, Government of Spain, Reglamento de Instalaciones Térmicas en los Edificios (RITE). Real Decreto 1027/2007 de 20 de julio, BOE 207, pp. 35931–35984, 2007.
- [70] Ministerio de la Vivienda, Government of Spain, Código Técnico de la Edificación (CTE). Real Decreto 314/2006 de 17 de marzo, BOE 74, pp. 11816–11831, 2006.
- [71] Chen, D. & Chen, H.W., Using the Köppen classification to quantify climate variation and change: an example for 1901–2010. *Environmental Development*, **6**, pp. 69–79, 2013.
- [72] Ministerio de la Presidencia, Government of Spain, Procedimiento básico para la certificación de eficiencia energética de edificios de nueva construcción. Real Decreto 47/2007 de 19 de enero, BOE 27, pp. 4499–4507, 2007.
- [73] Ministerio de la Vivienda, Government of Spain, Ministerio de Industria, Turismo y Comercio, Government of Spain, Instituto para la Diversificación y Ahorro de la Energía. Condiciones de aceptación de procedimientos alternativos a Lider y Calener, 2009.
- [74] Ministerio de Industria, Turismo y Comercio, Government of Spain, Ministerio de la Vivienda, Government of Spain, Instituto para la Diversificación y Ahorro de la Energía. Escala de calificación energética. Edificios de nueva construcción. Madrid: IDAE, 2009.
- [75] Newton, D., James, R. & Bartholomew, D., Building energy simulation – a user’s perspective. *Energy and Buildings*, **10**, pp. 241–247, 1988.
- [76] Crawley, D.B., Hand, J.W., Kummert, M. & Griffith, B.T., Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, **43**, pp. 661–673, 2008.
- [77] Asociación Técnica Española de Climatización y Refrigeración, Universidad de Valencia, CERMA.V. 2.2, www.atecyr.org, 2011.
- [78] AENOR, European Technical Specification. Solid biofuels. Terminology, definitions and descriptors. UNE-EN 14588, 2010.
- [79] Van Loo, S. & Koppejan, J., *The Handbook of Biomass Combustion and Co-firing*, Earthscan: London, 2007.
- [80] Ministerio de Industria Energía y Turismo, Government of Spain, Geoportal. <http://geoportal.mityc.es>.
- [81] Comisión Nacional de la Energía, www.cne.es.
- [82] Instituto para la Diversificación y Ahorro de la Energía, www.idae.es.

- [83] Theodosiou TG, Papadopoulos AM, The impact of thermal bridges on the energy demand of buildings with double brick wall constructions. *Energy and Buildings*, **40**, pp. 2083–2089, 2008.
- [84] AENOR, Thermal performance of buildings. Calculation of energy use for heating. Residential buildings. UNE-EN 832:2000, 2000.
- [85] Dion, L., Lefsrud, M. & Orsat, V., Review of CO₂ recovery methods from the exhaust gas of biomass heating systems for safe enrichment in greenhouses. *Biomass and Bioenergy*, **35**, pp. 3422–3432, 2011.
- [86] Joelsson, J. & Gustavsson, L., Swedish biomass strategies to reduce CO₂ emission and oil use in an EU context. *Energy*, **43**, pp. 448–468, 2012.
- [87] Koo, C., Hong, T., Lee, M. & Seon Park, H., Development of a new energy efficiency rating system for existing residential buildings. *Energy Policy*, **68**, pp. 218–231, 2014.