Quantitative analysis of the divergence in energy losses allowed through building envelopes

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Abstract

There is currently a lack of international harmonization on the insulation requirements for the buildings. Given that this parameter defines the maximum energy losses allowed through a thermal envelope, building energy consumptions consumption can vary considerably between countries. Both the United States of America (US) and the European Union (EU) should address this problem by unifying the energy design criteria of their buildings. The EU requires that all new buildings constructed starting in 2020 must be nearly zero-energy buildings (nZEB), as defined in the Directive on Energy Efficiency in Buildings of 2010.

To evaluate the extent of this lack of harmonisation, in this paper are calculated the maximum energy losses through the thermal envelope of a typical dwelling when applying various international regulations (such as the US regulations and those established by Germany, France, England and Wales, and Spain). The results are compared with those obtained when applying the requirements of the Passivhaus standard (taken as a reference for nZEB in the EU). It will be verified that there are major differences in the energy losses allowed through building envelopes among these countries and among the different climate zones defined in each country.

Moreover, the challenges set by these countries related to energy consumption and CO2 emissions are also reviewed. The disparity between the objectives proposed by these countries suggested a distinct tendency towards increasing current differences in their standards.

Keywords

International regulations; envelope energy losses; nZEB; Passivhaus; greenhouse gas emissions; energy consumption

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1. Introduction

With the approval of the Kyoto protocol in 1997, common objectives were established at an international level to reduce CO2 emissions and energy consumption to avoid their adverse effects on the environment [1-6]. Given that the limits established in the Kyoto protocol have been insufficient to halt climate change, these limits were revised in 2007 and new plans for action were proposed.

As a result, the EU approved a packet of measures known as “20-20-20”. Among others, these measures have the goal of reducing energy consumption and CO2 emissions by 20% before the year 2020 [10, 11]. The construction sector is among the principal sectors responsible for energy consumption and CO2 emissions, accounting for approximately 40% of each [7, 9]. One of the European directives approved to reach the “20-20-20” objectives is the 2010 Directive on Energy Efficiency in Buildings (DEEB), which requires the construction of nearly zero-energy buildings (nZEB) starting in 2020 [12]. In the US, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the International Code Council (ICC) have also published several recommendations that aim to drastically reduce building energy consumption.

The DEEB directive and its subsequent Development regulations indicate a lack of harmonisation among the different countries in the EU concerning energy efficiency requirements in buildings [13-16]. Insufficient information provided by the European Directive about how nZEBs should be built has resulted in each country establishing different energy parameters to define these types of buildings. To mitigate this problem, the European Commission has proposed the city of Darmstadt’s passive houses, built according to the Passivhaus standards, as an example of an nZEB [17]. This article shows that there is also a lack of harmonisation in the United States regarding the parameters that define building energy losses in different climate zones. However, to the authors´ knowledge, there are no documents that address this problem.

The majority of international rules on energy efficiency establish several maximum thermal envelope transmittances for each climate zone to limit energy losses through the building thermal envelope. In contrast, the Passivhaus standard establishes a different criterion limiting maximum energy consumption for both heating and cooling to 15 kWh/m2 year instead of fixing the transmittances [18]. The standard proposes a set of transmittance values as a guide to achieving this objective. Limiting energy consumption due to energy losses through the building envelope is a key task needed to achieve this objective given that these losses are responsible for the majority of the total energy consumption of dwellings [19-27].

This lack of harmonisation among maximum energy losses allowable through the envelope has already been analysed from a regulatory standpoint in a previous work, which compared the parameters that regulate those losses in different countries. The research shows that the root of the problem lies in limiting the thermal envelope transmittance in each country for different climate zones defined on the basis of different ranges of degree-day variation, rather than limiting maximum energy losses. A new procedure has recently been developed that allows harmonize these energy losses in different climate zones (the International Procedure for the Optimal Design of Thermal Envelopes, or IPODTE) [28].

This article broadens that analysis and quantifies the existing differences between the maximum thermal envelope energy losses allowed by different countries. Given that two-thirds of the emissions produced and energy consumed by the building sector come from the residential sector [29-32], will be calculated and compared the energy losses

through the envelope of a residential dwelling type. The calculation uses the transmittance values imposed in the climate zones defined by various countries in the EU and by the US. The EU countries included in the analysis are Germany, France, England and Wales, and Spain, which are representative of different climates. The obtained values were compared with the requirements of the Passivhaus standard, which served as a reference for nZEB.
Finally, the long-term measures and objectives proposed by different countries to reduce CO_2 emissions and energy consumption will be also analyzed, especially in the construction sector. The existing disparity in these countries' future challenges suggested that the differences in their established requirements could widen in the future.

2. Background

The energy losses that occur through each enclosure of a thermal envelope can be calculated using Equation 1:

$$\text{Energy losses through the enclosure in a year} = \sum U \cdot A \cdot (\text{degree-days per year}) \text{ in W} \quad (1)$$

where U is the thermal transmittance of the enclosure ($W/(m^2 \cdot k)$) and A is the enclosure area (m^2).
The term annual degree-days indicates the differences throughout the year between the average outside temperature $\overline{T}i$ and a reference base temperature, Tbase, at which it is considered necessary to air condition a room. The sums account only for positive values, as indicated by the + superscript in Equations 2 and 3:

$$Heating\ Degree\ Days = HDD = \sum_1^N (T_{base} - \overline{T}_i)^+ \text{ in K} \quad (2)$$
$$Cooling\ Degree\ Days = CDD = \sum_1^N (\overline{T}_i - T_{base})^+ \text{ in K} \quad (3)$$

where N is the number of days in the winter (Equation 2) or in the summer (Equation 3) [33].
The thermal envelope is considered to include the basement walls, exterior walls, floor, roof, and any other building element that encloses a conditioned space. This boundary also includes the boundary between the conditioned space and any exempt or unconditioned space. The thermal transmittance is the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area $Btu/(h \cdot ft^2 \cdot °F)$ or $W/(m^2 \cdot K)$. Both definitions were taken from the International Energy Conservation Code (IECC) [34].
The thermal transmittance is calculated using Equation 4:

$$U = 1/R_i + \sum \lambda_i/e_i + 1/R_e \quad (4)$$

where λ_i is the thermal conductivity of each material in W/(mK), e_i is the thickness of each layer of material in meters, and R_i and R_e are the surface thermal resistances of the interior and exterior air, respectively, in $m^2 \cdot K/W$.

3. Analysis of annual envelope energy losses in a typical dwelling in the countries under study

This section analyses the extent of the dysfunction created by setting transmittances according to the different degree-day-variation climate zones defined by the different countries. The energy loss caused for the envelope will be calculated for a typical dwelling in each of the climate zones in all of the countries under study to quantitatively demonstrate that the energy losses are not harmonised.

3.1. Baseline data

To guarantee the best possible representation of actual conditions in the calculation of envelope energy losses, a dwelling was selected that contained the most habitual percentage of enclosure typologies in the envelope (floor, roof, exterior walls and hollows). These percentages corresponded to an exterior wall surface similar to the sum of the floor and roof surfaces, and a window/door percentage of approximately 30% of the exterior wall surface [35]. This study considers a dwelling that matched these percentages and had a distribution and size coinciding with the typical housing standards defined by the Spanish Institute for Diversification and Energy Savings (IDAE) and the National Statistics Institute of Spain (INE) (Figure 1) [35, 36]. The 85 m2 dwelling is composed of a living room, three double bedrooms, a kitchen, a bathroom, a half-bath, and a hallway. This typical dwelling was located in a real residential housing block project with 20 dwellings (4 apartments per floor). Figure 2 shows the layout of the dwelling and its location within the residential block. The studied dwelling is a real project [37].

Figure 1. Typical house and standard housing block that was used to calculate the envelope energy losses

Figure 2. Sections of the thermal envelope

The envelope surfaces and the environmental conditions considered for the calculation are summarised in Table 1.

Table 1. Parameters for the calculation of the energy losses

3.2. Calculation of the current envelope energy losses in a typical dwelling

Section 2 details the formulas used to calculate the energy losses through the building envelope (Equation 1) and the number of heating and cooling degree-days in a year (Equations 2 and 3, respectively). If a base temperature of 20°C is used, which is the minimum base temperature recommended in EN 15251:2008 [33], the annual envelope energy losses in a typical dwelling can be calculated according to Equation 5:

$$\text{Energy loss through the enclosure in a year } (\text{in W}) = \Sigma\, U \cdot A \cdot (\text{degree} - \text{days per year in base of } 20^{o}\text{C}), \quad (5)$$

The annual degree-days for each zone studied were selected from the ASHRAE database [39] and the free Free-Ze software program [40].

Using the formula shown in Equation 5, the maximum annual envelope energy losses of a typical dwelling, as defined in Section 3.1, will be calculated in all climate zones of Germany, France, England and Wales, Spain and the US, and it will be compared with the implementation of the Passivhaus Standard in Germany. Within each climate zone, the city with the most adverse weather conditions was selected. Extreme cases, in which the data are not within the limits of degree-days in the interval used to define the climate zone, were excluded.

The following conditions were adopted to select transmittance values for the calculation.

The rules impose limiting values of thermal transmittance in the building envelopes in all of the countries under study, except for England and Wales. Thereafter, the facilities necessary for the planned building to achieve CO_2 emissions and energy consumption levels below the established limits and obtain different energy qualifications must be selected.

However, For England and Wales, it is necessary to choose initially the desired facilities and then calculated the thermal transmittance of the enclosures required to comply with limiting CO_2 emission and energy consumption values. The Foundation for Housing Research proposes different thermal transmittance values that enable a building to comply with maximum CO_2 emissions for the different facility combinations. In this study, the limiting transmittances provided by this Foundation were selected for the case when the most common combination of facilities was sought, which corresponds to a block of homes with a gas heating system with radiators, supporting solar panels to provide hot sanitary water [41-43]. The region with the most adverse weather and the most restrictive transmittance data provided in the reference documents was selected.

In Germany, where no climate zones are defined and there is great variation in degree-days, two calculations were performed: one for a city with one of the harshest climates and the other for a city with one of the mildest climates. The comparison of these calculations will confirm that the requirement of the same transmittance nationwide exhibits allowable energy losses that are notably different for different locations [44].

Spain has five established climate zones (A-E) in which different thermal transmittances are required for each part of an envelope. The subzones that depend on the severity of the weather in the summer were not considered in the calculation because the only parameter that changes is a modified solar factor for windows, which is not under consideration in this analysis [45].

France defines three climate zones (H1-H3), which require the same transmittance in zones H1 and H2 and in locations of H3 at altitudes greater than 800 m. Different transmittance values are imposed in the locations in zone H3 at an altitude below 800 m [46, 47].

The US has 8 different climate zones (1-8), and the subzones that are created depending on humidity were also not considered because the required transmittance limit does not vary between these subzones [34, 48, 49].

The limiting transmittance values for each enclosure required for each climate zone in the countries being studied are shown in tables 2 and 3.

Table 2. Transmittances of each climate zones selected in EU

Table 3. Transmittances of each climate zones selected in USA

Moreover, the thermal bridges created by pillars were taken into account in the calculations. In Germany, DIN 4108 [50] provides different coefficients of thermal transmittance reduction for each type of thermal bridge, whereas France sets no limits for thermal bridges but does give limits for the joints between enclosures. In England and

Wales, the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP) also provides the minimum allowable insulation values for thermal bridges, differentiating between a total of twenty-tree different types [41]. In Spain, the Basic Document: Limitation of Energy Demand (DB HE 1) does not require any transmittance limit for thermal bridges. This regulation only indicates that thermal bridges should be included in the calculation of the average transmittance of enclosures when the surface of each is greater than 0.5 m^2. The Passivhaus standard requires that insulation always be located on the outside of the structure without any breakage to prevent thermal bridges. The US does not provide any indications for thermal bridges.

The annual envelope energy losses in every climate zone were obtained using a spreadsheet program. Table 4 shows a calculation example of envelope energy losses using climate zone E in Spain as a reference. Table 5 shows the final results for each climate zone defined in each country studied in the EU and the US.

The deviations in the energy losses were calculated for each climate zone with respect to the results that would be obtained for an nZEB that take as a reference requirements of the Passivhaus standard), these results being considered the desired energy target in the EU.

Table 4. Enclosures energy losses for a typical house in climate zone E in Spain

Table 5. Degree-days of the cities for which the envelope energy losses were calculated and envelope energy losses in a typical house over the course of one year

4. Discussion

The results obtained in paragraph 3 can be observed graphically in Figure 3.

Figure 3. Envelope energy losses for each country under study

It can be observed that any of the analysed regulations reaches the results obtained when applying the Passivhaus standard requirements.

The analysis reveals that the envelope energy losses that were observed in France, Germany, and England and Wales are notably similar. These countries are close to meeting the standard of nZEB. In fact, the regulations of these countries indicate that future revisions are intended to achieve the Passivhaus standard values. Although these countries are the closest to reaching the energy consumption targets, they exhibited a mean deviation of 34% (see table 5 for typical deviation and mean deviation data).

The greatest energy losses were obtained in the US and the second greatest in Spain. The rules of both countries allow for exceeding the obtained energy losses by more than 150% when applying the energy consumption target. In addition, the German and US laws are the regulations with the greatest variance in energy loss values within the respective territories. In the case of the US, the typical deviation between the energy losses of the different climate zones was 15.9%. In Germany, where no climate zones are defined, the typical deviation was determined by calculating the energy losses in the most severe climate and in an intermediate climate, so the result was a more extreme calculation compared to the others. The obtained typical deviation in Germany was 13.71%. It was paradoxical to discover that the country closest to complying with energy consumption targets among all the countries being studied was that with the least harmonisation in allowable envelope energy losses.

This analysis shows that the transmittance values required for different climate zones are not properly harmonised because the energy efficiency factor controlled by the transmittance (the envelope energy loss) exhibits significantly different values across climate zones.

At a transnational level, it could be observed that the minimum insulation requirements that the EU aims to achieve by 2020 will most likely exceed the insulation needs required to achieve the energy consumption target, even though its thermal insulation values are much greater than those required in the US.

5. Future challenges relative to energy consumption and CO2 emissions

After proving that the current energy efficiency requirements of buildings are not harmonized, this article examines whether the long-term objectives set by the different countries (Table 6) will alleviate this problem. Each country has regulations, guidelines, and energy plans that establish marked reductions in energy consumption and greenhouse gas emissions. Furthermore, these reductions need to be achieved in the long term to meet the main requirements set by the 2010 Directive on Energy Performance of Buildings. These objectives can be achieved by addressing the areas of industry, transportation, and construction, the latter of which is responsible for 40% of the total energy consumption and greenhouse gas emissions. Table 6 provides targets for greenhouse gas reductions, which are the only values that are set by most of the studied plans and programs, assuming that a reduction in the energy consumption is directly related to a reduction in the greenhouse gas emissions.

Table 6. Future challenges in the energy efficiency sector in the countries under study

Both the energy efficiency values and the future challenges are not currently harmonized, so it could make that the differences in the required values increase in the future.

Although the goals for reducing energy consumption and greenhouse gas emissions set by Germany, France, and the United Kingdom in 2020 (approximately 40%) are much more demanding than the minimum set by the EU (nearly doubling the minimum), the values set by Spain are below the required minimum.

In addition, several countries, such as Germany and the UK, have recently approved Climate Change Adaptation Plans, which include commitments to expanding the quantitative requirements mandated at the European level due to changes in the climate-environmental setting that have occurred in recent years [54, 59]. Therefore, these countries are attempting to reduce the greenhouse gas emissions by 80% by 2050 compared to the emissions measured in 1990.

In the USA, the Policy Guide on Planning and Climate Change, which was adopted in 2012, suggests that a reduction of at least 80% in greenhouse gas emissions compared with the 1990 levels should be achieved by 2050 [64]. Moreover, ASHRAE aims to achieve a 50% improvement in the requirements for energy efficiency in buildings. Nevertheless, these reductions are only recommended and do not require a commitment to compliance, as is the case in many European countries. The only commitment stipulated is a reduction of approximately 3% in the emissions of greenhouse gases by 2030 compared to the 2006 levels. A review of the current emission levels set by the Clean Air Act [65] is being performed by various studies, such as the National Global Change Research Plan 2012-2021: A Strategic Plan for the U.S. Global Change Research Program [63], the Regulatory Plan and the Semiannual Regulatory Agenda [66]. Other guidelines include improvements of existing laws to reduce CO2 emissions [67].

Based on all of the analyses conducted in this article, the need to create a comprehensive methodology regulated by international organizations is inferred. This methodology should allow the unification of criteria and energy efficiency objectives in buildings across different countries.

6. Conclusions

This work has demonstrated that the energy losses allowed through building envelopes for an example of a typical dwelling vary substantially among the rules of the different countries under analysis, and even among the climate zones of a single country. The results obtained in the countries under analysis located in northern Europe more closely approached the requirements for the nZEB buildings that will go into effect in the EU starting in 2020. Moreover, the Spanish and US requirements were shown to be very far from these targets (by more than 150%), with greater differences in the most extreme climate zones. Because of the major disparity in the targets established for these countries, the differences will be difficult to minimise in the immediate future. In addition, these objectives were established using different improvement percentages over the current situation of each country, which are already divergent.

The results indicate the need to establish a methodology that replaces the current requirements for maximum transmittance values given by each country, which refer to climate zones defined using different degree-day amplitude ranges. Strategies such as the IPODTE could contribute to closing this gap by defining the maximum limits to envelope energy losses at an international level and adopting a world map of degree-days using a single base temperature. Only in this way will all countries impose overall heat transfer coefficient buildings that use identical consumption criteria.

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Interior of the house					
Room	***$T_{operativa}$ (°C)***	***Thermal envelope surface (m^2)***			
		Window	***Enclosure***	***Partition walls***	***Roof***
Bathroom	20	0	0	0	3.120
Half-Bath	20	1.575	3.725	0	3.370
Living Room	20	5.040	9.785	8.900	22.540
Kitchen	20	3.225	4.750	11.650	9.270
Bedroom 1	20	3.990	4.760	0	12.130
Bedroom 2	20	2.080	10.095	0	12.090
Bedroom 3	20	3.360	10.040	0	11.400
Exterior of the house					
$T_{operativa}$ of unheated adjoining enclosures = 12ºC [38]					
T External = sum of annual degree-days (using a base temperature of 20°C)					

Table 1. Parameters for the calculation of the energy losses

Tipos de Cerramientos	***Transmitancias en W/m2K en cada país estudiado de la EU [18, 34, 41-49]***									
	España					France		U.K.	Germany	Passivhaus in Germany
	A	B	C	D	E	H1-H3	H3 <800			
Walls in contact with the outside and the ground	0.94	0.82	0.73	0.66	0.57	0.36	0.40	0.20	0.20	0.15
Suelos (Forjado)	0.53	0.52	0.50	0.49	0.48	0.20	0.25	0.20	0.28	0.15
Cubiertas	0.50	0.45	0.41	0.38	0.35	0.20	0.25	0.14	0.20	0.15
Ventanas de PVC	5.10	4.55	3.35	2.9	2.77	1.30	2.10	1.50	1.30	0.8
Tabiquería	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.15

Table 2. Transmitancias de cada zona climática en estudio en la EU

Tipos de cerramientos	***Transmitancias en W/m2K en cada zona climática de USA [18, 34, 41-49]***							
	1	2	3	4	5	6	7	8
Walls in contact with the outside and the ground	0.86	0.70	0.59	0.51	0.45	0.40	0.40	0.29
Suelos (Forjado)	1.83	0.49	0.49	0.42	0.36	0.32	0.29	0.29
Cubiertas	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Ventanas de PVC	6.81	4.26	3.69	2.27	1.99	1.99	1.99	1.99
Tabiquería	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20

Table 3. Transmitancias de cada zona climática en estudio en USA

Losses through enclosures = Σ U · A · (degree-days per year, calculated with a baseline temperature of 20°C) (W)						Pillar losses (W)		
Enclosure	Enclosure	Partition wall	Window	Roof	Total	No. of pillars	Pillar area (m^2)	Pillar losses
Half-Bath				4223.86	4223.86			0.00
Bathroom	8212.73	0	16905.58	4562.31	29680.61			0.00
Living Room	21573.58	38.45	54097.85	30514.65	106224.52	1.50	1.13	2480.36
Kitchen	10472.61	50.33	34616.18	12549.73	57688.85	1.00	0.75	1653.57
Bedroom 1	10494.66	0	42827.46	16421.59	69743.71	1.00	0.75	1653.57
Bedroom 2	22257.05	0	22326.10	16367.44	60950.59	2.00	1.50	3307.14
Bedroom 3	15617.52	0	36065.23	15433.32	67116.07	1.00	0.75	1653.57
Total losses	395628.22					10748.21		
	Total envelope losses = 406376.42 W							

Table 4. Enclosures energy losses for a typical house in climate zone E in Spain

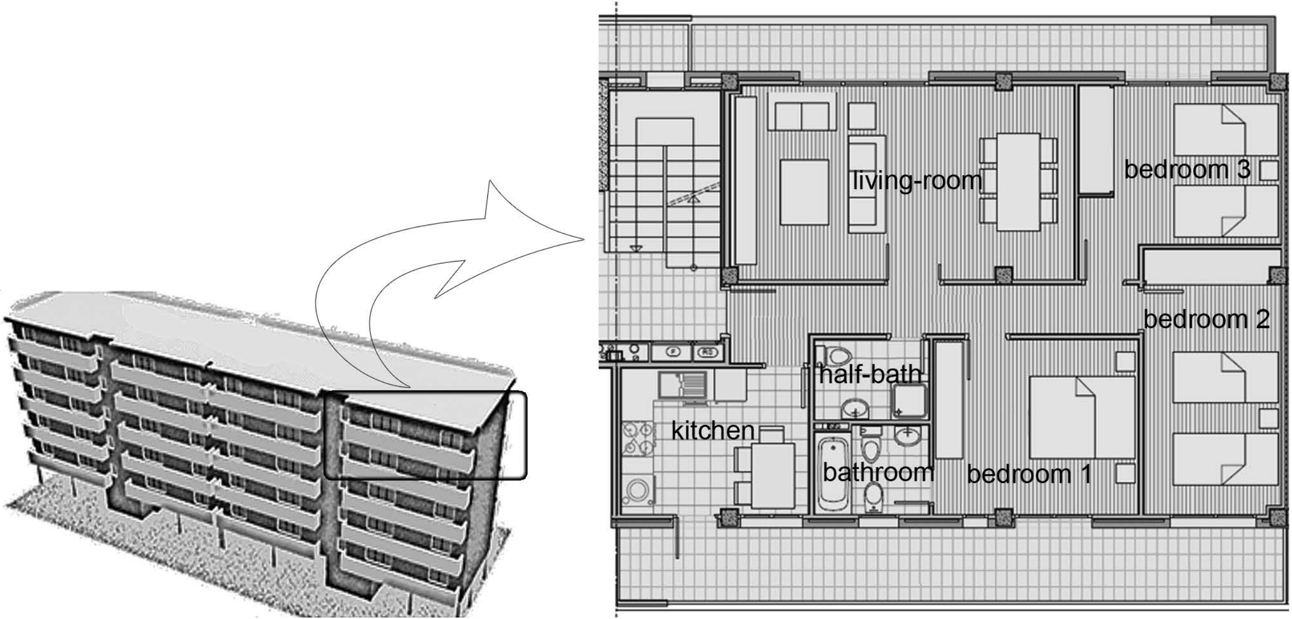
Country	Climate zone	City (region)	Annual degree-day (K; calculated with a baseline temperature of 20ºC)			Annual envelope energy losses (W)	% excess from the nZEB (154,323.44 W)
			Heating	Cooling	Total		
Passivhaus		*Bavaria (Hof)*	*4595*	*70*	*4665*	***154323.44***	***0***
Germany		Bavaria (Hof)	4595	70	4665	226893.42	47.02
		Karlsruhe	3299	227	3516	172165.48	11,56
	Mean annual consumption					***199529.45***	***29.29***
	Typical deviation between energy losses in the different climate zones					***13.71%***	
France	H1, H2 and H3 (> 800 m)	Strasbourg	3439	201	3640	205621.12	33.24
	H3 (< 800 m)	Avignon	2456	481	2937	229631.13	48.80
	Mean annual consumption					***216963.89***	***40.59***
	Typical deviation between energy losses in the different climate zones					***5.54%***	
England and Wales		Perth (Auchterarder)	4204	7	4211	***202889.27***	***31.47***
Spain	A	Málaga	1179	743	1922	346611.58	124.60
	B	Córdoba	1684	1045	2729	437443.88	183.46
	C	Oviedo	2711	87	2798	362931.74	135.18
	D	Vitoria	3311	176	3487	398238.07	158.05
	E	Burgos	3598	270	3868	406376.42	163.21
	Mean annual consumption					***387617.05***	***151.17***
	Typical deviation between energy losses in the different climate zones					***8.34%***	
USA	1	Hawaii (Honolulu)	0	2583	2583	498605.61	223.09
	2	Arizona (Yuma)	378	2590	2968	401136.14	159.93
	3	Oklahoma (Vance AFB)	2220	1057	3277	388728.25	151.89
	4	Oregon (Redmond Roberts Field)	3633	127	3760	328737.80	113.02
	5	Michigan (Saginaw Tri City Airport)	3871	314	4185	329169.66	113.30
	6	Montana (Butte Bert Mooney Airport)	5116	42	5158	391437.86	153.65
	7	Alaska (Fort Richardson BMYA)	5958	2	5960	450610.05	191.99
	8	Alaska (Fairbanks International Airport)	7515	40	7555	534295.70	246.22
	Mean annual consumption					***404113.70***	***161.86***
	Typical deviation between energy losses in the different climate zones					***15.9%***	

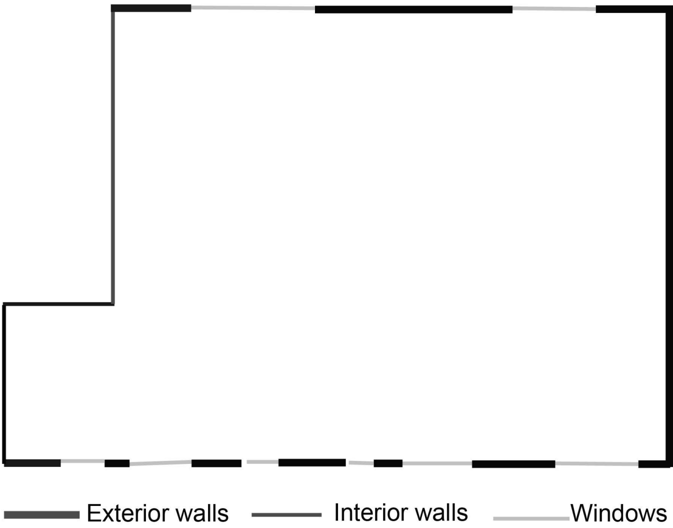
Table 5. Degree-days of the cities for which the envelope energy losses were calculated and envelope energy losses in a typical house over the course of one year

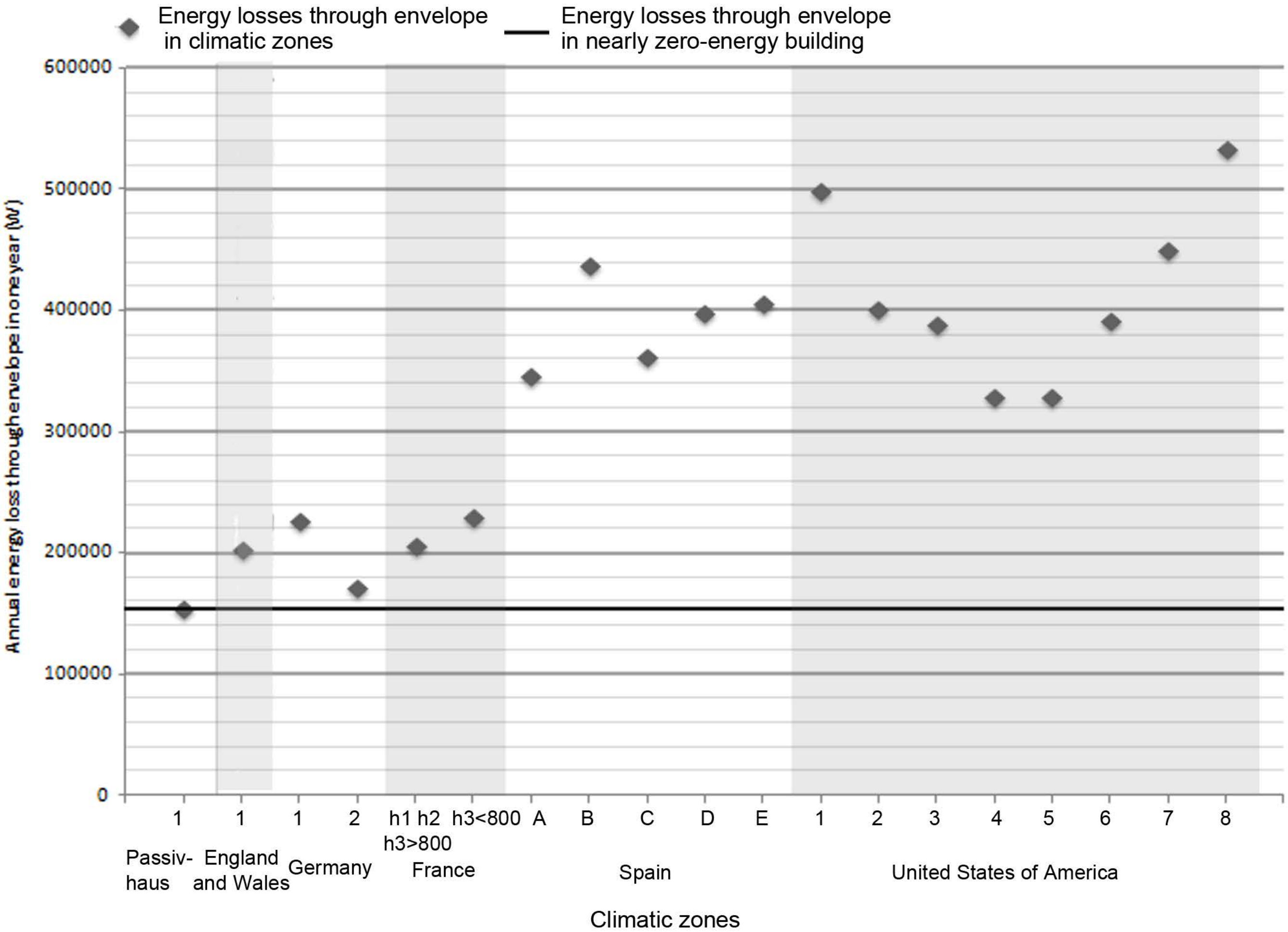
COUNTRY	REPORT, GUIDELINES, OR ACTION PLAN	LONG TERM GOALS		
		GENERAL OBJECTIVES	**ENERGY CONSUMPTION REDUCTION**	**GREENHOUSE GAS REDUCTION**
EUROPEAN UNION	*Action Plan for Energy Efficiency: Realizing the Potential, 2008 [51]*	Maintain the global temperature increase below 2°C by reducing the energy consumption and using renewable energy.	20% by 2020 compared to that in 1990	20% in 2020 compared to that in 1990
	European Directive: 2009/28/EC [52]	Meet 20% of the energy consumption needs in the EU with renewable sources by 2020.	–	–
GERMANY	*Action Plan for Energy Efficiency in Germany [53]*	Promote the construction of houses with a lower energy consumption of 60 to 40 $kW \cdot h/m^{2}$.	45% by 2020 compared to that in 1990	40% by 2020 compared to that in 1990
	Report on energy consumption [54]	Meet 35% and 60% of the energy requirements with renewable sources by 2020 and 2050, respectively. An action plan is developed to achieve this.	–	80% by 2050 compared to that in 1990
	Energy efficiency report [55]	Achieve the Passivhaus standard values in the regulations.	–	–
FRANCE	*Climate Plan 2004 [56]*	Limit the air conditioning resources and minimize the electricity demand.	40% by 2020 compared to that in 1990	–
	2011 Climate Change Adaptation Plan [57]	Promote the use of renewable energy sources and energy recovery and improve the energy efficiency of existing buildings in the energy and construction sectors to achieve the plan of 2004.	–	–
UNITED KINGDOM	*2008 Climate Change Act [58]*	Set total greenhouse gas reduction values and intermediate deadlines.	–	80% by 2050 compared to that in 1990
	Action Plan: A forward look at what standards may be in 2010-13 [59]	Set total greenhouse gas reduction values and intermediate deadlines.	–	44% by 2013 compared to that in 2006.
	Standard Assessment Procedure: SAP 2009 [42]	Require the Passivhaus transmittance standard in future revisions.	–	–
SPAIN	*Energy Savings and Efficiency Action Plan 2011-2020 [60]*	Provide valued measures to achieve the objectives stated in Article 14 of Directive 2006/32/EC.	15.9% in 2020 compared to that in 1990	20% by 2020 compared to the current value
U.S.	*Advanced Energy Design Guides of ASHRAE [61] recommended by U.S. Department of Energy*	Reduce the energy consumption by 50% in non-residential buildings by 2015 compared to the consumption stipulated by standard 90.1-2004. This is the first step toward constructing buildings with a net energy of zero.	50% in non-residential buildings by 2015	–
	Guide to Building Energy Codes Program: Building Energy Codes 101: An Introduction [62]	Provide values to decrease the energy consumption and greenhouse gas emissions under the new rules obtained by the building energy standards.	3.5 quadrillion Btu per year by 2030	Approximately 3% in 2030 compared to that in 2006
	National Global Change Research Plan 2012-2021[63]	Provide information on possible measures to reduce climate change. There is no commitment to achieve any values.	–	–

(-): This information is not available

Table 6. Future challenges in the energy efficiency sector in the countries under study


living-room
bedroom 3
bedroom 2
half-bath
kitchen
bathroom
bedroom 1


Exterior walls
Interior walls
Windows



Energy losses through envelope in climatic zones
Energy losses through envelope in nearly zero-energy building
Annual energy loss through envelope in one year (W)
600000
500000
400000
300000
200000
100000
0
1
1
1
2
h1 h2 h3>800
h3<800
A
B
C
D
E
1
2
3
4
5
6
7
8
Passiv-haus
England and Wales
Germany
France
Spain
United States of America
Climatic zones