Review of European ventilation strategies to meet the cooling and heating demands of nearly zero energy buildings (nZEB)/Passivhaus. Comparison with the USA.

Silvia Guillén-Lambea[1, 2,*], Beatriz Rodríguez-Soria[1], José M. Marín[2]

[1] *University Center of Defense, Ctra. Huesca, s/n, 50090, Zaragoza, Spain.*

[2] *Aragón Institute of Engineering Research (I3A), Thermal Engineering and Energy Systems Group, University of Zaragoza, Torres Quevedo Building, C/Maria de Luna 3, 50018 Zaragoza, Spain.*

Abstract.

The parameters and conditions that govern the ventilation requirements in residential buildings under current regulations worldwide are not harmonized. The reduction in energy demand and the increase in the thermal comfort in dwellings are mainly conditioned by these parameters.

This article reviews and compares the ventilation flow rates in residential buildings in various countries: the United States of America, Germany, France, the United Kingdom, and Spain. It also compares the requirements of these countries with the requirements of the Passivhaus construction standard, which is recommended by the European Union as an example of nearly zero-energy buildings (nZEB). Furthermore, a model for a dwelling is created using TRNSYS software.

First, simulations have been performed with the flow rates, ventilation strategies and envelope transmittance required by the regulations of each country. The cooling and heating demands have been obtained for representative cities in different climate zones. With these results, the impact of ventilation parameters in the heating demand of the proposed Spanish dwelling is analyzed. Secondly, the same dwelling has been simulated with the thermal envelope transmittance values recommended by the Passivhaus standard. The ventilation strategies of each country have been maintained. The influence of the ventilation can be observed uninfluenced by other design parameters.

It is found that with the current ventilation strategies, the heating and cooling demand values required by Passivhaus can be reached in only a few warm climates. In other cases, the ventilation strategies will need to change, and heat recovery ventilation will be required.

Keywords

Ventilation; European regulations; Passivhaus; Residential dwellings, Climatic zones

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[*] Corresponding author. *Silvia Guillén-Lambea. University Center of Defense, Ctra. Huesca, s/n, 50090, Zaragoza, Spain.*
Email address: sguillen@unizar.es, tel. +34 976 739838

1. Introduction.

The exhaustion of certain non-renewable energy sources and the effects on climate change caused by CO2 emissions [1] have resulted in the current worldwide concern for reducing energy consumption.

The current energy dependence in some industrialized countries can produce large economic imbalances in the world [2]. It is also expected that energy consumption in developing countries will be higher than that of industrialized countries by 2020.

In March 2007, the European Council adopted an integrated climate and energy policy to combat climate change and increase energy security in the EU (with 70% energy dependence) and to achieve an increase in the competitiveness of member countries. To achieve these objectives, a set of requirements was approved which must be met by 2020 [3,4]: a 20% reduction in energy consumption, a 20% reduction in CO emissions based on 1990 levels, and that 20% of EU energy consumption must come from renewable resources. In January 2008 the European Commission proposed a mandatory law to implement the "20-20-20 climate and energy package". This package became law in June 2009 [3,4].

To regulate energy consumption in the building sector, the EU published the 2010/31/EU European Directive [5] requiring that all new buildings to be constructed in the EU starting in 2020 (and all new public buildings starting in 2018) should be nearly zero-energy buildings (nZEB). The European Commission has taken the constructive methodology Passivhaus, developed in Germany by the Passivhaus-Institut Darmstadt, as a reference for nZEB [6]. This constructive methodology has spread throughout Europe as a reference for the drafting of regulatory changes aimed at adapting buildings to nZEB [7].

The importance of taking steps to reduce energy consumption in the construction sector is reflected by different organizations (such as the Intergovernmental Panel on Climate Change [8]) and has been pointed out by various authors as this sector is responsible for approximately 40% of energy consumption and greenhouse gas emissions [9–11]. Two-thirds of these emissions come from residential and commercial buildings [12–16]. A substantial percentage of this consumption is due to ventilation systems in dwellings [17].

Various studies have examined the requirements of minimum ventilation flow rates in several countries [18–21]. Of special interest is the article [22] which reviews the ventilation flow rates in fifteen countries and later calculates the minimum air changes necessary in a Japanese housing type according to different regulations without including ventilation strategies. A more recent study [23] discusses ventilation standards in several European countries and analyzes the ventilation flow rate values obtained in different European dwellings. The report published by BPIE this year [24] outlines the ventilation rules in eight EU countries. However, none of these works includes American rules or the Passivhaus standard. Furthermore, they do not state whether the rules are adequate to meet nZEB requirements.

This article analyzes the main regulations concerning the ventilation of residential buildings in several countries. It assesses and quantifies how ventilation parameters and their regulation affect the heating and cooling energy demands of dwellings. The countries studied are: the United States of America, Germany, France, the United Kingdom and Spain. According to the *Implementation of the Energy Performance of Buildings Directive Country Reports 2008* [25], Germany, France and the United Kingdom are considered as references in the implementation of energy efficiency regulations in buildings. Spain is included as a Mediterranean Europe country for the purposes of comparison. In addition, the ventilation regulations of these countries are compared with the guidelines and conditions concerning ventilation recommended by Passivhaus [6,26,27]. The European countries selected are representative of the different climate zones of the European Union with one exception: the colder Northern climate. The reason for this is that Nordic countries have already implemented (like Finland [28]) or are in the process of implementation of the Passivhaus recommendations in its regulations. The USA has been included in the study for two reasons. First, because of the similarity between its climate zones and those of Europe (as supported by the standard ASHRAE 90.1-2013 [29] that identifies the equivalence between US and EU climate zones). And secondly, because the Passivhaus standard is well extended across the country [30].

Furthermore, a dwelling situated in a block of houses has been modeled in TRNSYS [31]. The conditions established by each country to meet the envelope and the ventilation system requirements according to the different rules under study have been applied. All other parameters which influence the heating and cooling demands such as indoor temperature [32], infiltration [33] and internal loads have been kept constant in all the simulations. The heating demand due to ventilation has been obtained for the different climate zones of each country.

Secondly, the same dwelling has been simulated with the thermal envelope transmittance values recommended by the Passivhaus standard. The ventilation strategies in each country have been maintained. The influence of the ventilation can be observed uninfluenced by other design parameters.

Finally, simulations have been performed using the thermal transmittance and ventilation strategy recommended by Passivhaus for the same climate zones as the countries under study.

The main conclusion is the need to implement heat recovery in ventilation systems to meet the demands of the Passivhaus-nZEB. The results shows that the energy demand limit set by the Passivhaus standard is difficult to achieve by simply increasing the thermal insulation of the envelope.

2. Review of European and United States regulations governing ventilation in residential buildings.

The main function of the ventilation is to ensure the indoor air quality ensuring extraction agents harmful to humans. CO2 is a readily measurable agent, which has been established as reference of hygienic quality of the interior spaces. The air in the countryside has a CO2 concentration around of 380 ppm and the air on the cities around of 450 ppm. The CO2 concentration in interior spaces must be less than 1200 ppm. [31]. The air ventilation flow should guaranty that the CO2 concentration at the dwelling remains under this level.

Both the EU and the USA regulate ventilation systems through mandatory regulations indicating both quantitative flow rate values and ventilation strategies.

The regulations concerning ventilation in different countries and the conditions of energy efficiency of buildings are briefly explained below. These apply in the United States of America, Germany, France, the United Kingdom and Spain. The Passivhaus standard is also included.

For each analyzed country, an introduction to the rules is provided, describing how ventilation flows rates are imposed and detailing regulation strategy.

The full regulatory framework is reflected in Table 1.

Table 1. Regulatory framework in the countries under study. This information was compiled by the author.

2.1. United States regulations.

The “American Society of Heating, Refrigerating and Air-conditioning Engineers” (ASHRAE) publishes standards used worldwide as a reference for the calculation and design of air conditioning systems. Many European Standards (EN) on indoor air quality and air conditioning are based on this standard.

The ASHRAE 62.1.2013 Standard “Ventilation for Acceptable Indoor Air Quality”[34] defines ventilation in all conditioned spaces except for single family and multi-family low-rise residential buildings with less than three stories. In this standard, ventilation air flow in the "breathing areas" (internal volume of enclosures) is established at l/s per person or l/s per m2 of dwelling.

Otherwise, the ASHRAE 62.2.2013 standard: “Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings” [35] regulates ventilation in single family and multi-family low-rise residential buildings with less than three stories. In this standard, intermittent and continuous ventilation are allowed. However, it recommends controlled and intermittent mechanical ventilation. The standard points out that continuous fan operation greatly increases energy consumption and introduces the same air amount under all conditions of use, even in extreme climates.

This standard includes infiltration in the calculation of the ventilation only if the infiltration has been measured. In this case, the recommended ventilation rate is reduced by the rate of infiltration only when the infiltration constitutes less than 2/3 of the total flow rate.

The minimum flow rates for continuous and intermittent ventilation are shown in Table 2.

2.2. European regulations.

The European standard EN15251: 2007 *'Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*' [36] was adopted by the CEN on 26/03/2007.

This standard provides ventilation flow rates for use if there are no national regulations. It sets out four categories of ventilation flow rates depending on the quality of the indoor environment. Class II represents a normal level of expectation regarding the indoor air quality of new and refurbished residential buildings. Ventilation flow rates depend on the average use of the residence and can be adapted depending on the degree of occupation. In this standard, ventilation flow rates are recommended during the hours of occupation. The calculation procedure for Class II is as follows. First, the ventilation flow rate is calculated based on the floor area of the dwelling by applying a value of 0.42 l/sm^2. Secondly, the supply flow is calculated based on the occupation using a value of 7 l/s per person (living room and bedrooms) and, thirdly, it is calculated depending of the floor area of the living room and bedrooms considering 1 l/sm^2. The final ventilation flow should be the highest value of the three flow rates obtained. It is completed by adjusting the supply to the extract flow rates of the kitchen, bathrooms and toilets. These values are indicated in Table 2.

Concerning strategy, the standard explicitly recommends a minimum ventilation flow rate between 0.05 l/sm^2 and 0.1 l/sm^2 in residential buildings for vacancy periods. Furthermore, it indicates that ventilation systems with variable flow can control the air flow according to occupancy, the pollutant load or the production of moisture.

2.3. Spanish regulations.

In Spain, the Technical Building Code (CTE) published in 2007 [37] establishes the requirements to be met by buildings in relation to the basic requirements of safety and habitability. It consists of various Basic Documents (DB). The most recent update of the Basic Energy Saving Document (hereinafter HE) [38] was published on 12 September, 2013. This document regulates the actions of the thermal envelope of the building and the systems and facilities that consume energy.

The Basic Health Document HS 3: Indoor Air Quality [39] (hereafter DB-HS 3), regulates the ventilation air flow and the design conditions of the ventilation system of dwellings.

The minimum ventilation air flows in residential buildings are defined for each type of enclosure, both dry and wet, and are shown in Table 2.

This document requires that the outdoor air enters the dwelling by inlet openings located in dry rooms, and is expelled by exhaust openings in wet rooms. Therefore, the sum of the flows into the dry rooms should be increased to be equal to the sum of the output flow from the wet rooms.

Concerning strategy, the ventilation, either hybrid or mechanically controlled, should operate with the same flow rates for 24 hours.

2.4. German regulations.

In Germany the Energy Saving Act was adopted in 1976 (Energieeinsparungsgesetz-EnEG) and most recently revised in 2009 [40]. This law is the legal basis for the development of later regulations.

The Energy Conservation Ordinance - EnEV 2014 [41] regulates the requirements of energy saving buildings in terms of envelope and the installation of heating, cooling, ventilation, hot water and lighting, thus leaving all coordinated enforcement within the same regulation. The ventilation parameters in Germany are set out in the DIN 1946-6 Ventilation in residential buildings [42] and the DIN 18017-3 Ventilation in bathrooms and toilets without external windows [43]. Recommended values are indicated in Table 2.

The DIN1946-6 specifies four levels of ventilation, depending on the fan speeds to ensure sufficient air with different conditions of use and load: ventilation for protection from humidity, reduced ventilation, nominal ventilation and intensive ventilation. The norm states that the air changes per hour (ACH) required to reduce the content of carbon dioxide and water vapour from the air are between 0.5 (to avoid building damage caused by mould due to moisture when there are no occupants) and 1 for maximum occupancy.

Regarding the strategy, the German standard advocates mechanically controlled ventilation in an airtight building, to control energy losses and to act on them.

2.5. English regulations.

In the UK, each constituent country (England and Wales, Scotland, and Northern Ireland) publishes its own regulations, which dictate the ultimate objectives of energy efficiency and the numerical values that specific energy factors must achieve. The law common to England and Wales was selected for this study. In England and Wales, the definitions, procedures, and performance levels that should be met by buildings are included in the 1984 Building Act and subsequent amendments [44]. These performances parameters are developed under a compendium of documents, which are known as the Building Regulations of 2000. Of these, the document governing the energy efficiency of residential buildings is the *"Approved Document L1A: Conservation of fuel and power- New dwellings, 2010 edition"* [45] and the document outlining the basis for ventilation systems is the *"Approved Document F: Ventilation, 2010 edition*"[46].

The latter document indicates that uncontrolled air infiltration should be minimized since it cannot be acted on and that it should be replaced by controlled ventilation. Thus, it calculates the required ventilation considering that the building has no infiltrations. If the air permeability of the building is greater than 5 m^3/h at 50 Pa, it assumes an infiltration of 0.15 ACH, and decreases the ventilation flow required. The air extraction ventilation is performed in wet rooms and is called "Extract Ventilation". The air supply is provided through both wet and dry rooms and is called "Whole Dwelling Ventilation". The *Extract Ventilation* flow rates required are tabulated in the norm depending on the room and if ventilation is continuous or intermittent. For dry rooms, the *Whole Dwelling Ventilation* flow rates required are tabulated in the norm depending on the number of rooms in the house, considering two occupants for a double room and one occupant for the rest.

Ventilation flow rates are calculated for the winter period. If additional ventilation is required in the hot months, "Purge ventilation" comes into operation.

These values can be found in Table 2.

The document explicitly states that both continuous and intermittent extraction are allowed, the latter being considered more efficient not only energetically but also for indoor air quality. It further indicates that ventilation flows can vary when the building is unoccupied. To compensate for this lack of ventilation when the building is occupied again, "Purge Ventilation" is performed by opening the windows.

Both manual and mechanical controls are specified as valid. The control can be based on any of these three parameters: occupancy, humidity and air pollution evaluated by measuring the CO_2.

2.6. French regulations.

In France the law R.111-20: Building Code and habitability ("Code de la construction et de l'habitation") [47] sets out the general conditions that must be met by residential buildings. The ventilation of dwellings in France is regulated by the "Order of 24 March 1982 on provisions for ventilation of dwellings" [48] and its subsequent amendments on 27 March of the same year and 28 October 1983. This order indicates that ventilation must be permanent only when the outside temperature obliges windows to be kept closed. It further specifies that if there is a hood in the kitchen, the ventilation flow rate can be decreased in the kitchen. The air supply must enter through dry rooms and be extracted from wet ones.

The permanent ventilation flow rates required for wet rooms by French regulations are based on the number of main rooms (living rooms and bedrooms) regardless of the number of occupants of the dwelling. The flow rates are listed in Table 2.

French legislation encourages ventilation control through individual measurement devices. If these are installed, the ventilation rates can be reduced. In this case, the legislation regulates the minimum total flow that must be extracted from the kitchen in m^3/h and the total minimum flow in housing.

Likewise, it also allows for a mechanical device that automatically modulates the ventilation flow to reduce the airflow at times when it is not needed. Therefore, the total minimum flows are further reduced. It also allows the use of CO_2 and humidity measuring devices that are responsible for regulating the progress of fan operation.

2.7. Passivhaus recommendations.

The Passivhaus standard defines a ‘passive house’ as follows [49]: "A passive house is one that can ensure climatic comfort providing energy for heating and / or cooling only through the ventilation air."

In the Passivhaus standard, the ventilation rate must be the minimum necessary to ensure the hygiene of the interior rooms, considering this value to be between 8.3 l/s and 8.9 l/s per person (for residential use) [50]. It also recommends regulating the exchange rate depending on the activity. Ventilation must be mechanically controlled via a heat exchanger to avoid introducing air at ambient temperature. The use of heat recovery systems in the ventilation circuit is required by the Passivhaus standard.

Houses built under this standard have an average heating demand lower than 15 kWh/m^2 a year, which involves a maximum consumption of approximately 10 W/m^2.

Table 2. Ventilation regulations and standards in the countries under study.

3. Simulation of energy demand due to ventilation in a standard dwelling for the countries under study

3.1. Dwelling description and parameters of the model

The dwelling has a representative size and layout for a typical family composed by 4 persons: a kitchen, a living room, three bedrooms and two bathrooms and a net area of 81.15m^2. The ceiling height is 2.5m and the apartment is located on the top floor of a building of 4 floors. Regarding its orientation, the dwelling has windows on the north facade in the living room and in the double bedroom, and on the south facade in the kitchen, bathroom and two bedrooms. Only the hall and toilet have no exterior windows. The dwelling’s layout is showed in Figure 1. This layout was already considered in a paper to study the annual envelope energy losses in different countries [51].

The area of each room is indicated in Table 5.

Figure 1. Dwelling’s layout.

A model has been developed in TRNSYS [31] to simulate the energy demand for heating and cooling of the apartment.

The general considerations which remain constant in all the simulations are:
- The size and spatial orientation of the dwelling.
- Sun protection on the windows.
- Shading from adjacent buildings or other buildings has not been taken into consideration.
- No thermal bridges or air infiltrations through the envelope have been considered.
- The variation of heat transfer coefficients of the outer surfaces due to the effect of the wind has not been considered.
- The thermal inertia of the walls.

The input parameters considered in the model and that remain constant in all the simulations are listed below. They remained unchanged in all the simulations, even if the requirements in the regulations of each country vary. The objective is to evaluate only the impact of the norms and standards regarding ventilation in dwellings as described in the first part of this article.The input parameters unchanged in all the simulations are as follows:
- The dwelling occupation and its associated thermal loads. These are detailed in paragraph 3.1.1.
- The infiltration due to opening windows is as required by Spanish law [38]. Opening windows occurs during summer months (July to September) between 1 and 8 hours, inclusive. It is assumed that the living spaces have air infiltration caused by opening windows of 4 air changes per hour.
- The set temperature is the same for all simulations although these values also differ depending on the country regulations. The simulations were performed with a room temperature set at 21°C for heating and 25°C for cooling. These temperatures meet all the requirements of the international standards analyzed [7].
- Temperatures for adjacent areas follow Spanish legislation [38]: for adjacent homes 24ºC in summer and 18ºC in winter and unheated public areas 26ºC in summer and 12ºC in winter.

The input parameters of the model which vary depending on the country where the dwelling is located and its current regulations are as follows:

- The transmittances of the envelope are those required in the regulations depending on the climatic zone of the country where the dwelling is located. The values are shown in Table 3.

Table 3. Average envelope transmittance limit values depending on climatic zone.

- The ventilation flow rate and strategy follows the regulations. In some cases, the ventilation flow rate is affected by occupation of the dwelling. Occupation profiles are detailed in section 3.1.2.
- The model uses the climatic data of the city in which it is located for calculating energy demands. Details can be found in section 3.2.

The simulations provide instant energy demand for heating and cooling throughout the simulation period considered (1 year) including the energy required to heat the ventilation air during the winter months. In the results tables (Tables 8 and 9), the energy demand required for cooling the ventilation air during the summer season is not included because this is negligible compared to the overall demand throughout the year. According to the Savings and Energy Efficiency Plan (Plan de Ahorro y Eficiencia Energética PAEE 2012-2020) [52] in Spain, heating represents 41.7% of the total energy demand in a residential building whereas cooling represents only 0.4%.

3.1.1. Internal loads

The internal loads generated by occupancy, lighting and the use of equipment taken into account in the model are those defined in DB HE1 of the Spanish legislation [38].

In the case of sensible and latent loads due to occupation, the nominal load is calculated by considering three people in the house, with a heat generation equivalent to being seated in a restaurant according to ISO 7730: 2005 [53]. This nominal load is reduced by a factor of occupancy listed in Table 4.

For internal sources, a load of 5 W/m^2 has been considered multiplied by a reduction coefficient depending on the time of day, also indicated in Table 4.

Table 4. Reduction coefficients of internal loads applied in the model depending on the time of day.

3.1.2. Flow and ventilation strategies.

Ventilation air rates included in the model are shown in Table 5.

For countries with intermittent ventilation flow rates, the values in the table are the maximum rates. To simulate ventilation strategies, two occupancy calendars have been defined with reduction coefficients depending on the day of the week and the time of the day.

Germany is the only country which includes in its regulations a strategy depending on the occupation. Therefore, the first calendar is based on the strategy recommended in that legislation (called Occupational Germany). The second gathers the recommendations of European standard EN 15251: 2007 (called Occupational Europe).

Table 5. Ventilation flow rates included in the model according to the regulations of each country.

The coefficients in the two occupation profiles are shown in Table 6.

For the definition of the reduction coefficients in Occupational Germany, the values are those prescribed in DIN1946-6 [42]. The norm specifies that the ventilation flow rate should be between 0.5 and 1 ACH, depending on the use and the load. Furthermore, in the case of the existence of a flow regulator in the dwelling, the fan can operate at four speeds according to the reduction coefficients below:

1. Ventilation for protection against humidity: 0.2 ACH (11.3 l/s for the simulated dwelling).
2. Reduced ventilation: 0.2 ACH (11.3 l/s for the simulated dwelling).
3. Nominal ventilation: People at home: 0.5 ACH (29.5 l/s for the simulated dwelling).
4. Intensive ventilation: Guests at home ACH (56.4 l/s for the simulated dwelling).

The French regulation requires a ventilation flow rate of 45.8 l/s for the simulated dwelling in the case of not having control devices. However, these flows can be reduced to 25.0 l/s if the housing has individual control devices (for every room) and down to 5.6 l/s in the case of having mechanical ventilation devices with automatic modulation. The French legislation does not refer to any ventilation strategy based on occupation. Due to the large number of possibilities and in order not to create distortion in the results, the Occupational German calendar has also been applied in the simulations at French locations. This calendar's coefficient resulted in an average flow rate of 20.1 l/s, which largely meets the French legislation.

English law requires a flow rate of 29 l/s for continuous ventilation and a minimum flow rate of 60 l/s for intermittent operation. The simulations were performed with continuous ventilation since the regulation does not recommend a strategy to follow in case of intermittent ventilation. Furthermore, the mean reduction coefficients for the Occupational Germany calendar are 0.41 for working days and 0.54 for weekends. This implies that both strategies with continuous or intermittent flow would give similar results.

In the case of Spain, continuous ventilation has been used because this is required by its own regulations. Continuous ventilation has also been chosen for the USA because the American legislation does not indicate or recommend strategies. Besides, as with the English regulations, for intermittent flow ventilation the flow rates are doubled. Thus, implementing reduction coefficients from the Occupational Germany calendar would give similar results.

The second calendar includes the recommended strategy of the European standards, based on the recommended minimum flow for unoccupied hours where the air flow rate should range between 0.05 l/sm^2 and 0.1 l/sm^2. A coefficient of 0.5 for sleeping hours has also been considered. This calendar was used to perform the simulations with the Passivhaus-recommended transmittances and air flows for all the cities studied.

Table 6. Coefficients for the two occupation profiles defined.

3.2. Climate data.

Representative cities from each of the climatic zones defined in the countries surveyed have been selected. Table 7 lists the cities selected in each country for performing the simulations. The climatic zones defined in each country are also detailed.

Table 7. Representative cities from each of the climatic zones defined in the countries surveyed.

3.2.1. USA.

The ASHRAE 90.2-2013 standard divides the American territory into three geographical zones based on the humidity level: A-Moist, B-Dry and C-Marine. It also distinguishes 8 geographical areas based on the severity of the winter climate from 1 (mild climate) to 8 (the coldest). A total of 16 climatic zones are distinguished in the USA. 8 cities were selected for the study, one for each winter climate zone.

The climate files for the simulations in American cities are in TMY3 format (Typical Meteorological Year 3) [54].

3.2.2. European climatic zones

In Spain, the Technical Building Code (CTE) in its Basic Document HE1 [38] distinguishes five geographical areas depending on the severity of the climate in winter (from lowest to highest: A, B, C, D and E) and four geographical areas depending on the climate severity in summer (from lowest to highest: 1, 2, 3 and 4). For each Spanish climate zone a letter indicates the severity of the winter climate and a number the severity of the summer climate. A total of 12 climatic zones are distinguished in the Spanish mainland. A representative city from each climatic zone has been selected for the study.

The climate files for simulations in the Spanish cities are in SWEC format (Spanish Weather for Energy Calculations) [55].

Germany and the UK do not distinguish climate zones. The energy requirements and associated parameters are the same throughout these countries. Two cities in each country have been selected.

In France, the regulation divides the country into three geographical areas according to the climatic severity in winter (from lowest to highest: H3, H2 and H1) and four geographical areas according the

climatic severity in summer (from lowest to highest: a, b, c and d). A total of 8 climatic zones are distinguished in France. Seven representative French cities have been selected.
The climate files for simulations in Germany, the UK and France are in IWEC format (International Weather for Energy Calculations) [56].

3.3. Output parameters.

TRNSYS takes the heat balance for each thermal zone. The model calculates the energy demand for heating and cooling for a period of one year. In addition, the percentage of this demand due to ventilation is obtained. The energy balance for each room and the whole dwelling is governed by the following equation:

$$\dot{U}_{AIR} = Q_{HEAT} - Q_{COOL} + Q_{INF} + Q_{VENT} + Q_{COUP} + Q_{TRANS} + Q_{GINT} + Q_{SOL} + Q_{SOLAIR} \text{ [KJ/h]} \quad (1)$$

Where:
$\dot{U}_{AIR}$ Change of internal energy in the zone.
Q_{HEAT} Power of heating
Q_{COOL} Power of cooling
Q_{INF} Infiltrations gains
Q_{VENT} Ventilation gains (negative value for ventilation gains in tables 8 and 9 indicates losses due to ventilation).
Q_{COUP} Coupling gains
Q_{TRANS} Transmission into the surface
Q_{GINT} Internal gains (convective and radiative)
Q_{SOL} Absorbed solar gains on all inside surfaces of zones
Q_{SOLAIR} Convective energy gain of zone due to solar radiation transmitted through external windows which is transformed immediately into a convective heat flow to internal air.

Negative values indicate losses instead of gains.

4. Results

4.1 Results according to country regulations

Table 8 shows the results of the energy consumption in the selected cities.

Table 8. Heating and cooling demands according to country regulations.

In Spain, the heating demand due to ventilation varies between 40% and 51 %, being very similar in the different climatic zones. In contrast, the cooling demand in the hottest zones, such as Almeria, can be double that of the cooler zones, such as Burgos.
The ventilation losses in Barcelona are more than double those of Nice due to the Spanish regulations that require continuous ventilation while the French regulations allow discontinuous ventilation. Thus, in spite of having similar maximum ventilation flows, - 48 l/s for Spain vs. 45.8 l/s for France-, the daily air volume entering into the house is 4147 m^3 in Barcelona and 1744 m^3 in Nice. The ratio of energy consumption due to ventilation and the total energy consumption is very close in both cities, but the total energy demands are very different because the wall transmittance is greater in Spain than in France.
A comparison of the results obtained for towns with colder climates, Strasbourg and Munich, shows different values for the ventilation losses. The explanation is that, although an identical occupancy profile is applied to both cities, the maximum ventilation flow is greater in the German town (56.4 l/s vs 45.8 l/s). Notwithstanding, the heating demand is similar in both towns due to the greater restrictions on the wall transmittance in Germany than in France. The results for heating demand due to ventilation cannot therefore be directly compared.

In LA city, the ventilation losses of the dwelling are greater than its heating demand because of its high solar gains (eq. 1). If there were no ventilation losses, a heating system would not be necessary. For example, reducing the ventilation flow by half reduces the heating demand to 11.7 kWh/m^2·year. Removing the ventilation system reduces the heating demand to 3.8 kWh/m^2·year and the heating system would only have to work in the months of December and January.

4.2 Results according to Passivhaus transmittances and optimized ventilation flows

To compare the ventilation losses in the cities under study and to deduce the ventilation strategies required, simulations have been undertaken in two steps:

1) First, the transmittances are given the values according to the Passivhaus standards, while keeping the ventilation levels in line with each country's regulations to avoid the interpretation distortions observed in the previous section. The Passivhaus transmittances have been introduced in the following ways:
   - For Spain, climatic zones from A to D.
   - For France, climatic zone H3.
   - For the USA, climatic zones from 1 to 3.

   For the other countries, the transmittance values are those corresponding to the Passivhaus standard for the centre and north of Europe (Table 3).
2) In a second step, besides applying the same Passivhaus values for the transmittances, the same values for the ventilation flows have been used for every city according to Passivhaus recommendations and to the flow regulation strategy recommended by the European standard EN 15252 explained in section 3.1.2.

The following conclusions can be drawn from the results, shown in Table 9.

Table 9. Heating and cooling demands according to Passivhaus transmittances and optimized ventilation flows.

If the transmittance values are reduced, resulting in a better-isolated dwelling, the ventilation losses represent almost its total thermal loads. It is more efficient to recover the ventilation energy than to increase the thermal isolation. This can be seen by comparing, in Tables 8 and 9, the results of the towns belonging to the UK because of its very demanding isolation regulations.

By comparing again the cities of Barcelona and Nice, -which have very similar Mediterranean climates and whose heating demands are very similar (14.5 % less for Barcelona) if the same ventilation flows and wall transmittances are used (part 2 in Table 9) - the initial results showed a heating demand for Barcelona twice that of Nice, due only to the differences in French and Spanish ventilation strategies (30 % greater for Spain).

In the Spanish case, the results obtained when using the Passivhaus transmittance values indicate that the winter heating demand due only to ventilation surpasses the limit allowed by the standard DB HE1 (Table 10).

Table 10. Heating and cooling demands allowed by Spanish regulations depending on the climatic zone for the simulated dwelling.

In the colder towns where the more relevant parameters have been optimized (Table 9, part 2), in spite of assuming no infiltrations by the building closures, the values obtained are very far from those required by the Passivhaus standard (15 kWh/m^{2}year, fig. 2)) and, as a consequence, by the nZEB model.

With an appropriate ventilation strategy, the cooling demand becomes less problematic than the heating demand, except in hotter places like Houston or Miami where the high cooling demand makes it impossible to reach the nZEB limit without energy recovery.

Only in mild climates, such as Almeria and Malaga in Spain or LA in the USA, can the heating and cooling nZEB demands be fulfilled without heat recovery.

Figure 2. Heating and cooling demands compared to Passivhaus requirements.

As mentioned, all the simulations were performed with a room temperature set at 21°C for heating and 25°C for cooling. Moreover, finally additional simulations have been done with a temperature set at 20ºC for heating, value according to the UK, Germany and USA standards [7]. The results obtained for Jaen, as a representative warm climate city, are: 19.57 kWh/m^{2}year for heating demand (vs 25.46 kWh/m^{2}year) and -18.89 kWh/m^{2}year for heating demand due to ventilation (vs -20.41 kWh/m^{2}year). The results obtained for Berlin, as a representative central European city, are: 41.91 kWh/m^{2}year for heating demand (vs 48.06 kWh/m^{2}year) and -32.93 kWh/m^{2}year for heating demand due to ventilation (vs -34.80 kWh/m^{2}year). The new energy demand obtained do not reach the objetive of nZEB energy demand either.

Regarding the cooling set temperature, 26ºC is the higher value required by the standards of the analyzed countries. The cooling demand for Jaen is reduced to 5.09 kWh/m^{2}year (vs 9.26 kWh/m^{2}year) and to 1.01 kWh/m^{2}year (vs 1.68 kWh/m^{2}year) for Berlin.

5. Conclusions

All over the world, national regulations require a steady reduction in thermal transmittance values, which involves ever-increasing airtightness in buildings. Consequently, the regulations recommend controlled ventilation systems in houses, while Spanish regulations specify continuous ventilation 24 hours a day.

In this paper, the ventilation flows and strategies set out in the regulations of the USA, Germany, the UK, France and Spain have been compared, together with the Passivhaus standard. It is concluded that the maximum ventilation flows are similar but the control procedures are very different. The paper also analyzes whether the requirements of nZEB for heating and cooling energy demands can be achieved with current ventilation strategies.

The results suggest that in cooler climates these limits cannot be achieved without heat recovery. In milder climates, if the transmittance values are reduced, the ventilation losses can almost be the equivalent of the entire heating demand of a dwelling. Buildings located in the warmest places, such as the south of Spain and parts of the USA, are the only ones capable of fulfilling the heating and cooling demands of nZEB without recovering the waste heat coming from ventilation.

6. References

[1] VijayaVenkataRaman S, Iniyan S, Goic R. A review of climate change, mitigation and adaptation. Renew Sustain Energy Rev 2012;16:878–97.

[2] International Energy Agency. Worldwide Trends in Energy Use and Efficiency. IeaOrg 2008:93.

[3] European Commission. Europe 2020: A strategy for smart, sustainable and inclusive growth. COM(2010). Brussels: 2010.

[4] European Commission. Energy 2020. A strategy for competitive, sustainable and secure energy. COM(2010) 2010:639 – end.

[5] European Commission. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Official Journal L153 2010:13–35.

[6] Buildings Performance Institute Europe (BPIE). Principles for Nearly Zero-energy Buildings. Paving the way for effective implementation of policy requirements. Brussels: 2011.

[7] Rodríguez-Soria B, Domínguez-Hernández J, Pérez-Bella JM, del Coz-Díaz JJ. Review of international regulations governing the thermal insulation requirements of residential buildings and the harmonization of envelope energy loss. Renew Sustain Energy Rev 2014;34:78–90.

[8] Intergovernmental Panel on Climate Change. IPCC Fifth Assessment Report: Climate Change 2013 (AR5). Geneva: 2014.

[9] European Parliament. 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. (Text with EEA relevance). 2006:0064–85.

[10] European Commission. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/ 32/EC Text with EEA relevance. Off J Eur Union 2012:L315–1/L315–56.

[11] Intergovernmental Panel on Climate Change. IPCC Foruth Assessement Report. Climate change 2007 (AR4) 2008. doi:ISBN 92-9169-322-7.

[12] Sharma A, Saxena A, Sethi M, Shree V. Life cycle assessment of buildings: A review. Renew Sustain Energy Rev 2011;15:871–5.

[13] Koukkari H, Kuhnhenne M BL. Energy in the sustainable European construction. Sustain. Constr., Lisbon: 2007, p. 23–34.

[14] Gaterell MR, McEvoy ME. The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings. Energy Build 2005;37:982–95.

[15] European Commission. Action Plan for Energy Efficiency: Realising the Potential. Brussels: 2006.

[16] de Alegría Mancisidor IM, Díaz de Basurto Uraga P, Martínez de Alegría Mancisidor I, Ruiz de Arbulo López P. European Union’s renewable energy sources and energy efficiency policy review: The Spanish perspective. Renew Sustain Energy Rev 2009;13:100–14.

[17] Taylor PG, D’Ortigue OL, Francoeur M, Trudeau N. Final energy use in IEA countries: The role of energy efficiency. Energy Policy 2010;38:6463–74.

[18] Uglow CE. Background ventilation of dwellings: a review. Watford, UK: Building Research Establishment; 1989.

[19] Crump D, Dimitroulopoulou S, Squire R. Ventilation and indoor air quality in new homes. Build Res Establ 2005.

[20] McWilliams J, Sherman M. Review of Literature Related to Residential Ventilation Requirements. Berkeley Natl Lab 2005:30. doi:LBNL 57236.

[21] Stratton JC, Wray CP. Procedures and Standards for Residential Ventilation System Commissioning : An Annotated Bibliography. 2013.

[22] Yoshino H, Murakami S, Akabayashi S, Kurabuchi T, Kato S, Tanabe S, et al. Survey on minimum ventilation rate of residential buildings in fifteen countries. AIVC 25th Conf., Prague: AIVC; 2004, p. 227–38.

[23] Dimitroulopoulou C. Ventilation in European dwellings: A review. Build Environ 2012;47:109–25.

[24] Kontonasiou E, Mariottini F, Atanasiu B. Analysis of residential building regulations. Buildings Performance Institute Europe. BPIE; 2015.

[25] European Commission: Directorate-General for Energy and Transport. Implementation of the Energy Performance of Buildings Directive Country reports 2008. Brussels: 2008.

[26] Griffiths N, Nolte I. Principles for nearly Zero-Energy Buildings. Brussels: Buildings Performance Institute Europe. BPIE; 2011.

[27] Szalay Z, Zöld A. Definition of nearly zero-energy building requirements based on a large building sample. Energy Policy 2014;74:510–21.

[28] Wehringer F, Scherberich M, Groezinger J, Boermans T, John A SJ. Overview of Member States information on NZEBs Working version of the progress report - final report. 2014.

[29] ASHRAE. Handbook of Fundamentals. Standard 90.1-2013. Energy Standard for Buildings Except Low-Rise Residential Buildings. 2013.

[30] Passive House Institute (PHI). Passive House Database. http://www.passivhausprojekte.de/index.php?lang=en#s_82e59ad0693b9756581f49180ee6910a (accessed February 27, 2016).

[31] Solar Energy Laboratory. TRaNsient SYstem Simulation program. TRNSYS 17. 2012.

[32] Moon JW, Han SH. Thermostat strategies impact on energy consumption in residential buildings. Energy Build 2011;43:338–46.

[33] Erhorn-Kluttig H, Erhorn H. Airtightness requirements for high performance building envelopes. ASIEPI Inf Pap 2009.

[34] ASHRAE. Handbook of Fundamentals. Standard 62.1-2013. Ventilation for aceptable Indoor Air Quality. USA: 2013.

[35] ASHRAE. Handbook of Fundamentals. Standard 62.2-2013. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. 2013.

[36] European committee for Standardization. EN 15251:2007 Indoor environmental input parametres for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. 2008.

[37] Gobierno de España. Código técnico de la Edificación, Parte I. 2010. www.codigotecnico.org (accessed May 13, 2015).

[38] Gobierno de España. Documento Básico HE Ahorro de Energía 2013. http://www.codigotecnico.org/cte/export/sites/default/web/galerias/archivos/documentosCTE/DB_HE/DBHE-2013-11-08.pdf (accessed May 13, 2015).

[39] Gobierno de España. Documento Básico HS Salubridad 2009. www.codigotecnico.org (accessed May 13, 2015).

[40] Bundesministeriums der Justiz in Zusammenarbeit. Gesetz zur Einsparung von Energie in Gebäuden (Energieeinsparungsgesetz-EnEG). "Energieeinsparungsgesetz in der Fassung der Bekanntmachung vom 1. September 2005 (BGBl. I S. 2684), das durch Artikel 1 des Gesetzes vom 28. März 2009 (BGBl. I S. 643) geändert worden ist. Bundesgesetzblatt Jahrgang 2009. Ein Service des Bundesministeriu. GERMANY: 2009.

[41] Jahrgang B. 3951 Zweite Verordnung zur Änderung der Energieeinsparverordnung. Vom 18 November 2013. Nr.67 2013.

[42] DIN Joint Committee. DIN 1946-6 2009-05 – Lüftung von Wohngebäuden. Germany: 2009.

[43] DIN Joint Committee. DIN 18017-3 2009-09 – Entlüftung von innenliegenden Räumen. Germany: 2009.

[44] Controller and Chief Executive of Her Majesty's Stationery Office and Queen's Printer of Acts of Parliament. Building act 1984 UK. England: Printed in England by W. J. Sharp.; 1984.

[45] HM Government. The Building Regulations, Conservation of fuel and power Approved Document Part L1A (2013 version) 2013:48.

[46] HM Government. The Building Regulations 2000 Approved Document F - Ventilation. October 2010.

[47] Republique Française. R.111-20 du Code de la construction et de l'habitation (Dernière modification : 10 mars 2015) 2015. http://www.legifrance.gouv.fr/affichCode.do?cidTexte=LEGITEXT000006074096 (accessed May 13, 2015).

[48] Ministère de l'industrie chargé de l'énergie le ministère de la santé et le ministère de l'urbanisme et du Logement. Arrêté du 24 mars 1982 relatif à l'aération des logements. France: 1982.

[49] Passive House Institute (PHI) n.d. http://www.passiv.de/en/ (accessed May 13, 2015).

[50] Wassouf M. De la casa pasiva al estándar Passivhaus. La arquitectura pasiva en climas cálidos. Editorial Gustavo Gili; 2014.

[51] Rodríguez-Soria B, Domínguez-Hernández J, Pérez-Bella JM, del Coz-Díaz JJ. Quantitative analysis of the divergence in energy losses allowed through building envelopes. Renew Sustain Energy Rev 2015;49:1000–8.

[52] Instituto para la Diversificación y Ahorro de la Energía (IDAE). Plan de Acción de Ahorro y Eficiencia Energética 2011-2020. Madrid: 2011.

[53] ISO (International Organization for Standardization). ISO 7730:2005. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. 2005.

[54] Wilcox S, Marion W. Users manual for TMY3 data sets. Golden. Colorado: National Renewable Energy Laboratory; 2008.

[55] Weather Data Sources, EnergyPlus Energy Simulation Software, available at n.d. http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm (accessed May 13, 2015).

[56] ASHRAE. International Weather for Energy Calculations (IWEC Weather Files) Users Manual and CD-ROM. Atlanta: 2001.

Figure 1

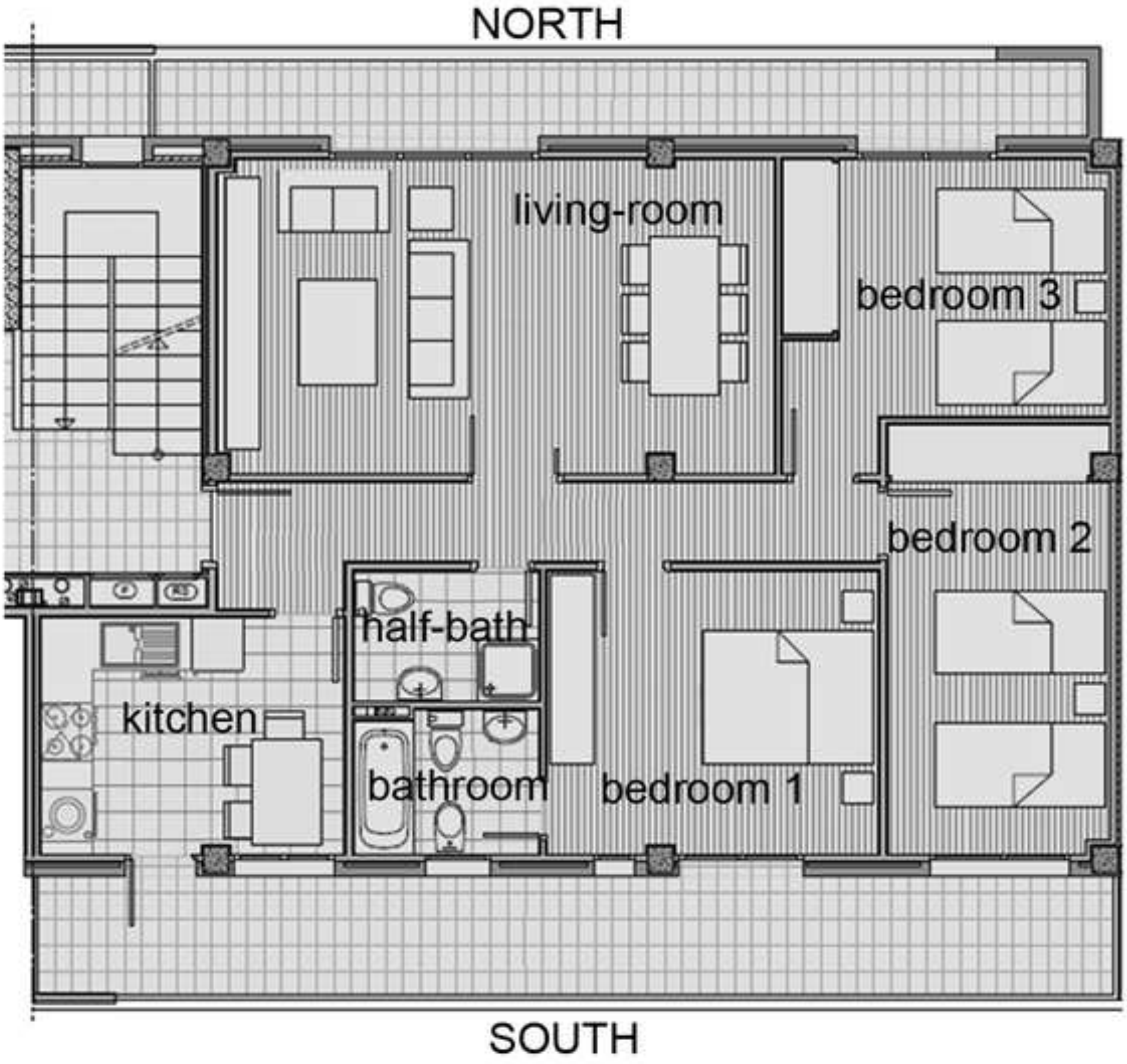
NORTH
living-room
bedroom 3
bedroom 2
half-bath
kitchen
bathroom
bedroom 1
SOUTH

Figure 2

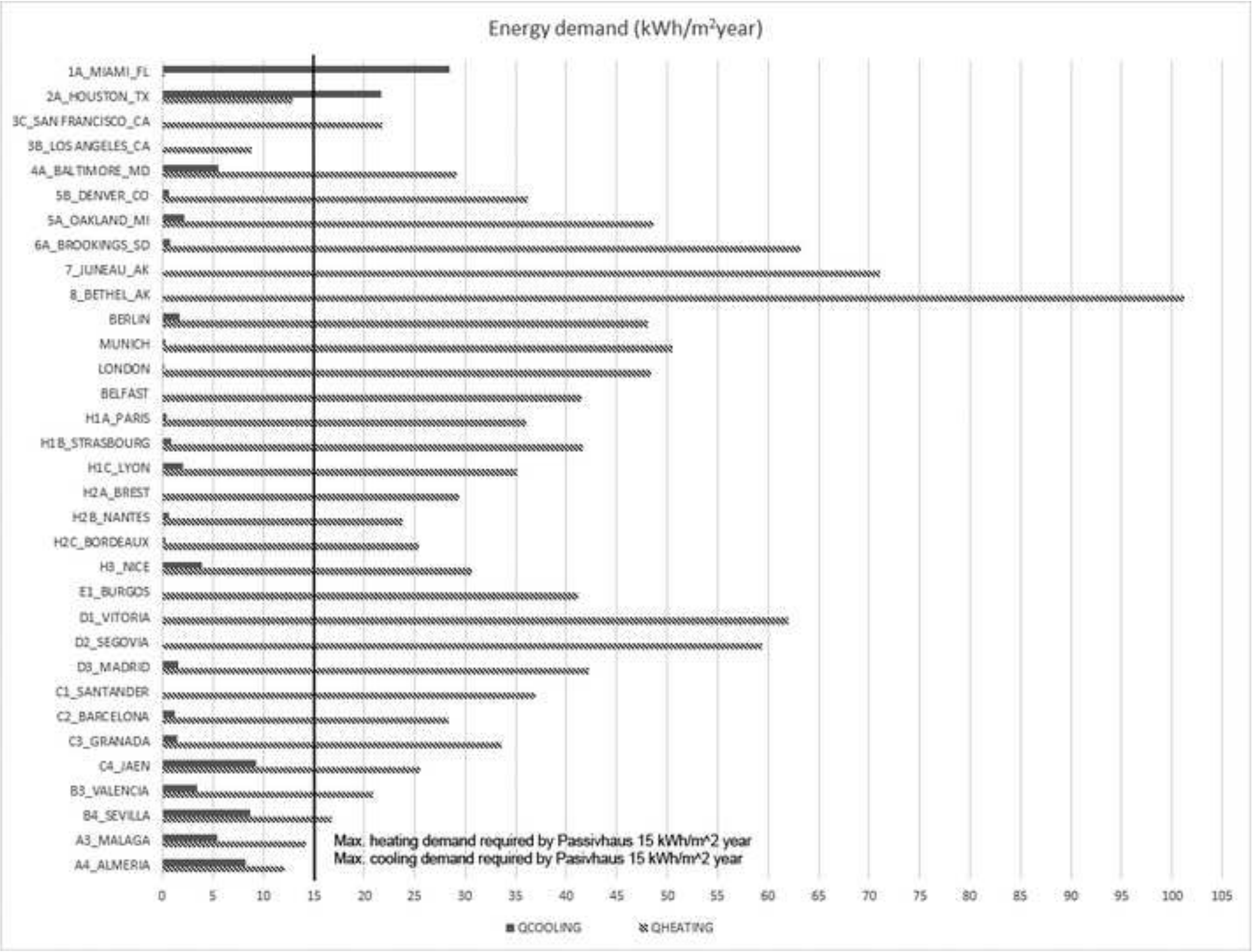
Energy demand (kWh/m²year)
1A_MIAMI_FL
2A_HOUSTON_TX
3C_SAN FRANCISCO_CA
3B_LOS ANGELES_CA
4A_BALTIMORE_MD
5B_DENVER_CO
5A_OAKLAND_MI
6A_BROOKINGS_SD
7_JUNEAU_AK
8_BETHEL_AK
BERLIN
MUNICH
LONDON
BELFAST
H1A_PARIS
H1B_STRASBOURG
H1C_LYON
H2A_BREST
H2B_NANTES
H2C_BORDEAUX
H3_NICE
E1_BURGOS
D1_VITORIA
D2_SEGOVIA
D3_MADRID
C1_SANTANDER
C2_BARCELONA
C3_GRANADA
C4_JAEN
B3_VALENCIA
B4_SEVILLA
A3_MALAGA
A4_ALMERIA
Max. heating demand required by Passivhaus 15 kWh/m^2 year
Max. cooling demand required by Pasivhaus 15 kWh/m^2 year
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
■ QCOOLING
▨ QHEATING

Table 1

International	Entity	At the supranational level	Country
ISO 7730:2005. Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.	**EU**	European Directives: 2010/31/UE European Standard (EN) EN15251:2007	Germany
			France
			U.K.
			Spain
	USA	ASHRAE Standards Standard 62-1-2013 Standard 62-2-2013	

Table 1. Regulatory framework in the countries under study. This information was compiled by the

Table 3

Average transmittance limit depending on the location of the building enclosure (W/(m2K))

Location	**SPAIN**					**GERMANY**	**UK**	**FRANCE**		**PASSIVHAUS**		**USA**						
Norm	*DB-HE1*					*EnEV 2009*	*Approved Document L1A*	*Ordre 24 mai de 2006*		*Provides different values for Central & North of Europe and Mediterranean locations.*		*ASHRAE 90.1-2013*						
Climatic zone	A	B	C	D	E	--	--	H3	H1-H2	CENT&NORTH	MEDIT.	1	2	3	4	5	6	7-8
External Walls	0.94	0.82	0.73	0.66	0.57	0.20	0.18	0.40	0.36	0.15	0.34	0.86	0.67	0.59	0.51	0.45	0.40	0.40
Floors	0.53	0.52	0.50	0.49	0.48	0.28	0.13	0.36	0.27	0.15	0.26	1.83	0.49	0.42	0.29	0.29	0.29	0.24
Roofs	0.50	0.45	0.41	0.38	0.35	0.20	0.13	0.25	0.20	0.15	0.26	0.15	0.15	0.15	0.12	0.12	0.12	0.10
Windows/ doors	4.10	3.25	2.48	2.48	2.48	1.30	1.40	2.10	1.80	0.80	1.40	2.84	2.27	1.99	1.99	1.81	1.81	1.81

Table 3. Average envelope transmittance limit values depending on climatic zone.

Table 4

		TIME OF DAY			
		1-7	**7-15**	**15-23**	**23-24**
Sensible & Latent Loads	Working day	1.00	0.25	0.50	1.00
	Weekend	1.00	1.00	1.00	1.00
Lighting	Every day	0.09	0.26	0.26	0.44
Equipment and devices	Every day	0.09	0.26	0.26	0.44

Table 4. Reduction coefficients of internal loads applied in the model depending on the time of day

Table 5

COUNTRY/STATE		USA	EUROPE	SPAIN	GERMANY	UK	FRANCE	PASSIVHAUS
Norm/Standard		ASHRAE Standard 62-1-2013	UNE EN 15252	DB HS3	DIN18017	Approved Doc. F Ventilation 2010	Arrêté du 24 Mars 1982	Standard Passivhaus
ROOM	Area (m2)[a]	Q (l/s)	Q Max (l/s)	Q (l/s)	Q Max (l/s)	Q (l/s)	Q Max (l/s)	Q Max (l/s)
Kitchen	9.18	25.7	26.6	18.2	25.0	13.5	33.4	17.6
Toilet	3.40	12.5	19.5	14.9	15.7	8.3	8.2	13.2
Bathroom	3.00	12.5	13.0	14.9	15.7	8.3	4.1	13.2
Bedroom 1	12.16	10.6	12.4	10.1	11.9	6.3	9.6	9.2
Bedroom 2	12.00	10.6	12.4	10.1	11.9	6.3	9.6	9.2
Bedroom 3	11.27	10.6	12.4	10.1	11.9	6.3	9.6	9.2
Living room	22.68	18.8	21.8	17.7	20.8	11.1	16.9	16.3
Whole dwelling		50.7	59.0	48.0	56.4	30.0	45.8	44.0
Type of ventilation		Continuous	Intermittent: Occupational Europe	Continuous	Intermittent: Occupational Germany	Continuous	Intermittent: Occupational Germany	Intermittent: Occupational Europe
Qv TOTAL (m3/day)		4380	2908 (wd) 2591 (we)	4147	2008 (wd) 2617 (we)	2592	1633 (wd) 2128 (we)	2168 (wd) 1932 (we)

Table 5. Ventilation flow rates included in the model according to the regulations of each country

[a] Corridor area 7.56 m^2

wd: working day

we: weekend

Table 6

		TIME OF DAY									
		0-7	**7-8**	**8-9**	**9-10**	**10-13**	**13-15**	**15-18**	**18-20**	**20-22**	**22-24**
OCCUPATIONAL GERMANY	Working day	0.50	0.50	0.50	0.20	0.20	0.50	0.20	0.50	0.50	0.50
	Weekend	0.50	0.50	0.50	0.50	0.20	0.50	0.20	0.20	1.00	1.00
OCCUPATIONAL EUROPE	Working day	0.50	1.00	1.00	0.17	0.17	1.00	0.17	1.00	1.00	0.50
	Weekend	0.50	0.50	1.00	1.00	0.17	1.00	0.17	0.17	1.00	0.17

Table 6. Coefficients for the two occupation profiles defined.

Table 7

COUNTRY/STATE	CLIMATIC ZONE	CITY
SPAIN	A4	ALMERIA
	A3	MALAGA
	B4	SEVILLA
	B3	VALENCIA
	C4	JAEN
	C3	GRANADA
	C2	BARCELONA
	C1	SANTANDER
	D3	MADRID
	D2	SEGOVIA
	D1	VITORIA
	E1	BURGOS
FRANCE	H3	NICE
	H2C	BORDEAUX
	H2B	NANTES
	H2A	BREST
	H1C	LYON
	H1B	STRASBOURG
	H1A	PARIS
UK	--	BELFAST
	--	LONDON
GERMANY	--	MUNICH
	--	BERLIN
USA	8	BETHEL (AK)
	7	JUNEAU (AK)
	6A	BROOKINGS (SD)
	5A	OAKLAND (MI)
	5B	DENVER (CO)
	4A	BALTIMORE (MD)
	3B	LOS ANGELES (CA)
	3C	SAN FRANCISCO (CA)
	2A	HOUSTON (TX)
	1A	MIAMI (FL)

Table 7. Representative cities from each of the climatic zones defined in the countries surveyed

Table 8

		ENERGY DEMAND (KWh/m^{2}year)				
COUNTRY/STATE	**CLIMATIC ZONE/CITY**	**QHEATING**	**QCOOLING**	**QTOTAL**	**QVENT**	**%**
SPAIN	**A4_ALMERIA**	58.76	11.26	**70.02**	-25.76	44%
	A3_MALAGA	66.23	7.22	**73.45**	-27.48	41%
	B4_SEVILLA	65.56	14.16	**79.72**	-29.59	45%
	B3_VALENCIA	79.90	3.89	**83.79**	-32.89	41%
	C4_JAEN	72.80	14.48	**87.28**	-37.38	51%
	C3_GRANADA	92.49	3.13	**95.62**	-44.07	48%
	C2_BARCELONA	80.08	1.37	**81.44**	-38.84	48%
	C1_SANTANDER	95.02	0.00	**95.02**	-38.84	41%
	D3_MADRID	101.18	2.58	**103.76**	-46.33	46%
	D2_SEGOVIA	133.85	0.05	**133.91**	-56.21	42%
	D1_VITORIA	136.42	0.05	**136.48**	-55.12	40%
	E1_BURGOS	145.04	0.00	**145.04**	-62.25	43%
FRANCE	**H3_NICE**	40.04	2.73	**42.77**	-16.12	40%
	H2C_BORDEAUX	45.89	0.31	**46.20**	-19.53	43%
	H2B_NANTES	43.80	0.31	**44.11**	-21.13	48%
	H2A_BREST	50.32	0.00	**50.32**	-20.72	41%
	H1C_LYON	57.94	1.81	**59.74**	-23.12	40%
	H1B_STRASBOURG	67.67	0.46	**68.13**	-25.25	37%
	H1A_PARIS	59.91	0.24	**60.15**	-23.31	39%
UK	**BELFAST**	53.44	0.00	**53.44**	-38.19	71%
	LONDON	60.14	0.05	**60.18**	-36.50	61%
GERMANY	**MUNICH**	67.14	2.46	**69.60**	-36.95	55%
	BERLIN	62.93	4.58	**67.52**	-32.67	52%
USA	**8_BETHEL_AK**	216.26	0.00	**216.26**	-117.54	-54%
	7_JUNEAU_AK	152.86	0.00	**152.86**	-84.97	56%
	6A_BROOKINGS_SD	149.63	1.53	**151.16**	-89.13	60%
	5A_OAKLAND_MI	122.53	3.53	**126.06**	-73.98	60%
	5B_DENVER_CO	100.97	1.76	**102.73**	-71.97	71%
	4A_BALTIMORE_MD	83.43	6.91	**90.35**	-59.65	71%
	3B_LOS ANGELES_CA	21.43	0.00	**21.44**	-29.35	137%
	3C_SAN FRANCISCO_CA	44.43	0.00	**44.43**	-39.80	90%
	2A_HOUSTON_TX	31.41	25.88	**57.28**	-27.24	87%
	1A_MIAMI_FL	6.99	36.73	**43.71**	-3.01	43%

Table 9

			ENERGY DEMAND PASSIVHAUS TRANSMITANCES (KWh/m^{2}year)					ENERGY DEMAND PASSIVHAUS TRANSMITANCES & VENTILATION FLOW RATES OCCUPATIONAL (KWh/m^{2}year)				
COUNTRY/STATE	**CLIMATIC ZONE/CITY**	**PASSIVHAUS**	**QHEATING**	**QCOOLING**	**QTOTAL**	**QVENT**	**QVENT %**	**QHEATING**	**QCOOLING**	**QTOTAL**	**QVENT**	**QVENT %**
SPAIN	A4_ALMERIA	PH MEDIT	21.15	8.84	**29.99**	-27.60	130%	12.13	8.22	**20.35**	-15.59	129%
	A3_MALAGA		24.49	5.74	**30.24**	-29.08	119%	14.22	5.41	**19.63**	-16.17	114%
	B4_SEVILLA		27.89	10.20	**38.10**	-31.07	111%	16.75	8.74	**25.49**	-17.21	103%
	B3_VALENCIA		34.37	3.52	**37.89**	-33.82	98%	20.90	3.45	**24.35**	-18.49	88%
	C4_JAEN		41.07	10.70	**51.77**	-37.72	92%	25.46	9.26	**34.73**	-20.41	80%
	C3_GRANADA		53.27	1.89	**55.16**	-44.03	83%	33.64	1.42	**35.06**	-23.49	70%
	C2_BARCELONA		45.15	1.05	**46.20**	-38.88	86%	28.36	1.21	**29.57**	-20.94	74%
	C1_SANTANDER		54.74	0.00	**54.74**	-38.69	71%	36.96	0.01	**36.97**	-20.50	55%
	D3_MADRID		63.35	1.81	**65.16**	-51.02	81%	42.23	1.60	**43.83**	-24.40	58%
	D2_SEGOVIA		85.85	0.02	**85.88**	-55.77	65%	59.41	0.06	**59.47**	-29.33	49%
	D1_VITORIA		87.85	0.00	**87.85**	-54.66	62%	61.91	0.00	**61.91**	-28.75	46%
	E1_BURGOS	PH NORTH	70.09	0.00	**70.09**	-61.93	88%	41.15	0.00	**41.15**	-32.75	80%
FRANCE	H3_NICE	PH MEDIT	26.35	8.63	**34.98**	-16.62	63%	30.66	3.92	**34.59**	-21.34	70%
	H2C_BORDEAUX	PH NORTH	20.44	0.41	**20.85**	-20.30	99%	25.45	0.33	**25.78**	-25.94	102%
	H2B_NANTES		18.70	0.85	**19.55**	-22.41	120%	23.75	0.61	**24.35**	-28.60	120%
	H2A_BREST		24.12	0.14	**24.26**	-21.75	90%	29.42	0.06	**29.48**	-28.04	95%
	H1C_LYON		29.38	2.27	**31.65**	-24.39	83%	35.13	2.03	**37.16**	-31.27	89%
	H1B_STRASBOURG		34.76	1.06	**35.83**	-26.10	75%	41.61	0.84	**42.44**	-33.72	81%
	H1A_PARIS		26.41	3.95	**30.36**	-16.57	63%	36.08	0.45	**36.53**	-31.36	87%
UK	BELFAST	PH NORTH	46.87	0.00	**46.87**	-38.26	82%	41.55	0.01	**41.56**	-32.37	78%
	LONDON		53.44	0.10	**53.54**	-36.48	68%	48.41	0.16	**48.57**	-30.97	64%
GERMANY	MUNICH	PH NORTH	48.24	0.39	**48.62**	-36.95	77%	50.46	0.35	**50.81**	-39.26	78%
	BERLIN		46.04	1.69	**47.73**	-32.69	71%	48.06	1.68	**49.74**	-34.80	72%
USA	8_BETHEL_AK	PH NORTH	160.71	0.00	**160.71**	-117.48	-73%	101.20	0.00	**101.20**	-58.29	-58%
	7_JUNEAU_AK		113.29	0.00	**113.29**	-84.78	75%	71.10	0.00	**71.10**	-42.43	60%
	6A_BROOKINGS_SD		106.35	0.88	**107.23**	-88.80	84%	63.21	0.78	**63.99**	-44.88	71%
	5A_OAKLAND_MI		84.86	2.37	**87.22**	-73.72	87%	48.70	2.12	**50.82**	-37.14	76%
	5B_DENVER_CO		68.79	0.82	**69.61**	-71.58	104%	36.09	0.65	**36.74**	-37.24	103%
	4A_BALTIMORE_MD		56.15	6.04	**62.18**	-59.56	106%	29.09	5.58	**34.67**	-30.88	106%
	3B_LOS ANGELES_CA	PH MEDIT	17.78	0.00	**17.78**	-28.50	160%	8.82	0.05	**8.87**	-15.84	180%
	3C_SAN FRANCISCO_CA		39.01	0.00	**39.01**	-39.15	100%	21.83	0.00	**21.83**	-20.32	93%
	2A_HOUSTON_TX		22.71	24.97	**47.68**	-27.65	122%	12.92	21.72	**34.64**	-15.30	118%
	1A_MIAMI_FL		0.93	31.76	**32.69**	-13.58	1464%	0.21	28.49	**28.70**	-8.67	4127%

Table 10

Winter Climate Zone	Heating demand (KWh/m^{2}year)
A/B	15.0
C	32.3
D	51.7
E	77.0
Winter Climate Zone	**Cooling demand (KWh/m^{2}year)**
1/2/3	15.0
4	20.0

Table 10. Heating and cooling demands allowed by Spanish regulations depending on the climatic zone for the simulated dwelling.

Table 2 New

COUNTRY/ STATE	STANDARD/NORM	VENTILATION AIR Whole dwelling ventilation rates	TYPE OF VENTILATION	EXHAUTS AIR FLOW RATES			SUPPLY AIR FLOW RATES	
				Kitchen	Bathroom	Toilet	Bedroom	Living room
USA	ASHRAE Standard 62-1-2013	Minimum ventilation rates in breathing zone: 2.5 l/s person or 0.3 l/s m^2.	CONTINUOUS VENTILATION	Min flow rate b: 25 l/s	Min flow rate c: 12.5 l/s	Min flow rate c: 12.5 l/s	--	--
		Occupancy [a]	INTERMITENT VENTILATION	Min flow rate b: 50 l/s	Min flow rate c: 25 l/s	Min flow rate c: 25 l/s	--	--
	ASHRAE Standard 62-2-2013	depending on the floor area or, alternatively, calculated using the equation: Qtot=0.15 AFLOOR+3.5 (NBR+1)	CONTINUOUS LOCAL VENTILATION	5 ACH	10 l/s	10 l/s	--	--
		Qtot total required ventilation rate (l/s) Afloor dwelling floor area (m^2)	DEMAND-CONTROLLED LOCAL VENTILATION	50 l/s [e]	25 l/s	25 l/s	--	--
EUROPE	UNE EN 15252	During occupancy continuous flow rate should be at least the biggest of the following values: 1) 0.42 l/s m^2 2) 7 l/s person at living and bedroom 3) 1 l/m^2 for living and bedroom floor areas During not occupancy ventilation rate could be reduced between 0.05 l/sm^2 and 0.1 l/sm^2	CONTINUOUS OR DEMAND-CONTROLLED VENTILATION. Ventilation rates could be reduced depending on the occupancy.	Min flow rate: 20 l/s	Min flow rate: 15 l/s	Min flow rate: 10 l/s	--	--
SPAIN	DB HS3	Continuous ventilation 24hours per day	CONTINUOUS VENTILATION	Min flow rate: 2 l/s m^2 + 50 l/s for appliance hood	Min flow rate: 15 l/s	Min flow rate: 15 l/s	5 l/s per person	3 l/s per person
GERMANY	DIN1946-6	Mechanical ventilation is required if the necessary air volume flow for moisture-proofing exceeds the air volume flow caused by infiltration. Demand controlled ventilation specify 4 levels for fan air flow: Pos 1: Protection against humidity. From 4.16 l/s (15 m^3/h) for 30 m^2 to 23.6 l/s for 210 m^2 (85 m^3/h) depending on floor area. Pos 2: Reduced ventilation. From 11.11 l/s (40 m^3/h) for 30 m^2 to 41.66 l/s for 210 m^2 (150 m^3/h) depending on floor area. Pos 3: Nominal ventilation. From 15.27 l/s (55 m3/h) for 30 m2 to 59.72 l/s for 210 m^2 (215 m^3/h) depending on floor area. Pos 4: Intensive ventilation. From 19.44 l/s (70 m3/h) for 30 m2 to 79.16 l/s for 210 m^2 (285 m^3/h) depending on floor area.	NATURAL OR FAN ASSISTED VENTILATION	Nominal ventilation in case of mechanical ventilation: 12.5 l/s (45 m^3/h)	Nominal ventilation in case of mechanical ventilation: 12.5 l/s (45 m^3/h)	Nominal ventilation in case of mechanical ventilation: 7 l/s (25 m^3/h)	--	--
	DIN18018	Applies for ventilation of bathrooms and toilets without windows Air flow requirements only related to exhaust air rooms, not to the entire house	CONTINUOUS VENTILATION (minimum high rate)	11.11 l/s (40 m^3/h) during a Min of 12 hours	5.55 l/s (20 m^3/h) during a Min of 12 hours	5.55 l/s (20 m^3/h) during a Min of 12 hours	--	--
			INSTANTANEOUS VENTILATION (minimum rate)	16.66 l/s (60 m^3/h)	8.33l/s (30 m^3/h)	8.33l/s (30 m^3/h)	--	--
UK	Approved Doc. F Ventilation 2010	From 13 l/s (for 1 bedroom dwelling) to 29 l/s (for a 5 bedroom dwelling). Whole ventilation flow rate always higher than 0.3 l/s m^2. Occupancy [f] If dwelling permeability is 5 m^3/(h m) a 50 Pa, takes 0'15 ACH as infiltration rate which will be reduced from the total ventilation rate.	CONTINUOUS EXTRACT VENTILATION (minimum flow rate)[g]	13 l/s	8 l/s [h]	6 l/s [i]	--	--
			INTERMITTENT EXTRACT VENTILATION (minimum flow rate)	30 l/s + appliance hood flow rate or 60 l/s	15 l/s [h]	6 l/s [i]	--	--
FRANCE	Arrêté du 24 Mars 1982 Modifié par arrêté du 28 octobre 1983	Whole dwelling ventilation during winter: continuous ventilation has to be assured. With regulation control device, the total minimum flow assured for whole dwelling from 9.72 l/s (35 m^3/h) for 1 room dwelling to 37.5 l/s (135 m^3/h) for 7 room dwelling [j]	CONTINUOUS EXTRACT VENTILATION (minimum flow rate)	From 20.8 l/s (75 m^3/h) for 1 room dwelling to 37.5 l/s (135 m^3/h) for a 5 or more room dwelling	From 4.16 l/s (15m^3/h) for 1 room dwelling to 8.33 l/s (30 m^3/h) for a 5 or more room dwelling	4.16 l/s (15m^3/h)	--	--
		With mechanical ventilation and control device, the total minimum flow assured for whole dwelling from 2.77 l/s (10 m^3/h) for 1 room dwelling to 9.72 l/s (35 m^3/h) for 7 room dwelling.	DEMAND CONTROLLED VENTILATION BY REGULATION DEVICES (total minimum flow rate)	Regulation device: From 5.55 l/s (20 m^3/h) for 1 room dwelling to 12.5 l/s (45 m^3/h) for a 7 room dwelling	--	--		
PASSIV-HAUSS	Standard Passivhaus	From 8.33 l/s to 8.88 l/s (30-32 m^3/h) per person Controlled ventilation depending on the occupancy	--	--	--	--	--	--

Table 2. Ventilation regulations and standards in the countries under study.

[a] Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

[b] For continuous system, the lower rate may be used. Otherwise use the higher rate.

[c] Rate is for a toilet room intended to be occupied by one person at a time. For continuous system operation during normal hours of use lower rate may be used. Otherwise use the higher rate.

[d] Whole-building mechanical systems are not required if window operation is a locally permissible method of providing ventilation and provided that at least one of the following conditions is met:

the building has no mechanical cooling and is in zone 1 or 2 of the climate zone or the building is thermally conditioned for human occupancy for less than 876 h per year.

[e] Vented range hood (including appliance-range hood combinations) required if exhaust fan flow rate is less than 5 kitchen ACH.

[f] This is based on two occupants in the main bedroom and a single occupant in all other rooms. This should be used as default value. If a greater level of occupancy is expected add 4 l/s per occupant.

[g] Total extract rate should be al least the whole dwelling ventilation rate

[h] Bath room and utility room

[i] For sanitary accommodation

[j] For France, no differences between bedrooms and living rooms apply