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Trends in building ventilation requirements and inspection in Spain

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1 General introduction

In Spain, the construction sector has undergone significant changes over the last twenty years due to new ventilation standards driven by increased awareness of indoor air quality (IAQ) and energy efficiency, as well as environmental policies.

The Código Técnico de la Edificación (Building Code, CTE) [1] has been the main regulation governing the quality of buildings since 2006, addressing all related aspects, including energy efficiency and IAQ. The CTE includes provisions aimed at promoting adequate IAQ in residential buildings, while also limiting energy demand across all building types.

Furthermore, it is worth noting that since 1998, the Reglamento de Instalaciones Térmicas de los Edificios (Regulation on thermal systems in buildings, RITE) [2] has been setting the standards for IAQ in non-residential buildings.

It is important to acknowledge that both regulations are continuously evolving to keep up with advances in techniques and knowledge, as well as to ensure compliance with European Directives.

Construction has a significant impact on both the country's overall energy consumption and greenhouse gas emissions. Residential and tertiary buildings are responsible for 26% of total energy consumption, with the residential sector alone accounting for 17% of energy consumption. In particular, 45% of the residential sector's energy consumption is due to heating and cooling, with a large share corresponding to ventilation needs [3].

This article aims to cover the following national trends:

- IAQ requirements and market,
- energy requirements and market,
- inspection of ventilation systems,
- innovative systems and market, and
- impact of the COVID-19 pandemic.

1.1 Dwellings

Before 2006, there were no national regulations in place regarding IAQ in dwellings. The ventilation system was mainly reliant on the occupants' habits of opening windows, high infiltration rates through the building envelope (mainly window frames), and the extraction of stale air through thermal buoyancy-based vertical stacks placed in wet rooms (primarily bathrooms and toilets, and in some cases, kitchens). IAQ was generally considered adequate in mild climates or seasons, but problems tended to occur in cold climates or seasons because occupants did not perform the opening of windows so diligently [4][5]. Additionally, during thermal inversion episodes occurring in hot periods, stale air may not be exhausted through the vertical stacks. All these facts, together with a steady increase in energy efficiency requirements for the building envelope in general and windows in particular, leading to more airtight windows, brought the need of the development of IAQ regulations that set threshold values for IAQ requirements [6][7].

The Section HS 3 Calidad del aire interior (Indoor air quality) [1] within the CTE established the first regulation on IAQ in Spanish dwellings in 2006. This regulation, approved by Real Decreto (Royal decree) 314/2006 on March 17th, sets minimum constant ventilation flow rates for the supply and exhaust to and from the habitable rooms.

Despite its relevance as a first step towards achieving a minimum IAQ, it was slow to gain general acceptance among construction stakeholders, while at the same time presenting some problems.

The required ventilation flowrates were not adjustable, so energy efficient systems such as demand-controlled ventilation systems based on variable ventilation flowrates, were not normally deemed acceptable unless a comprehensive statement of compliance was provided, which was an obstacle to its use. This led to a period of industry adaptation in which the major manufacturers of energy efficient ventilation systems had to apply for technical approval of their products.

The required ventilation flowrates were overestimated because they were based on a conservative occupancy pattern, meaning in this case an obstacle to achieve adequate energy efficiency.

In 2010, with the adoption of the recast EPBD (Energy Performance of Buildings Directive, 2010/31/UE, 19 May 2010), EU Member States faced new challenges. The revised EPBD target was to increase the level of performance by 2020 to reach nearly-zero energy buildings. In order to achieve this target in Spain, a comprehensive revision of the energy requirements related mainly to the thermal envelope was performed in 2013, leading to an increase of the energy efficiency of buildings; although this was deemed insufficient as the energy performance of buildings is also affected by ventilation systems. To further improve energy efficiency, the use of ventilation systems with variable flow was necessary, as it would almost certainly lead to a reduction of the overall ventilation flowrate and, consequently, to a reduction of the energy demand for heating and cooling, while maintaining a good level of air quality.

Therefore, in 2017, in order to solve the above-mentioned problems, the current performance-based IAQ regulation was adopted, which facilitates the use of smart ventilation systems while complying with the highest IAQ standards and reduces the constant flow rates that were previously set [8].

Within the general framework of updating regulations, Section HS 3 is currently undergoing a revision to deepen its performance-based approach and to include the latest state-of-the-art developments [9][10][11].

1.2 Non-residential buildings

In relation to non-residential buildings, the regulations on IAQ are set by the RITE [2]. RITE is mandatory at a national level since 1998 by Real Decreto (Royal decree) 1751/1998, 31 July, and has been revised several times: in 2007, 2013 and 2021.

In 2007 it was revised to transpose the EPBD (Energy Performance of Buildings Directive, 2002/91/CE, 16 December 2002) and to take into account the text of the then newly approved CTE.

In 2013 the aim of the revision was to transpose the recast EPBD [12].

In 2021 it was revised again to transpose Directive (UE) 2018/844.

RITE is currently undergoing a revision to keep it up to date with all recently adopted related Directives and to include the latest developments in the state of the art.

2 National trends in IAQ requirements and market

2.1 Requirements on ventilation of dwellings

As mentioned above, mandatory requirements on ventilation of dwellings are set in the Código Técnico de la Edificación (Building Code, CTE) in Section HS 3 Calidad del aire interior (Indoor air quality) [1]. The current version dates from 2017.

The scope of the requirements for newly built buildings is:

– private residential buildings, including the interior of dwellings, waste rooms and storage rooms, and garages' buildings.

The scope for existing buildings is:

– extensions,
– the whole building when major retrofitting is performed, and
– the affected areas in minor retrofitting actions.

Requirements for dwellings are established to be able to control pollutants generated by buildings' users, materials and furnishment. This way, indoor CO_2 concentration is set as the indicator of IAQ related to users' activities and, in addition to this, a minimum ventilation flow is required to extract pollutants derived from building materials, finishes and furnishment.

Therefore, taking CO_2 as an indicator, the following performance-based requirements must be fulfilled by means of simulation at design level (it is not required to demonstrate fulfilment via on site measurement) or by the use of minimum constant ventilation flows taken as accepted solutions:

– CO_2 average annual concentration in each room must not exceed 900 ppm,
– CO_2 annual accumulated over 1,600 ppm must not exceed 500,000 ppm·h, and
– minimum flow rate of 1.5 l/s per habitable room during periods of non-occupancy

Peak CO_2 concentrations above 900 ppm may occur, but this is considered adequate, as long as the annual average concentration and the cumulative condition are not exceeded.

Simulation should be conducted under design conditions such as number of occupants, occupancy scenarios, weather conditions, CO_2 production rate, annual average outdoor CO_2 concentration, airtight envelope and doors in closed position. These design conditions are set out in Appendix C of Section HS 3.

For each room the minimum constant ventilation flowrates that perform as **accepted solutions** are displayed in Table 1, depending on the type of dwelling according to the number of bedrooms. These constant flowrates meet the performance-based requirements under the above design conditions.

Fresh air must be supplied to dry rooms and stale air must be extracted from wet rooms. Accordingly, two ventilation flows must be calculated using Table 1: total supply flow and total exhaust flow. Both flows must be balanced, so the biggest one is taken as the total ventilation flow for the design of the system.

For the forthcoming future, the foreseen change will deepen into the performance-based approach, probably looking into stepping away from CO_2 as the IAQ indicator and setting out thresholds for actual pollutants. The greatest challenge for this change relies on establishing the relationship between pollutants concentration and effect on occupants' health. Other challenges involve, for instance, the accuracy and availability of pollutants sensors for controlling ventilation systems.

Table 1 : Minimum constant ventilation flowrates for dwellings (Table 2.1 of Section HS3, CTE)

Type of dwelling	Minimum constant ventilation flowrates (l/s)				
	Dry rooms			Wet rooms	
	Master bedroom	Bedrooms	Dining and living room	Global	Per room (kitchen and bathrooms)
0 or 1 bedrooms	8	-	6	12	6
2 bedrooms	8	4	8	24	7
≥ 3 bedrooms	8	4	10	33	8

2.2 Ventilation systems in residential buildings stock and market

According to the Instituto Nacional de Estadística (National Statistics Institute, INE) [13], in 2021 the total number of dwellings was 26,623,708, including 3,837,328 that were empty and 2,514,511 with sporadic use.

Regulations and standards in Spain have had a significant influence on the ventilation systems market, contributing to its sustained growth. In recent years, this market has experienced remarkable growth, driven mainly by increasing awareness of IAQ and regulatory updates.

The strictness in these regulations and standards not only define the standards for ventilation systems but may also be triggering the demand and growth in the ventilation market in Spain.

Although there are not official statistics on the type of ventilation systems installed in dwellings, from 2006, when CTE was approved and came into force, all new dwellings must have a mechanical or hybrid ventilation system, with fully natural ventilation not allowed. In the DB HS3 hybrid ventilation is defined as a system designed to operate in accordance with the principles of natural ventilation when the atmospheric pressure and temperature conditions are favourable, and to function with a mechanical exhaust when they are unfavourable.

In general, the most widespread ventilation system in newly built dwellings in Spain consists of a hybrid centralised exhaust fan placed on the roof at the end of the vertical ventilation stack located in the wet rooms together with windows with micro-ventilation placed in the dry rooms to allow the inlet of fresh air. The micro-ventilation system is a device integrated into the window frame (usually tilt-and-turn) that is activated by the window handle leaving an opening of between 4 and 5 millimetres around the perimeter of the active window sash. It allows a small but permanent air flow.

Although air inlets such as trickle vents are also permitted in the CTE to supply fresh air, there is some rejection of their use because some of them do not have the means to be completely closed. In spite micro-ventilation not being the best way for delivering fresh air because it has to be operated manually and occupants are mostly unaware of its operation, developers and designers rather implement it because it does not arise as much rejection as air inlets.

The second most common ventilation system in newly built dwellings in Spain is the single-flow mechanical system. It usually consists of an exhaust fan which can be centralised, placed on the roof, or individual, placed in each dwelling in the suspended ceiling of one of the bathrooms. The fan is connected through ducts to all wet rooms. For the supply of fresh air, both micro-ventilation and air inlets can be used.

In more advanced cases, mechanical double-flow systems are used, where stale air is exhausted like in the previous system, but fresh air is taken from outside through a heat recovery unit and supplied to the dry rooms via a duct network. This latter system tends to be a smart and demand-controlled ventilation system (DCV).

The deployment of DCV with a smart and demand-controlled ventilation system remains relatively uncommon, with the exception of humidity-controlled ventilation systems in dwellings.

The most commonly used materials for ducting are thermoplastics and galvanized steel.

In existing dwellings built before 2006, natural ventilation is the most widespread ventilation system. It is based on thermal buoyancy through a vertical ventilation stack in combination with airing, opening and closing windows, and infiltration through the building envelope, mainly joinery.

For renovation, it is very common in Spain to install hybrid roof-mounted extractor fans at the top of vertical ventilation stacks and to replace old, rather permeable windows with airtight ones with, in some cases, micro-ventilation. In the absence of micro-ventilation or other means of fresh air intake (other than opening windows), surface condensation is quite likely to occur in poorly insulated buildings, even if condensation did not occur prior to renovation.

Dwelling occupants are becoming increasingly aware that good air quality at home can improve their health and well-being, especially after the COVID-19 pandemic, when ventilation was stressed as one of the main means of avoiding infection.

The use of air filters and cleaners in dwellings is not generalized.

2.3 Requirements on ventilation of non-residential buildings

Mandatory requirements on ventilation of non-residential buildings are set in the Reglamento de Instalaciones Térmicas de los Edificios (Regulation on thermal systems in buildings, RITE) [2]. The current version is from 2021.

These buildings must have a ventilation system for providing enough outdoor air flowrate that avoids, in rooms with human activity, the accumulation of high concentration of pollutants according to Table 2, that establishes four IAQ categories (IDA) depending on the use of the building. Procedure from EN 13779 [14] can be used to fulfil this requirement.

Table 2 : IAQ categories (RITE)

IAQ categories	Examples
IDA 1 (optimal)	Hospitals, kindergartens
IDA 2 (good)	Offices, museums, classrooms
IDA 3 (average)	Shops, cinemas, restaurants, gyms
IDA 4 (poor)	Laundry rooms

In order to fulfil such categories, RITE establishes 5 different methods for the calculation of the needed outdoor rate:

- airflow per occupant indirect method,
- airflow per net floor area indirect method,
- perceived air quality direct method,
- CO2 concentration direct method, and
- dilution method.

According to the airflow per occupant indirect method, for habitable rooms, minimum ventilation flow rates are set out for each IDA (See Table 3).

Table 3 : Minimum ventilation flowrates for each IDA (Table 1.4.2.1 of RITE)

IDA Categories	$dm^3/(s$ per person$)$
IDA 1	20
IDA 2	12,5
IDA 3	8
IDA 4	5

According to the net floor area indirect method, for non-habitable rooms, minimum ventilation flowrates are set out for each IDA (See Table 4).

Table 4 : Minimum ventilation flowrates for each IDA (Table 1.4.2.4 of RITE)

IDA Categories	$dm^3/(s\ m^2)$
IDA 1	Non applicable
IDA 2	0,83
IDA 3	0,55
IDA 4	0,28

The perceived air quality direct method is based on CR 1752 [15]. It is hardly used due to its complexity.

The CO_2 concentration direct method can be used for premises with a high metabolic activity (party halls, sport and leisure centres, etc.), as CO_2 is a good indicator of human bioeffluent emissions (See Table 5).

Table 5 : Indoor-outdoor CO2 concentration difference for each IDA (Table 1.4.2.3 of RITE)

IDA Categories	ppm (*)
IDA 1	350
IDA 2	500
IDA 3	800
IDA 4	1.200

* CO2 concentration (in parts per million by volume) above CO2 concentration in outside air

Dilution method follows the specifications established in EN 13779 [14]. When there are known emissions of specific polluting materials, the dilution method shall be used.

In addition to this, RITE establishes filtration requirements based on outdoor (ODA) and indoor (IDA) air quality, requiring efficient filtration systems in areas with poor air quality (ODA3) or high indoor standards (IDA1/IDA2). Air filters and purifiers have become key to maintaining healthy spaces, reducing airborne contaminants.

2.4 Ventilation systems in non-residential buildings stock and market

According to the Ministerio de Transportes, Movilidad y Agenda urbana (Ministry of Transport, Mobility and Urban Agenda, MITMA) the building stock in Spain for non-residential use is close to 2 million properties as stated by the statistics of the Catastro (Real Estate Cadastre).

Regulations and standards in Spain have had a considerable influence on the ventilation market, contributing to its sustained growth. During 2022, this market experienced a remarkable growth, mainly driven by the increasing awareness of indoor air quality and the regulatory updates in place.

The strictness in these regulations and standards not only define the standards for ventilation systems but may also be triggering the demand and growth of the ventilation market in Spain.

There is no specific information on the number of buildings in Spain that are equipped with a ventilation system. However, there are several regulations and recommendations regarding ventilation systems, which suggests that there is a significant focus on ensuring adequate ventilation in buildings.

As per a market analysis carried out by AFEC (Air Conditioning Equipment Manufacturers Association) [16]:

- the market in air distribution and diffusion increased by 19.7% from 2021 to 2022,
- the Air Handling Units and Ventilation Units market also increased by approximately 10% from that same period,
- the residential ventilation market and the industrial/tertiary ventilation market increased 13.7% and 17.5% respectively. These categories represent 20.3% of the total revenue in 2022 from HVAC products.

COVID-19 emphasized the importance of good IAQ, not only highlighting the crucial role of maintaining good ventilation but also propelled initiatives and a broader understanding among individuals and professionals about the significant impact that indoor air quality has on health and well-being, especially in enclosed spaces. This situation has raised awareness regarding indoor air quality, which is why many companies and organisations are including the need to renew and purify indoor air in their policies and procedures.

Society is becoming increasingly aware that good air quality in the workplace can improve the health, well-being, and productivity of occupants, improving worker's performance. Studies have shown the high economic costs in the loss of productivity and the cost in medical expenses due to poor air quality. This awareness of the importance of IAQ has skyrocketed the demand for services and products that improve IAQ and has enhanced the development of new ventilation and filtration technologies and placed greater emphasis on equipment maintenance. This coupled with new regulations, foresees a growth in the global market of indoor air quality control in the coming years.

Spain's market features mechanical filters such as HEPA, electronic filters (e.g., ionisers, precipitators), gas-phase filters (like activated carbon), and UVGI. The use of mechanical ventilation and autonomous equipment or filters in central air systems is encouraged in order to reduce the inhalation of aerosols in indoor spaces.

In the upcoming years, several changes are expected in ventilation and air filtration in Spain, manifesting a proactive response to the growing needs to optimise indoor air quality and energy efficiency. Increased adoption of advanced technologies, such as smart air conditioning, which contribute to the decarbonisation and sustainability of buildings, is expected. In addition, a boost in connectivity is expected to facilitate better measurement, regulation, control and monitoring of ventilation and filtration systems. All of this is geared towards energy efficiency, without overlooking the maintenance of optimal air quality, thus integrating innovative solutions that address both environmental and indoor health and comfort challenges.

3 National trends in energy requirements and market

3.1 *Energy requirements*

Mandatory requirements on energy saving are set in the Código Técnico de la Edificación (BuildingCode, CTE) in DB HE Ahorro de energía (Energy saving) [1].

DB HE aims to ensure that adequate conditions of habitability and comfort of its occupants are achieved by making rational use of energy, reducing its consumption to sustainable limits and ensuring that a large part of this consumption comes from renewable sources.

DB HE is applicable to newly constructed and existing buildings when certain interventions are carried out in them (extensions, change in use and renovations), grading the requirements accordingly. In the same way, requirements vary depending on use and climate, differentiating between private residential use and other uses as well as the different climate zones.

DB HE incorporates the latest updates of the Energy Performance of Buildings Directive [12] until 2021 and is currently in the process of revision to keep up to date to the latest version. The full transposition of the directive is further completed by other documents and procedures that implement calculation methods or develop a framework for the energy performance certificates (EPCs).

The DB HE consists of seven sections, each aimed at the different aspects of energy performance (energy use, energy needs, systems performance, renewable energy use and generation, sustainable mobility infrastructure). Sections HE 0, HE 1 and HE 2 are related to ventilation as described below.

Section HE0 deals with two global indicators related to energy use:

- total primary energy consumption ($C_{ep,tot,lim}$), which limits the total energy needs of the building, including energy from renewable sources (See Table 6),
- primary energy consumption from non-renewable sources ($C_{ep,nren,lim}$), which limits the use of energy from non-renewable sources (See Table 7).

Table 6 : Total primary energy consumption limits (DB HE, CTE)

Use	Type	Limit value $C_{ep,tot,lim}$ (kW·h/m²·year)					
		Winter climatic zone					
		α	A	B	C	D	E
Private residential	New buildings and extensions	40	50	56	64	76	86
	Renovations and change of use to private residential	55	75	80	90	105	115
Other	All	165+ 9·C_{FI}	155+ 9·C_{FI}	150+ 9·C_{FI}	140+ 9·C_{FI}	130+ 9·C_{FI}	120+ 9·C_{FI}

C_{FI}: Average internal load (W/m²)

Table 7 : Primary energy consumption limits from non-renewable sources (DB HE, CTE)

Use	Type	Limit value $C_{ep,nren,lim}$ (kW·h/m²·year)					
		Winter climatic zone					
		α	A	B	C	D	E
Private residential	New buildings and extensions	20	25	28	32	38	43
	Renovations and change of use to private residential	40	50	55	65	70	80
Other	All	70+ 8·C_{FI}	55+ 8·C_{FI}	50+ 8·C_{FI}	35+ 8·C_{FI}	20+ 8·C_{FI}	10+ 8·C_{FI}

C_{FI}: Average internal load (W/m²)

These indicators follow the methodology established in EN ISO 52000-1:2019 [17], with an hourly energy use calculation and a monthly balance. So far, only the used energy resources are evaluated (step A or export factor k_exp=0 in terms of EN ISO 52000-1), leaving the consideration of the positive impact of exporting energy (resources saved to the grid) for a later revision (export factor k_exp=1).

The impact of ventilation on these indicators comes both from the energy used to operate ventilation systems as well as from the energy needs due to air exchange with the outdoor environment (ventilation and infiltration).

Section HE 1 deals with the conditions to limit energy needs and includes specific provisions on ventilation and airtightness performance and characteristics. It states that buildings must be designed and constructed in such a way that they need little energy to achieve comfort conditions, according to its use and the climatic conditions of the environment, which may imply controlling the air permeability of the elements of the thermal envelope.

Specifically, the following requirements are established:

– in new buildings for private residential use of more than 120m², the air change rate at 50 Pa (n_{50}) shall not exceed the values set in Table 8,
– the air permeability at 100 Pa of windows and doors belonging to the building thermal envelope, shall not exceed the limit values ($Q_{100,lim}$) set in Table 9.

Section HE 2 deals with the performance of energy related systems (heating, cooling, domestic hot water (DHW), ventilation) referring to the *Reglamento de Instalaciones Térmicas en los Edificios* (Regulation on thermal systems in buildings, RITE). This includes minimum performance levels of fans or heat recovery systems, the transposition of the European Ecodesign regulations [18] and even the required ventilation levels for spaces other than dwellings.

Table 8 : Air change rate limits (DB HE, CTE)

Limit value of the air change rate at a pressure difference of 50 Pa n_{50} (h^{-1})	
Compactness[1] V/A (m^3/m^2)	**n_{50}**
≤2	6
≥4	3

The limit values for the intermediate compactness (2<V/A<4) are obtained by interpolation

Table 9 : Air permeability of windows and doors limits (DB HE, CTE)

Limit value for air permeability of openings in the thermal envelope $Q_{100,lim}$ ($m^3/h\cdot m^2$)					
Winter climatic zone					
α	**A**	**B**	**C**	**D**	**E**
≤ 27 (class 2)	≤ 27 (class 2)	≤ 27 (class 2)	≤ 9 (class 3)	≤ 9 (class 3)	≤ 9 (class 3)

The permeability shall be obtained taking into account, where applicable, the shutter box.
Permeability values established in UNE-EN 12207:2017.

3.2 Other drivers in energy performance

European strategy for the decarbonisation of the building stock sets the guide on which national energy saving regulations are established.

The current revision of the Energy Performance of Buildings Directive [12] establishes a scenario for the decarbonisation of the European building stock by 2050 with the aim of mitigating climate change by reducing greenhouse gas emissions. It sets a target for all new and existing buildings to be zero-emission by 2050, as well as a number of intermediate milestones, such as those committed to in the so-called European Green Pact [19], a consequence of the Paris Agreement, with a 55% reduction in net greenhouse gas emissions by 2030 compared to 1990 levels, and a further intermediate level by 2040.

The baseline scenario for the EU building stock from which to reach this target is as follows:

- 40% of the EU's final energy and 36% of its emissions are accounted for by buildings,
- 75% of the building stock is inefficient according to current building standards,
- buildings are responsible for about half of the primary fine particulate matter (PM 2.5) emissions in the EU, leading to premature deaths and illness.

With this starting point, the European strategy to decarbonise the building stock is based on increasing the rate and depth of building renovations, especially of the most inefficient building stock, as well as improving information on energy efficiency and sustainability, so that this information enables end-users and technicians to make more climate-friendly decisions.

In order to achieve this global objective of climate neutrality, aspects such as the definition of a zero-emission building must be specified. The Directive defines a zero-emission building as a building with a very high energy efficiency in which the small amount of energy that is still needed is fully covered by energy from renewable sources generated on-site, from a renewable energy community or from a district heating and cooling system in accordance with the requirements of Annex III.

Therefore, the difference between those defined so far by the Energy Efficiency Directive [20] (EED) as nearly zero-energy buildings and zero-emission buildings is that in the latter all the onsite energy use must come from renewable sources, whereas in the first one only most of it.

Other aspects of the decarbonisation strategy (as set out in the proposal to amend the EED and in Directive 2018/2001 on the promotion of the use of energy from renewable sources [21]) involve the generalisation of renewable production, taking into account the potential of buildings and on-site production, the transformation of mobility, which is also closely linked to buildings, the energy supply networks, which interact with buildings, especially the electricity grid, the potential for energy storage, etc.

The strategy and framework established by the directive on the energy efficiency of buildings is specified in milestones and requirements such as that new buildings must be zero-emission buildings by 2027, in the case of public buildings, and by 2030, in all other cases.

[1] Compactness (V/A): Ratio between the volume enclosed by the thermal envelope (V) of the building (or part of the building) and the sum of surfaces ($A = \Sigma A_i$) of the thermal envelope. For compactness calculations, the thermal envelope is the enclosure of the habitable spaces of a building with heat exchange with the outside air or ground. Therefore, interior partitions and the enclosures in contact with other buildings or with adjacent indoor non-habitable spaces are excluded.
For the calculation of volume, the volume of the floor slab is included.

In addition, existing buildings must become zero-emission buildings by 2050, with intermediate energy efficiency targets, the so-called MEPS (Minimum Energy Performance Standards), to allow a progressive approach.

3.3 *Changes over the last years & changes foreseen*

Energy saving requirements in Spain have undergone a significant evolution:

- Approved in 1979, the old Basic Building Standard on *Condiciones térmicas de los edificios* (NBE CT-79, Thermal conditions of buildings) [22] was only focused on controlling thermal insulation of the elements of the thermal envelope.
- Subsequently, in 2006, CTE was approved and since then DB HE defines, in addition to a minimum quality of the thermal envelope, a maximum limit to the energy needs of the building, a minimum efficiency of thermal and lighting systems, as well as a minimum use of energy from renewable sources. Ventilation and infiltration were indirectly impacted by overall energy needs limitations and only window permeability was directly regulated, but energy consumption for the ventilation service was not taken into account in residential buildings.
- In 2013 the first major revision of the DB HE takes place, adding a new section (HE 0) which expressly limits the non-renewable primary energy consumption of buildings, which limits energy use, and fully takes into account the impact of ventilation and infiltration both in energy needs and energy use.
- The 2019 update, the second major revision of DB HE, maintains the previous structure but adjusts its calculation methodology to European standards and completes the existing set of indicators and conditions (total primary energy consumption, solar control, air renewal rate...). This revision sets a limit on the thermal envelope air permeability.
- Finally, in 2022, the last modification takes place, which incorporates a new section (HE 6) introducing electromobility in buildings as established by the European directive.

The share of ventilation and infiltration in the energy consumption in the overall building energy consumption is increasing (it could reach up to 30%) due to more demanding ventilation requirements to ensure a healthy indoor environment, as well as to the progressive tightening of insulation levels, the lower impact of the heating, cooling and DHW services due to an improvement in the efficiency of its related technologies, a wider use of renewable energy sources and a reduced energy needs allowance led by energy saving regulations.

Thus, due to the great importance of ventilation (and infiltration) to control the energy consumption levels, the evolution of the DB HE is focused on several issues:

– adjustment of ventilation flow rates used in energy performance evaluation so they are more accurate and better reflect actual rates,
– optimisation of integration of demand-controlled ventilation systems in energy performance evaluation methods and simulation tools,
– increasing the thermal envelope airtightness, especially when ventilation techniques use heat recovery systems or their efficiency depends on airtightness.

4 National trends in the inspection of ventilation systems

4.1 *Requirements on the inspection of ventilation systems*

RITE (Regulation on thermal systems in buildings) regulates both initial and periodic assessments of ventilation systems. It is a mandatory regulation covering all buildings with thermal installations.

4.2 *Inspection protocols*

In Spain, inspections of thermal installations must be carried out by authorised companies or inspection entities. Inspection entities may inspect their own installations (first party), act on behalf of the buyer (second party) or represent a third party like an insurance company or the government. Accredited entities, complying with the EN ISO/IEC 17020 [23], provide maximum assurance of technical competence.

These inspections evaluate the system's integrity, cleanliness design adequacy, operational efficiency, and various parameters such as airflow, pressure, ductwork airtightness, power consumption, indoor air quality, noise levels, and thermal comfort parameters.

Heating, ventilation, and air conditioning systems should undergo inspections every four years, with a comprehensive check of the thermal installation every fifteen years. Maintenance must align with established schedules and equipment specifications. Part of the maintenance involves indoor air pollution measurements per UNE 171330 [24] and hygienic assessments of duct networks as per UNE 100012 [25].

These inspections rely on precise measuring devices capable of assessing air flow type and velocity, and air contamination levels. These devices must be user-friendly and accurate for optimal system tuning.

Detected non-conformities are classified by severity and managed through a methodology that includes detection, immediate repair, cause analysis, corrective and preventive actions, follow-up, and verification for effective resolution.

5 National trends in innovative systems and market

In Spain, innovation in ventilation systems focuses on improving indoor air quality, energy efficiency, acoustics, thermal comfort, installation, maintenance, and cost reduction, with a special focus on smart ventilation. Trends indicate a strong focus on digitalisation and energy transition, as well as advanced metering and monitoring of systems. The adoption of smart ventilation systems helps buildings to become more sustainable and healthier, with optimised energy use and increased comfort for users.

Innovation in the ventilation sector faces regulatory barriers such as strict energy efficiency standards, complex and costly certification processes, regional differences in regulations and lack of standardisation. These challenges could limit flexibility in the adoption of new technologies and slow down the introduction of innovative products to the market.

The potential of these innovations lies in their ability to significantly transform both the energy performance of buildings and the well-being of their occupants [15] [26] [27].

5.1 *Innovative systems and Building Code*

The *Código Técnico de la Edificación* (Building Code, CTE) [1] consists of two parts:

- Part 1, which contains the general provisions and conditions for the application of the CTE and the essential requirements with which buildings must comply, and
- Part 2, consisting of the Basic Documents, DBs, for compliance with the essential requirements of CTE. These DBs are based on the consolidated knowledge of the different construction techniques and include accepted or deemed-to-satisfy solutions.

Innovative systems may deviate to a greater or lesser extent from the accepted solutions of the DBs, but they must adequately justify compliance with the essential requirements of Part 1. This assessment may be conducted by means of a technical approval process.

In the case of innovative ventilation systems in dwellings, prior to the 2017 amendment to Section HS 3, compliance with the essential requirements could only be achieved by comparing its performance with the one provided by accepted solutions based on constant flow rates.

In 2017, the essential requirement was quantified as a function of CO_2 plus a minimum flow rate during non-occupancy. This made it easier for innovative systems to demonstrate compliance with CTE.

In the case of innovative ventilation systems in buildings other than dwellings, the RITE describes IAQ according to CO_2 concentration, so assessment can be conducted by comparing provided IAQ with it.

5.2 *Procedure for the assessment of innovative systems: National Technical Approval*

In Spain, there are three organisations authorised by the competent Public Administrations to provide technical approval assessments of the performance of innovative products or systems that facilitate the application of the CTE. These are the *Instituto de ciencias de la construcción Eduardo Torroja* (Eduardo Torrroja Construction Sciences Institute, IETcc), the *Institut de Tecnología de la Construcció de Catalunya* (Catalonia Institute of Construction Technology, ITeC) and the *Fundación Tecnalia Research & Innovation* (Tecnalia).

The *Documento de Idoneidad Técnica* (National Technical Approval, DIT) is a voluntary document which is issued by the IETcc that contains a favourable technical assessment of the fitness for use of non-traditional or innovative materials, products, systems or procedures in building and/or civil engineering [28].

In the field of ventilation systems, there are currently three valid DITs on humidity-controlled ventilation systems in dwellings. This system automatically regulates the amount of air intake and exhaust based on the relative humidity of the indoor air (strongly influenced by human presence and activity) and optionally by occupancy detection, always ensuring a minimum level of ventilation. Intake vents are located in dry rooms (living rooms, dining rooms, bedrooms) and exhaust vents in wet rooms (kitchens, bathrooms, toilets and laundry rooms).

The verification of compliance with CO_2 quantification and minimum flow rate of Section HS 3 is carried out through simulation under design conditions. Occupancy criteria are established based on the parameters outlined in Appendix C of Section HS 3, while also considering variations in outdoor temperature and humidity.

6 Impact of the COVID-19 pandemic

The COVID-19 pandemic has demonstrated the crucial importance of ventilation and air filtration in indoor spaces to prevent transmission of the virus. In Spain, several measures have been taken and recommendations have been provided to improve ventilation and air filtration in response to the pandemic. For example, the government published different manuals on recommendations for ventilation systems based on preventing the spread of COVID-19 [29]. Regarding the minimum flowrate of ventilation, it is recommended to achieve at least a value of 12.5 l/s per occupant, a condition that can be achieved by increasing ventilation or reducing occupation.

Far from going away with the pandemic, the importance of indoor air quality is here to stay and has pushed the ventilation market to continue to grow over the last years.

7 Other points of attention or trends: acoustics and ventilation

The importance of ensuring good IAQ in buildings together with adequate energy efficiency is unquestionable; however, the ventilation systems used to achieve this goal lead to the generation of noise for different reasons.

Traditionally, opening windows was the most common method in dwellings to ventilate causing discomfort due to noise from the outside.

As ventilation systems evolved with national regulation of IAQ, new noise-related issues arose. Firstly, the vertical stack in hybrid systems may transmit the noise from the roof-mounted communal extractor and the stack itself may acoustically connect two different users. Secondly, single-flow mechanical systems present noise problems as well derived from the extractor. In addition to this, in both cases, the air intake is enabled either through window vents or micro-ventilation, thereby compromising the sound insulation of the façade. Regarding window vents, it is crucial to ensure they maintain the sound insulation of the façade. As for micro-ventilation, which is a micro-opening lock to enable fresh air in, this results in a loss of acoustic insulation of the window estimated at 10 dB [30].

In more advanced ventilation systems, like Mechanical Ventilation with Heat Recovery systems (MVHR), the heat recovery unit is usually installed inside the ceiling of non-sensitive rooms such as corridors, hallways or kitchens, but noise problems can now arise from noise transmission through the ductwork to the grilles placed in living rooms and bedrooms and can therefore be a cause of noise annoyance and dissatisfaction, especially at night time. These systems may operate continuously 24 hours/day so attention must be paid in the planning, design and construction of MVHR to minimize possible noise transmission paths. Minimizing duct-borne noise is vital, as several studies revealed that occupants will turn off the ventilation equipment if they find the noise from the system annoying [31].

In Spain noise from service equipment is nationally regulated at the national level in Decree RD 1367/2007 [32] [33] and locally through regional decrees and ordinances. Mandatory requirements on building acoustics are set in the CTE in DB HR *Protección frente al ruido* (Protection against noise) [1] referring to the above-mentioned decree regarding noise from service equipment. RD 1367/2007 sets out limit values for sound pressure levels due to building services and describes the noise measurement and assessment procedure, which also applies to ventilation noise. This decree is currently under revision in order to improve its applicability based on the experience of technicians and administrations gained during the years.

The scope of this decree extends to residential and non-residential buildings (administrative, health/hospital and cultural/educational use).

Requirements for sound pressure levels [34] [35] are established differently for the day (07-19h), evening (19-23h) and night (23-07h) periods, which is not common in other European countries. Table 10 shows, as an example, limit values for noise transmitted in dwellings due to building service equipment (extracted from RD 1367/2007-Table B2).

Table 10 : Noise limit values transmitted in dwellings due to building service equipment

Building use	Type of room	Noise limit values for building service equipment L_k (dBA) $L_{K,day}$	$L_{K,evening}$	$L_{K,night}$
Residential	Living rooms	40	40	30
	Bedrooms	35	35	25

The noise parameter used is $L_{Keq,T}$ which is the equivalent continuous sound pressure level where "T" stands for the time period and "K" indicates that the level has been corrected due to tonal, low frequency and impulsive components.

The assessment procedure in RD 1367 consists of a series of measurements of different noise parameters to be made to obtained noise levels and shows how the corrections have to be calculated.

In general, most European building regulations and their acoustic classification schemes refer to the ISO standards ISO 10052 [36] and ISO 16032 [37] for the measurement of sound pressure levels of ventilation systems, but some of them apply additional methods for low-frequency noise and corrections for pure tones, impulses and intermittent noise.

Measurement and assessment procedures in RD 1367 are different from these standards.

8 Conclusion

IAQ regulations in Spain are performance-based leading the most advanced regulations in the world. The IAQ requirement in dwellings is identified in terms of CO_2 concentration as an indicator. The main advantage of performance-based regulations is that they allow the use of innovative, energy efficient systems to fulfil the requirement. The requirements may be met through the utilisation of simulation or the implementation of minimum ventilation flow rates, which have been established as accepted solutions (see Table 1).

Ventilation market in Spain is a relatively recently arisen one but is strong and keeps increasing.

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10 Appendix

10.1 *Example of mandatory flowrate for typical buildings*

10.1.1 Dwellings

In this section some case studies of dwellings are presented with the design ventilation flowrates obtained according to the accepted solution included in CTE, based on minimum constant ventilation flowrates (l/s) using Table 1.

However other flowrates could be possible if simulation methods were used, as long as they fulfilled the performance-based requirements regarding CO_2 concentration.

Case study 1:

House of 90 m² (2.5 m height), 1 living room, 3 bedrooms (1 master (2 adults), 2 kids), 1 kitchen, 1 bathroom and 1 toilet.

Minimum constant ventilation flowrates (l/s) for a 3-bedroom house are displayed in Table 11.

Table 11 : Minimum flowrates for case study 1 (pre-balance)

Rooms	Q per room (l/s)		Total Q (l/s)
Living-room	10		Supply: 26
Master bedroom	8		
Bedroom 1	4		
Bedroom 2	4		
Kitchen	8	24	Exhaust: 33
Bathroom	8		
Toilet	8		
All wet rooms	33		

Because extraction and supply flowrates must be balanced, the design ventilation flowrate for the whole house is considered to be the highest value between them: 33 l/s. For the obtention of the design flowrates for each room this ventilation flowrate must be distributed among all the rooms, according to an assessment of the possible flow which takes into account the layout of the house, position of windows and inner doors, etc. (See example of balanced flows in Table 12).

Table 12 : Design flowrates for case study 1 (balanced)

Rooms	Q per room (l/s)	Total Q (l/s)
Living-room	12	Supply: 33
Master bedroom	11	
Bedroom 1	5	

Bedroom 2	5	
Kitchen	11	Exhaust : 33
Bathroom	11	
Toilet	11	

Case study 2:

Apartment of 50 m², 1 living-room, 1 bedroom, 1 kitchen open to the living-room, 1 bathroom.

Minimum constant ventilation flowrates (l/s) for a 1-bedroom apartment are displayed in Table 13.

Table 13 : Minimum flowrates for case study 2 (pre-balance)

<table>
<tr><th>Rooms</th><th colspan="2">Q per room (l/s)</th><th>Total Q (l/s)</th></tr>
<tr><td>Living-room</td><td colspan="2">6</td><td rowspan="2">Supply: 14</td></tr>
<tr><td>Master bedroom</td><td colspan="2">8</td></tr>
<tr><td>Kitchen</td><td>6</td><td rowspan="2">12</td><td rowspan="3">Exhaust: 12</td></tr>
<tr><td>Bathroom</td><td>6</td></tr>
<tr><td>All wet rooms</td><td colspan="2">12</td></tr>
</table>

The ventilation flowrate for the whole house is 14 l/s. An example of the balanced design flowrates for the rooms is displayed in Table 14.

In the case of a kitchen that opens onto the living-room, extraction must be provided in the area of the kitchen, and supply in the area of the living-room.

Table 14 : Design flowrates for case study 2 (balanced)

Rooms	Q per room (l/s)	Total Q (l/s)
Living-room	6	Supply: 14
Master bedroom	8	
Kitchen	7	Exhaust: 14
Bathroom	7	

10.1.2 Non-residential

In this section, some case studies of non-residential buildings are presented with the ventilation flowrates obtained according to the accepted solution included in RITE, based on minimum constant ventilation flowrates (l/s) using Table 2 and the indirect method from the number of occupants, in which the flowrate is calculated according to Table 3.

Case study 3:

A classroom of 50 m² with 25 students, 1 teacher.

For classrooms, the minimum IDA is 2 and the design flowrate is 325 dm^3/s.

Case study 4:

An office of 12 m² with 1 occupant.

For offices the minimum IDA is 2 and the design flowrate is 12.5 dm^3/s.

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