Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Legal regulation of ventilation rates in homes in Europe 2010–2022: Evolution and comparison study regarding Covid-19 recommendations

Rafael González-Sancha a, David Marín-García a,*, Manuel Duarte-Pinheiro b, Miguel José Oliveira c

a Department of Graphical Expression and Building Engineering, Higher Technical School of Building Engineering, University de Seville. 4A Reina Mercedes Avenue, Seville, 41012, Spain
b Department of Civil Engineering, Architecture and Georesources (DECivil) of Higher Technical Institute (ITS), CERIS, Universidade de Lisboa, Avenida Rovisco Pais 1, 1049-001, Lisboa, Portugal
c Higher Institute of Engineering, University of Algarve, 8005-139, Faro, Portugal

ARTICLE INFO

Keywords:
Ventilation
Dwellings
Regulations
Pandemic
Europe
SARS-CoV-2

ABSTRACT

The airborne transmission of SARS-CoV-2, the virus that causes Covid-19 disease, has been recognized as an essential route of contagion, so adequate ventilation is vital indoors. For this reason, the research goal focuses on carrying out the study and evolutionary and comparison analysis of the regulation of ventilation rates in dwellings in Europe (2010–2022) and on determining whether modifications are necessary for the said regulation based on the recommendations of competent international organizations. To do this, the methodology followed initially starts from the study carried out in 2010 by Christine Dimitroulopoulou, in which the existing regulation in various European countries regarding ventilation in dwellings was studied. Once this study has been analysed, it continues to update and compare the regulation of the different European countries cited in the said work, detecting during the process if a modification is necessary based on the recommendations indicated by international organizations such as the WHO or ECDC. The results and conclusions indicate that few countries have significantly changed their ventilation rates. Although the existing ones may be admissible, requiring controlled ventilation in the different regulations would be convenient.

1. Introduction

Historically, ventilation of inhabited spaces has been an aspect of interest on numerous occasions, as is the case in Ancient Greece, Rome (Hippocrates, 460-377 B.C.) or Egypt [1–5].

Despite that, in the Middle Ages, there was a setback that had a notable impact on the health of the population.

Later, attempts were sometimes made to remedy this situation with more height from floor to ceiling or with windows that are taller than they are wide, among other solutions [2].

However, it is not until well into the Modern Ege that a clear scientific concern for ventilation in dwellings appears. This is because even around 1700, the actual function of respiration was still unclear, although it was already known that expired air was not suitable for breathing.

Thus, the studies by Lavoisier (1781) concerning the importance of oxygen in respiration should be highlighted.

Boyle (1627–1691) and Hooke (1635–1703) 100 years earlier than Lavoisier (1667) already indicated how essential it was to supply clean air to the lungs.

Thanks to these studies from the 19th and especially the 20th century onwards, the need to renew indoor air and the importance of CO₂ level as an indicator of the adequate quality of air to breathe became apparent [1–5], highlighting, among others, Max J. Pettenkofer (1818–1901), that although he still defended some erroneous concepts, he established CO₂ levels above 1000 ppm as unacceptable indoors with several people in them.

Thus, in 1836 Thomas Tredgold calculated that a person needed at least 2 l/s of fresh air to breathe and light candles, and later the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), founded in 1894, based on the study carried out by John Billings (1836–1913) he recommended in 1895 as a minimum ventilation rate of 15 l/s per person [2].

Since then, ventilation has been a focus of interest from a medical

* Corresponding author.
E-mail address: damar@us.es (D. Marín-García).

https://doi.org/10.1016/j.buildenv.2022.109696
Received 25 July 2022; Received in revised form 6 October 2022; Accepted 9 October 2022
Available online 26 October 2022
0360-1323/© 2022 Elsevier Ltd. All rights reserved.
point of view (avoid diseases and their spread) and from a technical point of view (avoid discomfort, odours and gases that can disturb the comfort and well-being of the inhabitants of the buildings).

From a medical point of view, after the appearance of SARS-CoV-2, ventilation in the building field has been recognized as one of the resources to use to combat this problem [6], especially in residential buildings, since it is in dwellings where one of the highest levels of transmission and contagion occurs [7].

From this technical point of view, it should also be noted that ventilation rates have been affected in recent years by the trend towards more and more airtight houses to reduce heat losses.

However, concern for indoor air quality (IAQ) remains centered [8] maintaining thermal comfort [9] and at the same time trying to reduce energy consumption (nearly zero consumption building) [10].

Ventilation is identified with adequate air renewal in a room to maintain its quality [11] while comfort and desirable energy efficiency [12], making it possible to do it using any of the following systems commonly used in buildings [13]: i) Natural ventilation [14], which is a simple passive solution, low cost and with various techniques to apply commonly used in buildings [13]; ii) Mechanical or forced ventilation [11], usually a fan (or extractor) [14] with which, although the cost is higher, better air rates are achieved compared to natural ventilation [14]; iii) Hybrid ventilation: air renewal occurs as in natural ventilation and, when unfavourable, as in mechanical extraction ventilation [11,14].

In addition, for any study of ventilation, three basic elements must be known: i) Ventilation rate (m³/hr, l/s or ACH), that is, the volume of outside air that is supplied to the space or ACH (air changes per hour); ii) Air flow direction, that is, the path of airflow in buildings and spaces, which must be from clean areas to dirty areas; iii) Air distribution or airflow pattern. Outdoor air must be delivered to each part of the space and airborne contaminants generated in each part of the space must be removed effectively and efficiently.

It is evident that the “Air flow direction”, as well as the “Air distribution or airflow pattern”, are parameters that can favour or hinder achieving adequate ventilation.

However, ACH (Air Renewals per Hour) air renewal and its translation into ventilation rates usually attract interest for regulatory purposes and for this reason this study will focus on it. This is because the ventilation rate is defined as the exchange of a volume of air per unit of time and, in the case of ACH, each air renewal per hour means that in 1 hour, a volume of outside air is introduced equal to the volume of interior space that is being ventilated, which does not mean that with a single ACH the interior air has been completely eliminated by exterior air since due to mixing and other factors it is not possible in most cases.

Nevertheless, the other factors or parameters (“Airflow direction” and “Airflow distribution or airflow pattern”) must be such as to guarantee the ventilation rate (with adequate ACH) that indicates the regulation.

For it, although it is not the object of this study for the stated reasons, it should be noted that the design, dimensions, equipment and characteristics of the building, the dwelling and each of its partitions [16], as well as its envelope, are closely related to the possibility of achieving an adequate rate of ventilation, also taking into account the activities, people present and the required environmental conditions (temperature, humidity, etc.).

On the other hand, in terms of the need to regulate ventilation in dwellings with respect to other interior spaces, it should be noted that it is of great importance that it is the place where most people spend the longest time throughout their lives [17] and therefore fluid dynamics that lead to insufficient air quality should not be admissible [18].

Thus, there are previous studies of indoor ventilation [19–22], some even making comparisons between the minimum regulated ventilation and the real one [23].

Recently, the regulations on ventilation and its adaptation to the demands of Covid have been studied in some specific countries [24,25]. It is true that at the beginning of the pandemic, the WHO itself was slow to recognize airborne transmission, via aerosols [26].

However, after advances in research and the appearance of evidence on airborne transmission [27], this route was recognized, and its higher incidence indoors, as is the case in dwellings, and how it can be reduced with adequate ventilation.

Nonetheless, although there are numerous studies on the relationship between ventilation in residential buildings and dwellings and the risk of transmission of SARS-CoV-2 and viruses with similar behavior [28,29], no studies have been detected regarding the regulation of ventilation in dwellings in Europe from the point of view of its evolution and updating from 2010 to 2022 and its relationship with the SARS-CoV-2 pandemic, or viruses that cause illnesses ranging from common cold to pneumonia, Middle East Respiratory Syndrome (MERS), and Severe Acute Respiratory Syndrome (SARS).

In addition, except for specific cases of specific countries [24,25], no studies have been detected in this area on the level of need for a modification of said regulation based on the recommendations made by competent international organizations, especially to avoid the high mortality rates that led to the application of legislation never used to date [30].

That is why it is necessary to advance the study of legal regulation so that it considers effective measures that in the future help alleviate the effects of the pandemic suffered in the future.

For this reason, the fundamental goal of this research is the study of the different variations of the ventilation rate in dwellings in Europe, and more specifically, its evolution and update from 2010 to early 2022, making a comparison between European countries, to detect if a modification is necessary based on the recommendations indicated by the World Health Organization (WHO) and the European Center for Disease Prevention and Control (ECDE).

2. Methodology

The methodology (see Fig. 1) has focused on the search for information on housing recommendations and regulations in Europe in the last decade, from which conclusions have been deduced on which to rely as a reliable guide around the issue of ventilation, thus helping to obtain a more appropriate legal framework.

Once the search has been carried out, the work focuses on carrying out a comparison study between the current regulations and the recommendations related to the circumstances originating from the year 2019 with the appearance of Sars-CoV-2, to, through this comparison, get results and develop discussions with conclusions in this regard.

In relation to the countries analysed and the reason why not all countries in the European Union are addressed in this document, it should be noted that it is a representative sample of European countries with different climatology, but whose regulation is more related to ventilation directives, as already indicated in the study carried out by Christine Dimitroulopoulou [22] and which has served as a starting point for this research.

Regarding the documentary sources (normative) that were consulted, it starts from “EUR-Lex” in which there are texts published in the Official Journal of the European Union, Jurisprudence of the Court of Justice of the European Communities and documents of the Commission, etc. From each country in particular, official gazettes, bulletins, etc., as well as informative documents were consulted to detect the corresponding legal texts. Subsequently, the appropriate data were studied and extracted according to the purpose of the investigation. It should be noted that some of them were difficult to locate and payment was required to obtain them.

Finally, the criteria used to compare the regulations of the different countries were based on objective technical issues (fundamentally related to the quantification of ventilation rates), but also subjective ones related to other factors evaluated by recognized institutions (international and national entities and organizations).

Regarding how documentary sources were processed and how data
3. Results

3.1. WHO and ECDC recommendations on ventilation rates to avoid risks related to the transmission of the virus that causes Covid-19

Since it is a disease that spreads in the air with some ease, the WHO has recommended a series of measures [32], which focus on avoiding the permanence of people in places with poor or no ventilation, indicating the need to strengthen ventilation and renewal of outside air, maintaining of the flow.

In addition, at the European level, the European Center for Disease Prevention and Control (ECDC), in its document on heating, ventilation and air conditioning (HVAC) in the context of Covid-19 [27], offers a guideline on indoor ventilation.

This document encourages an increase in adequate maintenance of the facilities and the deviation of airflow to avoid the dispersion of pathogens.

It is also a supporter of controlling the entry-exit of air with adequate heat exchangers and properly maintained, without recirculation that could cause transmission risk.

On the other hand, it urges the implementation of technical standards that recommend minimum criteria related to the logistical design of closed spaces, including the physical location of mechanical ventilation systems.

This document even indicates the need to act based on scientific evidence and technical knowledge.

Finally, it leans more towards the use of mechanical or forced ventilation and towards avoiding sustained airflow for stationary people.

3.1.1. Recommendations of the WHO

The World Health Organization provided a complete set of recommendations in the “Roadmap to improve and ensure good indoor ventilation in the context of Covid-19” [34].

This document focuses on the need for a well-designed, maintained and operated system, specifically regarding residential settings and the rapid identification of Covid-19 cases, their isolation and management to reduce the risk of transmission in dwellings whenever a person is under care or home quarantine.

Also, the document focuses primarily on the isolation area and more specifically on the space or room identified for home care or self-quarantine, following the assumption that these zones can be considered separate spaces.

Fundamentally, what is offered are strategies and how to plan them. Almost all of these strategies are not meant to be considered for the entire residential area, but only for the isolation space.

However, all these strategies and their corresponding planning ultimately aim that, whether in the case of natural ventilation or cross ventilation, the minimum ventilation rate is 10 l/s/person (EN 16798-1) within the isolation area [34].

3.1.2. Recommendations of ECDC

Regarding the recommendations issued by the ECDC for ventilation expressed in the document “Heating, Ventilation and Air-Conditioning Systems” [33], the recommendations are compiling to respond to a guide on heating, ventilation and air conditioning (HVAC) systems in closed spaces in the context of Covid-19.

These guidelines are designed to carry out controls in closed spaces, the most important being to avoid the recirculation of untreated air whenever possible, considering the energy efficiency of HVAC systems and, if feasible, the use of natural cross ventilation. It also indicates that the minimum number of air changes per hour (ACH) must be guaranteed, which according to the ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers), is between 7 and 10 l/s per person [35].

On the other hand, from the said documentation [33], it is worth highlighting the Annex A1 of the ECDC national guidelines for heating, ventilation and air conditioning (HVAC) systems in EU countries and the UK in the context of Covid-19, supplemented by guidance from other regions.

Table 1

| Belgian | Norwegian |
|---------|------------|
| **Configuration** | **Air changes per hour (ACH)*** | **Hour of pollution reduction by 90%** |
| Closed windows without mechanical ventilation | 0.1–0.5 | 5–25 h |
| Slanted window (one side) | 1–2 | 1 h 15 min - 2 h |
| Room without windows with vent. mechanics | 4 | 37 min |
| Room without windows with increased vent. Mechanics | 8 | 20 min |
| Windows wide open | ±10 | 15 min |
| Windows wide open, on opposite walls | ±40 | 5 min |

* It takes at least 2.5 ACH to change at least 90% of the air in a room in Norway.
countries and international professional associations.

Regarding ventilation rates, except in Norway, in the annexe, there is no mention of specific rates in l/s and recommendations can only be observed in Belgium regarding air changes per hour (ACH) depending on the windows (Table 1).

In relation to these guidelines, the following general nuances should be highlighted: i) Some of the WHO and ECDC ventilation guidelines are sometimes not applicable in practice to conditions in certain locations, as is the case in Nordic countries, especially regarding the recommended degree of ventilation, indoor temperature and humidity; ii) From this document it can be deduced, specifically in Norway [33], and generally for all countries, that at least air changes must be maintained at 7 l/s per person in the room [35].

3.2. Evolution of ventilation regulation in dwellings in Europe in the last decade

In Europe, the regulation of ventilation in dwellings has been developed in each country following its criteria and, in some cases, certain guidelines of the European Union.

Table 2 shows the 2010 regulations [22] and those in force in 2022, relative to the member states that have been the subject of the study.

The regulations initially compiled have been taken from the study published in 2011 by Chrysanthe Dimitrouloupolou [22], being updated by the authors of this research for 2022.

In this work, it is worth noting the difficulty that this task has entailed because some of these standards are available at prices that could make their acquisition difficult for some citizens. This is not recommended, at least, when it comes to mandatory standards.

Regarding the countries chosen, there are 14, and it is understood that they are suitable for this study because they have developed their normative guide with different reference values regarding the matter to be dealt with.

Since this research focuses on ventilation rates, Figs. 2 and 3 show the summary of the rates contemplated in the regulations of the countries studied in 2010 and 2022, respectively. Fig. 4 shows the increases in ventilation rates contemplated in the regulations of the countries analysed between 2010 and 2022.

Although this research focuses on ventilation rates, the aforementioned regulation of each country also usually includes a series of particularities regarding said ventilation and its rates. Tables 3 and 4 reflect these with respect to the rates included in Figs. 2 and 3 for 2010 and 2022, respectively.

4. Analysis and discussion

Considering the proposed objective, the evolutionary analysis of ventilation rates by country is carried out below. For ease of understanding, Table 5 presents the results of the analysis in a condensed form.

After analyzing the data obtained (Table 5) within the scope of the objective set in this work, the following considerations are made:

In Belgium, the rates have been maintained because the Belgian regulation “NBN D 50-0001 1991 Dispositifs de ventilation dans le bâtiments d’habitation” is still in 2022, according to the Office of Standardization (NBN), which is responsible for developing standards in Belgium. Regulations present a low rate of ventilation in some rooms compared to others, such as the living room, which may be risk areas.

Even so, another Belgian entity, the Federal Public Service for Health, Food Chain Safety and the Environment, has drawn up and published a series of recommendations called “Practical recommendations for monitoring ventilation and air quality in Covid-19” [37] that the rates mentioned in the mentioned regulation do not vary, but indicate prevention practices to reduce risk.

These recommendations aimed at combating the Covid-19 pandemic contain a practical guide for implementing and monitoring ventilation and indoor air quality, trying to prevent the spread of the coronavirus and minimize its presence within spaces.

Therefore, the same ventilation rates have been maintained in this country, but with the recommendation to follow the instructions given by the federal public service until the pandemic is considered over in Belgium.

Regarding the Czech Republic, certain stability of the ventilation rates is observed between 2010 and 2022. However, it has not been possible to collect much data.

In Denmark, as can be seen in Table 5 compared to the year 2010, in the year 2022, the ventilation rates have changed in terms of obtaining them according to the type of ventilation and according to the room in question, being somewhat lower for rooms in residential buildings and changed in very large rooms, storage rooms and the like.

The regulations present a low ventilation rate in some rooms, which may be risk areas. However, authorities have considered and, in some cases, recommended or imposed the recommendations of WHO and ECDC [58].

As far as Finland is concerned, the ventilation rates have hardly
changed since 2010, where they are currently still governed by the same regulations.

The regulations present a low ventilation rate in some rooms compared to others, which may be risk areas.

Even so, this country follows the recommendations of Finland Institute of Health and Welfare, with a flow rate of 10 l/s/person, avoiding return air and airborne transmission of the coronavirus from one space to another where it should move, always from clean facilities to dirty ones.

Regarding France, the regulations on dwelling ventilation in 2022 are similar to those of 2010 but, as can be seen in Table 5, with certain differentiating nuances. Thus, since 2010 a rate has been contemplated for the entire building based on the number of habitable rooms (R) up to a maximum of 7 rooms.

In 2022 the ventilation rate values do not vary from 5 rooms or more. However, although some issues related to the number of environments or the minimum flow extracted are introduced, no significant variations are observed.

It can be seen that between 2010 and 2022, a regularity between rates has been maintained despite restrictions due to Covid-19. The regulations present a ventilation rate in some rooms that can be improved. However, much effort was made to follow the recommendations of the WHO and ECDC.

As for Germany, where ventilation rates in 2010 are set based on the occupants, compared to the year 2022, the rates are similar.

The regulations present a low ventilation rate in some rooms compared to others, such as the living room, which may be risk areas, but it must be taken into account that once this study was completed, the imminent publication of an update to DIN 18017 was detected in Germany, so it has not been possible to include it and it should be the subject of future studies.

However, to combat the new virus, external volume flows have been modified, the calculation algorithm and hygiene requirements of home ventilation systems have been adapted, as well as the operation of chimneys (vertical ducts) with natural ventilation systems (cross ventilation, well ventilation), or mechanical ventilation systems and their combinations in terms of compliance with the necessary indoor air quality, in each case with the guarantee protection against moisture.

As far as Greece is concerned, there have been no major changes. Thus, the Greek Legislative Framework Document of Reference specifies rates m3/h/person for complete housing and for rooms, which being somewhat lower in some rooms, which should make one wonder if this is convenient. However, due to the pandemic, the authorities have promoted monitoring of the protocols and recommendations made by the WHO and the ECDC regarding the interior ventilation of dwellings.

Concerning Italy, ventilation rates in 2010 and in 2022, are similar and present a low rate of ventilation in some rooms compared to others, which may be risk areas. But more restrictions are introduced due to the global pandemic. The recommendations given by the competent authorities (WHO and ECDC) are followed, which indicate rates of 11 m3/h per person according to the UNI 10339 standard (Ente Nazionale Italiano de Unificazione, 1995): “Hydraulic systems for healthcare purposes: generalization, classification requirements and standards” that establish the reference for the design of ventilation installations.

On the other hand, some indications of other standards from other neighboring countries are taken as a reference in terms of other parameters related to ventilation control, such as CO2 levels [59].

Regarding the Netherlands, ventilation rates in 2010 and 2022, are similar and present a low rate of ventilation in some rooms compared to others, which may be risk areas. However, as in most countries, the authorities follow the recommendations of the WHO and ECDC without changing the standard that specifies these rates.

In terms of Norway, between 2010 and 2022, there is a significant
The peculiarities of each country related to ventilation and its rates according to the existing regulation in 2010.

| Countries      | Rates set by the BBR2014 standard, where for the living room and for the bedroom, it is in l/s per m². Rest of spaces with rates according to regulations of the year 2010. | Table 4 The peculiarities of each country related to ventilation and its rates according to the regulations in force in 2022 compared to 2010. |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Belgium        | Same rate as 2010 due to the current validity of the standard. Rooms measured in l/s per m².                                                                                                          | Countries                                                                                                                          |
| Czech Republic | We do not have specific data, but rates similar to the year 2010.                                                                                                                              | Belgium                                                                                                                          |
| Denmark        | Rates of 0.3 l/s per m³ for all rooms according to standard DS 411:2011 + 1:2020.                                                                                                               | Czech Republic                                                                                                                     |
| Finland        | Same rate as 2010 with a recommended flow rate of 10 l/s/person.                                                                                                                               | Portugal                                                                                                                          |
| France         | Same rate as 2010 due to the current validity of the standard.                                                                                                                                   | Norway                                                                   |
| Germany        | Same rate as 2010. However, once this study was completed, the imminent publication of an update to DIN 18017 was detected in Germany, so it has not been possible to include it and it should be the subject of future studies. | Portugal                                                                                                                          |
| Greece         | Same rate as 2010 due to no major changes.                                                                                                                                                         | Spain                                                                         |
| Italy          | Same rate as 2010 but with more restrictions.                                                                                                                                                     | Spain, UK                                                                       |
| Netherlands    | Same rate as 2010 but following recommendations of competent bodies in the matter.                                                                                                                | Tables 2.1 of the DB HS3 aforementioned.                                                                                           |
| Norway         | Rates depend on the standard (Norwegian Code of 2021).                                                                                                                                             | For 2022, higher rates are observed in the living room and bedroom. It is necessary to consider the update made by the CTE in the same document (DB-HS3) in 2017.   |
| Portugal       | Same rate as 2010 but following recommendations of competent bodies in the matter.                                                                                                                | In Sweden, the regulations of 2010 and 2022 in their reference to the rates have not varied significantly in general terms.       |
| Spain          | The rates are based on the modification of the Basic Document HS 3 health regulations in Table 2.1. For the living room, a rate in l/s has been chosen, the same as for the bedrooms, where the rate is set according to the type of dwelling (3 or more bedrooms). As for the kitchen, the rate is set according to the current validity of the standard. | Therefore, the regulations present a low ventilation rate in some rooms compared to others, which may be areas of risk. However, the recommendations of the WHO and the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) have been followed de facto. |
| Sweden         | Rates set by the BBR2014 standard, where for the living room and for the bedroom, it is in l/s per m². Rest of spaces with rates according to regulations of the year 2010. | For 2022, higher rates are observed in the living room and bedroom. It is necessary to consider the update made by the CTE in the same document (DB-HS3) in 2017.   |

In construction, the transmission of SARS-CoV-2 through aerosols and its relationship to ventilation, especially in closed places, has been one of the most worrying problems in this field.

Thus, the inclusion in the normative regulation of measures to...

Increase in ventilation rates, especially in the living room and bathrooms, although previously they were very low compared to other countries. In this country there has been a significant change, because there is a ventilation rate of 7 l/s per person in the room and a CO₂ (minimum of 20%–30% depending on the time of year) that must not exceed 1000 ppm. There are the same rates for the kitchen and bathroom with WC and only WC, the but the ECDC recommendations are considered. The use of filters and HVAC ventilation systems is important.

In the case of Portugal, it is a country where both the rates for 2010 and 2021-22 are practically the same. The regulations present a ventilation rate that is understood to be balanced. Additionally, when the coronavirus entered the scene, this country continued with the measures recommended by the competent authorities to mitigate Covid-19.

Concerning Spain, the ventilation rates are in the specific regulations based on the Basic Documents (DB) of the Technical Building Code (CTE) of 2006, specifically in the Basic Document HS Health, and within this, the DB–HS 3 Indoor air quality. Which, the rates of interest for the year 2010 are from 2006. CTE admits a ventilation rate based on a
Table 5
The main results of the analysis in a condensed form.

**BELGIUM**
The ventilation rates between 2010 and 2022 are similar (See Figs. 2-4).

**CZECH REPUBLIC**
The ventilation rates between 2010 and 2022 are similar (See Figs. 2-4).

**DENMARK**

| Year | Ventilation rates | 2.4 cm³/m² for natural ventilation and 1.2 cm³/m² for mechanical ventilation, 0.3 l/s m² for all rooms in residential buildings and 0.18 l/s m² for very large rooms, storage rooms and the like. |
|------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2010 |                    |                                                                                                                                  |
| 2022 |                    |                                                                                                                                  |

**FINLAND**
The ventilation rates between 2010–2022 are similar (See Figs. 2-4).

| Number of habitable rooms (R) | m³/h | The whole building | K. with intermittent ventilation 2010–2022 | Shared BR. or showers or not and with WC 2010–2022 | Another BR. 2010–2022 | Number of BR. Unique Multiple |
|-------------------------------|------|-------------------|---------------------------------------------|-----------------------------------------------------|------------------------|-------------------------------|
| 1 (2010-2022)                 | 105  | 75(min 35)        | 15                                          | 15                                                  | 15                     | 15                            |
| 2 (2010-2022)                 | 120  | 90(min 60)        | 15                                          | 15                                                  | 15                     | 15                            |
| 3 (2010-2022)                 | 150  | 105(min 75)       | 30                                          | 15                                                  | 15                     | 15                            |
| 4 (2010-2022)                 | 165  | 120(min 90)       | 30                                          | 15                                                  | 15                     | 15                            |
| 5 (2010)/5 and more (2022)    | 210  | 135(min 105)      | 30                                          | 15                                                  | 30                     | 30                            |
| 6 (2010)                      | 210  |                   | -                                           | -                                                  | -                      | -                             |
| 7 (2010)                      | 210  |                   | -                                           | -                                                  | -                      | -                             |

Number of environments (2010–22)-Total minimum flow (m³/h)

| Number | Total | 10 | 10 | 15 | 20 | 25 | 30 | 35 |
|--------|-------|----|----|----|----|----|----|----|

**FRANCE**
The ventilation rates between 2010 and 2022 are similar (See Figs. 2-4). However, once this study was completed, the imminent publication of an update to DIN 18017 was detected in Germany, so it has not been possible to include it and it should be the subject of future studies.

| People | Surface | Natural Mechanics |
|--------|---------|-------------------|
| Up to 2 | ≤50 m²  | 60                |
| Up to 4 | –       | 90                |
| Up to 6 | >80 m²  | 120               |

**GERMANY**
The ventilation rates between 2010 and 2022 are similar (See Figs. 2–4). However, once this study was completed, the imminent publication of an update to DIN 18017 was detected in Germany, so it has not been possible to include it and it should be the subject of future studies.

| Room type | Volume | 8 m³ | >11 m³ | >15 m³ | >22 m³ | ≤8 m³ | ≤11 m³ | ≤15 m³ | ≤22 m³ | ≤30 m³ |
|-----------|--------|------|--------|--------|--------|-------|--------|--------|--------|--------|
| K. and other appliances for gas installation | (a1)   | 17 l/s (60 m³/h) | 25 l/s (90 m³/h) | 33 l/s (120 m³/h) |
| Sanitary facility | With a BR or shower | 13 l/s (45 m³/h) | 17 l/s (60 m³/h) | 25 l/s (90 m³/h) | (a2) |
| Without BR or shower | 8 l/s (30 m³/h) | 13 l/s (45 m³/h) | 17 l/s (60 m³/h) | (a2) | (a2) |

(continued on next page)
promote the highest possible ventilation should be encouraged, and above all, the indications at least of the WHO (World Health Organization), the ECDC (European Center for Disease Prevention and Control), the REHVA (Federation of Associations Heating, Ventilation and Air Conditioning) and non-European organizations such as ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers).

Regarding the ventilation rates in 2010 and their comparison with 2022, it is understood that they suffered little variation in most of the countries analysed, except Norway, which has raised the rates in certain interior areas (bedroom, living room) reaching rates of almost 7 l/s, that is, by multiplying by 50 the rate with respect to 2010, although it must be said that they were very low when compared to other countries.

Spain also changed its rates, increasing to almost double (from 3 to 7 l/s) in the living room and decreasing to just under half (from 5 to 3 l/s) in the bathroom, but before the pandemic.

As to whether there are differences between the rates according to geographic location, it can be stated that there are differences, especially between the countries of southern and northern Europe.

Returning to the question of the required ventilation values after the appearance of the pandemic and if it is necessary to change the legal regulation in general, it is understood that the values contained in most of the regulations could continue to be used.

On the other hand, it is important to note that most countries followed the recommendations suggested by the WHO and the ECDC.

As to whether there are differences between the rates according to geographic location, it can be stated that there are differences, especially between the countries of southern and northern Europe.

Regarding the improvement proposals to help alleviate the effects of the pandemic, the best formula for closed spaces is to maintain productive air exchange, limit the maximum number of people, and ensure efficient systems in air ventilation and energy.

Finally, this research has certain limitations, among which are the nuances, criteria and changing measures of the norm that make

| Room                     | 2010 Ventilation rates                                                                 | 2022 Ventilation rates                                                                 |
|--------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Laundry spaces           | 8 l/s (30 m³/h)                                                                        | 13 l/s (45 m³/h)                                                                        |
| Kitchen                  | 17 l/s (60 m³/h)                                                                       | (a1) Volumes for which the installation of type A gas appliances is not allowed. This installation is allowed for B11BS equipment, as the site is only intended to host this year (see also PN 1037-3-1). |
| Car parks and garages    | –                                                                                      | –                                                                                      |
| Waste warehouses         | –                                                                                      | –                                                                                      |

ABBRévIATIONs: (LR) Living room; (BER) Bedroom; (T) toilet; (BR) Bathroom (B) Bath; (K) Kitchen (DR) Dining Rooms.
Table 6
The main results of the analysis carried out regarding the evolution of the regulation of ventilation rates, the recommendations during the pandemic and the differences between periods and countries.

| Countries   | Variation of ventilation rates 2010/21-22 | In addition to the established regulation, the recommendations of Covid-19 are followed | The regulation of ventilation rates have been modified by Covid-19 recommendations | The Covid-19 recommendations followed in the country include prevention and monitoring practices |
|-------------|------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| Belgium     | Same rates                               | Yes                                                                              | No                                                                               | Yes                                                                                                               |
| Czech       | Similar rates                            | Yes                                                                              | No                                                                               | Yes                                                                                                               |
| Reich       |                                        |                                                                                  |                                                                                   |                                                                                                                   |
| Denmark     | Similar or slightly lower rates in some cases | Yes                                                                                | No                                                                                    | Yes                                                                                                               |
| Finland     | Same rates                               | Yes                                                                              | No, but indicate that flow rate of 10 l/s/person, avoiding return                  | Yes                                                                                                               |
| France      | Similar, but in 2022 the ventilation rates are considered differently | Yes                                                                              | No                                                                                   | Yes                                                                                                               |
| Germany     | Similar, but the external volume flows, the calculation algorithm and the requirements of dwellings ventilation systems have been modified. Once this study was completed, the imminent publication of an update to DIN 18017 was detected in Germany, so it has not been possible to include it and it should be the subject of future studies. | Yes                                                                              | No (See comments in the second column of this table)                                                              | Yes                                                                                                               |
| Greece      | Same rates                               | Yes                                                                              | No                                                                               | Yes                                                                                                               |
| Italy       | Similar rates, but with same restrictions | Yes                                                                              | No (some indications of other standards of other neighboring countries)            | Yes                                                                                                               |
| Netherlands | Same rates                               | Yes                                                                              | No                                                                               | Yes                                                                                                               |
| Norway      | It has increased rates in certain inland areas (bedroom and living room). Rates depend on the standard (Norwegian Code of 2021) | Yes                                                                              | Yes                                                                                   | Yes                                                                                                               |
| Portugal    | Same rates                               | Yes                                                                              | No                                                                                   | Yes                                                                                                               |
| Spain       | Similar rates, except in living room and bedroom where they increase | Yes                                                                              | They have been modified in some cases (CTE), but due to the Covid recommendations since the modifications are previous | Yes                                                                                                               |
| Sweden      | Same rates except for the living room and the bedroom, but it has not varied significantly | Yes                                                                              | No                                                                                   | Yes                                                                                                               |
| UK          | Same rates                               | Yes                                                                              | No                                                                               | Yes                                                                                                               |

comparison difficult, the differentiation between what the regulations indicate and what is used to do in each country, or the impossibility of including, in this research, all the regulations of the different autonomous regions that extend the national regulations.

Funding
This research received no external funding.

CRediT authorship contribution statement

Rafael González-Sancha: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. David Marín-Garcia: Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – original draft, Writing – review & editing. M.D. Pinheiro: Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. M. Oliveira: Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability
Except for reasoned requests, research data is not shared because it continues to be used by researchers for other work.

Acknowledgements
To the Department of Graphic Expression and Building Engineering and to the Architecture Library of the University of Seville, for facilitating the consultation of the corresponding bibliography.

References
[1] J. Sundell, On the history of indoor air quality and health, Indoor Air 14 (Suppl 7) (2004) 51–58, https://doi.org/10.1111/J.1600-0668.2004.00273.X.
[2] J.E. Janssen, The history of ventilation and temperature control: the first century of air conditioning, ASHRAE J. 41 (1999) 48–52, https://www.ashrae.org/file%20library/about/mission%20and%20vision/ashrae%20and%20industry%20history/ASHRAE%20History%20Bulletin.pdf. (Accessed 1 April 2021).
[3] D. Gribble, Natural ventilation, harnessed by New Kingdom Egyptian tomb builders, may explain the changed floor levels in the Valley of the Kings tomb KV5, Tunn. Undergr. Space Technol. 24 (2009) 62–65, https://doi.org/10.1016/J.TUST.2008.03.001.
[4] L. Hensen Centnerova, On the history of indoor environment and it’s relation to health and wellbeing, Rehab. J. 55 (2018) 14–20, https://pure.tue.nl/ws/files/97240601_14_20_RJ1802_WEB.pdf. (Accessed 13 April 2021).
[5] J. Sundell, Reflections on the history of indoor air science, focusing on the last 50 years, Indoor Air 27 (2017) 708–724, https://doi.org/10.1111/INA.12368.
[6] K. Azuma, U. Yanagi, N. Kagi, H. Kim, M. Ogata, M. Hayashi, Environmental factors involved in SARS-CoV-2 transmission: effect and role of indoor environmental quality in the strategy for COVID-19 infection control, Environ. Health Prev. Med. 25 (2020) 1–16, https://doi.org/10.1186/s12199-020-00904-2.
[7] D. Marín-Garcia, J.J. Moyano-Campos, J.D. Bienvenida-Huertas, Distances of transmission risk of COVID-19 inside dwellings and evaluation of the effectiveness
municipal-de-protecao-civil/legislacao/gaz/NP_1037-1_Ventilacao_produtos_c_ombustao_aparelhos_gas-Ventilacao_natural.pdf, 2002. (Accessed 10 April 2021).

[54] I.P.Q.-Instituto Português da Qualidade, NP 1037-1:2015 Ventilação e evacuação dos produtos da combustão dos locais com aparelhos a gás Parte 1: Edifícios de habitação. Ventilação natural. https://pdfcoffee.com/np-1037-1-2015-pdf-free.html, 2015. (Accessed 8 April 2021).

[55] Government of Spain, Ministry of Industry Energy and Tourism, RITE (Regulation for Thermal Installations in Buildings) BOE-A-2007-15820 (2007) 35931-35984. https://www.boe.es/buscar/doc.php?id=BOE-A-2007-15820. (Accessed 20 April 2021).

[56] HM Government (UK), The Building Regulations 2010. Approved Document F, Ventilation Dwellings. Requirement F1: Means of ventilation Regulations: 39, 42 and 44 (2021) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1045918/ADF1.pdf, (Accessed 26 January 2022).

[57] S. Benoy, et al., Aanbevelingen voor de praktische implementatie en bewaking van ventilatie en binnenluchtkwaliteit in het kader van COVID-19. https://werk.belgie.be/sites/default/files/content/documents/Coronavirus/Implementatieplan_ventilatie.pdf, 2021. (Accessed 1 January 2022).

[58] P. Lindé, Denmark: The ‘new normal’ pioneer with lower vaccination coverage than Spain | Society | EL PAÍS English Edition. https://english.elpais.com/society/2021-09-22/denmark-the-new-normal-pioneer-with-lower-vaccination-coverage-than-spain.html, 2021. (Accessed 1 January 2022).

[59] E. Lepore, P. Aguilera Benito, C. Piña Ramírez, G. Viccione, Indoors ventilation in times of confinement by SARS-CoV-2 epidemic: a comparative approach between Spain and Italy, Sustain. Cities Soc. 72 (2021), 103051, https://doi.org/10.1016/j.scs.2021.103051.

[60] S. Kunkel, E. Kontonasios, A. Arcipowska, F. Mariottini, B. Atanasiu. Indoor air quality, thermal comfort and daylight. Analysis of residential building regulations in eight EU member states, Buildings Performance Institute Europe (BPIE), 2015, pp. 1-99. http://bpie.eu/wp-content/uploads/2015/10/BPIE_IndoorAirQuality2015.pdf. (Accessed 14 April 2021).