Building and Environment 226 (2022) 109696

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Legal regulation of ventilation rates in homes in Europe 2010–2022: Evolution and comparison study regarding Covid-19 recommendations

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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 CO_2 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 CO_2 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

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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

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 [15]; 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 (m^3/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 h 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 since 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

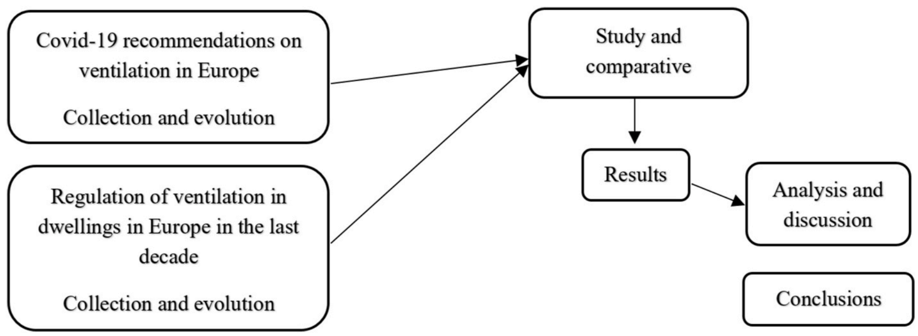

Fig. 1. Methodological flowchart.

were collected from them, the technique used was to categorize, investigate and interpret documents, including their isolated and comparative analysis [31]. Because the study looked at the ventilation rate, this process focused on extracting data related to it.

Furthermore, since it is about comparing the data on this ventilation rate, the metrics and their units of measurement expressed in the different documents were standardized through the corresponding equivalences.

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

Table 1
Belgian and Norwegian recommendations for ventilation (European Center for Disease Prevention and Control) [33].

Belgian		
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		
Norwegian		
• The number of air changes must be kept at 7 l/s per person in the room, and CO_2 must not exceed 1000 ppm. The limit recommendation on CO_2 must be balanced with humidity (minimum of 20% humidity in winter and 30% humidity in summer).		

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 Chrysanthi Dimitroulopoulou [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.

Table 2
Regulations [22] relative to ventilation in dwellings under study.

Countries	Regulation 2010	Regulation 2021-22
Belgium	NBN D 50-0001 1991 [36,60]	The same regulations as they are still in force today (according to the Belgian standardization office)
Czech Republic [37]	CSN 73 4301 [38]	ČSN 73 4301: 2004 + Z1: 2005 + Z2: 2009 + Z3: 2012 + Z4: 2019 - Residential buildings
	CSN 73 0540	ČSN 73 0540-2: 2001 + Z1: 2012
Denmark [39]	DS 418:2002	DS 418:2011+ up to 1:2020 Calculation of heat loss from buildings [40]
Finland	NBC-D2 [41]	The same regulations with updates
France	Order March 24, 1982 [42]	Order March 24, 1982 is currently in force but with updates (last updated August 27, 2021)
Germany [43]	DIN 1946 PART 6 [60] DIN 18017	DIN 1946–6:2019-12 DIN 18017:2020-05 [45]. 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.
	VDI 2088 [44]	The same regulations (withdrawal in 1995)
Greece	General Building Regulation Ley 1577/1985 [46] reformed byLey 2831/2000 [47]	The same regulations with updates [48].
Italy	Decreto Sanità del 5 luglio 1975 [49] Legislative Decree 192/2005, UNI EN 15251 [60]	The same regulations with updates [49] Other standards of interest norma UNI 10339; UNI EN 15251; ASHRAE 62; among other [50]
Netherlands [51]	Construction Decree.1992	Construction Decree. 2012
Norway [52]	Norwegian Building Code 1987	Norwegian Building Code 2021
Portugal	NP 1037–1:2002 [53]	NP 1037–1:2015 [54]
Spain	CTE DB-HS [11] and RITE [55]	CTE DB-HS [11] and RITE [55]
Sweden	Swedish Building Standard BBR1994	Swedish Building Standard BBR2014 (BFS2014:13 – BBR21) [60]
UK	Construction regulation, Part. F [56]	The same regulations with updates

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 deventilation 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" [57] 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

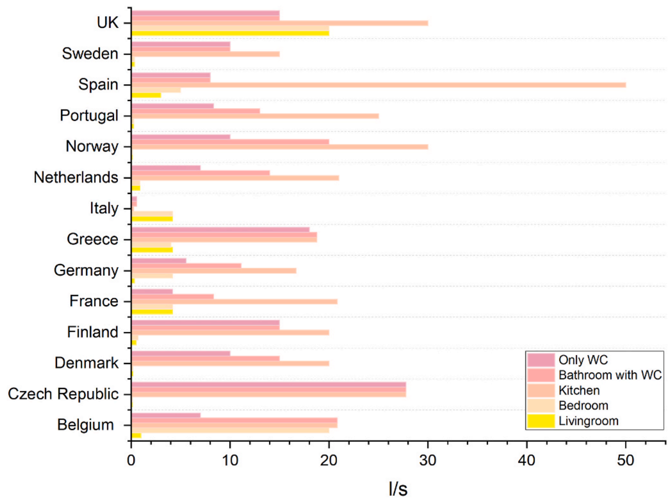

Fig. 2. Ventilation rates are contemplated in the normative regulation of the countries analysed in 2010.

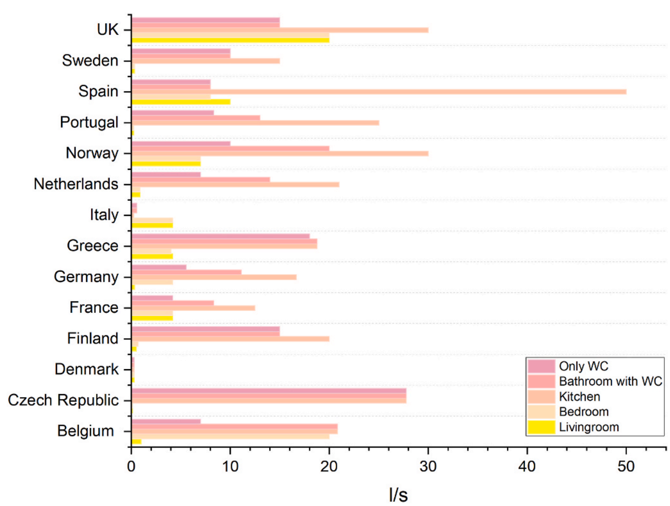

Fig. 3. Ventilation rates contemplated in the normative regulation of the countries analysed in 2022. Once this study was completed, the imminent publication of an update to the DIN 18017 standard was detected in Germany, so it has not been possible to include it in these graphs.

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

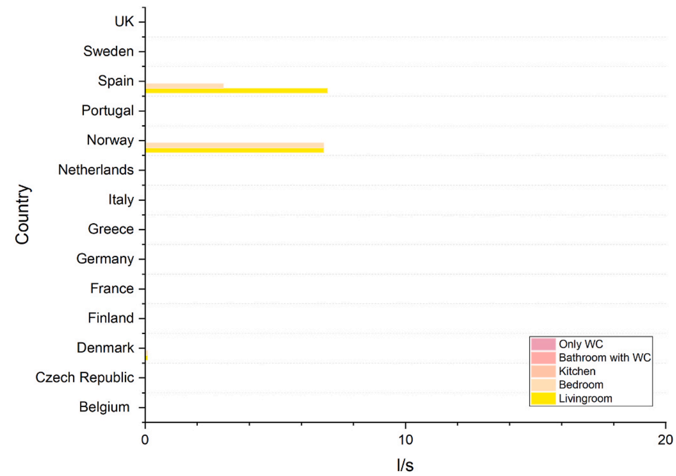

Fig. 4. Increases in ventilation rates contemplated in the regulations of the countries analysed between 2010 and 2022. Once this study was completed, the imminent publication of an update to the DIN 18017 standard was detected in Germany, so it has not been possible to include it in these graphs.

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 m^3/s 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 CO_2 levels [59].

Regarding the **Netherlands**, ventilation rates in 2010 and 2022, are similar and present a low ventilation rate 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

Table 3
The peculiarities of each country related to ventilation and its rates according to the existing regulation in 2010.

Countries	
Belgium	Rooms measured in l/s per m^2.
Czech Republic	The living room and bedroom have been calculated by averaging between 0.3 and 0.6 air changes per hour (h-1), resulting in 0.45 h–1 = 0.125 l/s. For the other rooms (kitchen, bathroom with WC and only WC), m^3/h have been converted into l/s.
Denmark	Assumptions for the rates of the living room and bedroom. The rates for the rest of the spaces are based on the DS 418:2002 standard.
Finland	The rate for living rooms is reflected in l/s per m^2. As for the bedroom, it is reflected in l/s per person, choosing the higher rate of the two given.
France	Choice of an average of 3 R (3 habitable rooms) for each rate based on space.
Germany	The rate of 1.25 h-1 air changes per hour (average between 1.5 and 1.0 h-1) is equal to 0.35 l/s 4.17 l/s is chosen in the bedroom according to the DIN EN 15251 standard. In the kitchen, a rate of 16.67 l/s is chosen, equivalent to 60 m^3/h, considering the kitchen with windows with a general air flow. 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.
Greece	Rates are conversions from m^3/h per person to l/s.
Italy	Rates are conversions from m^3/h per person to l/s in the living room. For the bedroom, a hypothesis is made taking data from the living room. As for the kitchen and the bathroom + WC, they are conversions from h-1 to l/s.
Netherlands	Rates are conversions from m^3/h per m^2 to l/s in the living room. Bedroom, kitchen, bathroom + WC and only we are conversions from m^3/h to l/s.
Norway	Rate of 0.5 h–1 = 0.14 l/s, chosen for the living room and bedroom as is, according to Annex 1, not less than 0.5 h-1. Same bedroom rate as living room.
Portugal	Data extracted from the NP 1037-1 2001 standard, choosing a volume between 15 and 22 m^3 for the kitchen, a hypothesis of 13 l/s for the bathroom (min is 12.5 l/s) and for only the WC 8.33 l/s is chosen, being the minimum according to regulations.
Spain	The rates are based on the Basic Document HS 3 health regulations in Table 2.1. For the living room, a rate for occupancy 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 based on what is indicated by other parameters, and for the bathroom with a WC and only the WC, the same rate is taken depending on the type of home (3 or more bedrooms).
Sweden	The rates set for the living room and the bedroom are based on the rates for the entire building and are in l/s per m^2.
UK	The living room and bedroom rates are set at rates for the entire building. For the kitchen, an extraction rate is chosen for the bathroom with WC and only the WC.

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 CO_2 (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 the WC, 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 4
The peculiarities of each country related to ventilation and its rates according to the regulations in force in 2022 compared to 2010.

Countries	
Belgium	Same rate as 2010 due to the current validity of the standard. Rooms measured in l/s per m^2.
Czech Republic	We do not have specific data, but rates similar to the year 2010.
Denmark	Rates of 0.3 l/s per m^2 for all rooms according to standard DS 411:2011 + 1:2020.
Finland	Same rate as 2010 with a recommended flow rate of 10 l/s/person.
France	Same rate as 2010 due to the current validity of the standard.
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.
Greece	Same rate as 2010 due to no major changes.
Italy	Same rate as 2010 but with more restrictions.
Netherlands	Same rate as 2010 but following recommendations of competent bodies in the matter.
Norway	Rates depend on the standard (Norwegian Code of 2021).
Portugal	Same rate as 2010 but following recommendations of competent bodies in the matter.
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 2010 standard, and for the bathroom with a WC and only the WC, the same rate is charged depending on the type of dwelling (3 or more bedrooms) and a minimum per local.
Sweden	Rates set by the BBR2014 standard, where for the living room and for the bedroom, it is in l/s per m^2. Rest of spaces with rates according to regulations of the year 2010.
UK	Same rate as 2010, focusing on the use of mechanical ventilation systems in dwellings.

Table 2.1 of the DB HS3 aforementioned.

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 **Sweden**, the regulations of 2010 and 2022 in their reference to the rates have not varied significantly in general terms.

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.

Finally, the **United Kingdom's** ventilation rates in 2010 in general present ventilation rates without major differences between the different rooms of the dwellings, except in one of them where it is higher.

The ventilation rates in the year 2022 are practically the same, and the same regulations are used without prejudice to comply with recommendations given by the WHO (world health organization) and by the REHVA (Federation of European associations of heating, ventilation and air conditioning).

Table 6 summarizes the analysis performed on the differences (for the specific criteria) between both dates (2010–2022) and between countries, and whether or not there have been changes in the regulation of the ventilation rate, and also whether, regardless of this, the countries have assumed the application of the Covid recommendations of the WHO and the ECDC.

5. Conclusions

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

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

2010	**Ventilation rates**	**2.4 cm^2/m^2 for natural ventilation and 1.2 cm^2/m^2 for mechanical ventilation,**
2022		**0.3 l/s m^2 for all rooms in residential buildings and 0.18 l/s m^2 for very large rooms, storage rooms and the like.**

FINLAND

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

FRANCE

Number of habitable rooms (R)	**m^3/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. 2010–2022 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**	**30**	**15**
5 (2010)/5 and more (2022)	**210**	**135(min 105)**	**30**	**15**	**30**	**15**
6 (2010)	**210**	**-**	**-**	**-**	**-**	**-**
7 (2010)	**210**	**-**	**-**	**-**	**-**	**-**

Number of environments (2010–22)-Total mínimum flow (m^3/h)

Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Total	**10**	**10**	**15**	**20**	**25**	**30**	**35**

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.

The whole building	LR	BR and guest BER.	Intensive ventilation	With T	B	K			
People	Surface	Ventilation (m^3/h)							
		Natural	Mechanics						
Up to 2	<50 m^2	60	60	1.0–1.5 h^{-1}	<15 m^3/h **	200 m^3/h for K.	40 m^3/h	20 m^3/h	40 m^3/h
Up to 4	–	90	120						
Up to 6	>80 m^2	120	180						

*With continuous ventilation the flow rate is 20–45 m^3/h. In the kitchen and the integrated kitchen, normal ventilation of 40 m^3/h (>12 h occupation per day) with 60 m^3/h for total and general airflow is obtained.
** and normal ventilation of 40 m^3/h.
*** without Windows.

GREECE

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

For the entire dwelling (flat, house, united, separated, etc.)			BER	K	BR
8,5 m^3/h/person	12–17 m^3/h/person	15 m^3/h/person	12–17 m^3/h/person	50–85 m^3/h/person	50–85 m^3/h/person

ITALY

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

Natural ventilation for the whole building	LR	BER	K	BR with WC
15 m^3/h/person	15 m^3/h/person	12–17 m^3/h/person	1 h-1	2 h-1

NETHERLANDS

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

LR	BER	K	BR with WC
300 m^3/h	0.9 dm^3/s per m^2 (3.24 m^3/h per m^2)	21 dm^3/s (75.6 m^3/h)	14 dm^3/s (50.4 m^3/h) WC exclusively 7 dm^3/s (25.2 m^3/h)

NORWAY

In this country from 2010 to 2022 there has been a significant change in the rate of ventilation of the LR and the BR.

2010		**2022**	
Ventilation rates (m^3/h)		**Ventilation rates (l/second per person)**	
LR	**BR with T**	**Room**	**BR and K**
36 + 72	**Minimun of 10 and máximum of 30<!–Para Run-on–>**	**7**	**7**

PORTUGAL

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

Room type	Volume ≤8 m^3	>8 m^3 ≤11 m^3	>11 m^3 ≤15 m^3	>15 m^3 ≤22 m^3	>22 m^3 ≤30 m^3	
K. and other appliances for gas installation	(a1)	17 l/s (60 m^3/h)	25 l/s (90 m^3/h)	33 l/s (120 m^3/h)		
Sanitary facility	With a BR or shower	13 l/s (45 m^3/h)	17 l/s (60 m^3/h)	25 l/s (90 m^3/h)	(a2)	
	Without BR or shower	8 l/s (30 m3/h)	13 l/s (45 m^3/h)	17 l/s (60 m^3/h)	(a2)	(a2)

(*continued on next page*)

Table 5 (*continued*)

PORTUGAL						
	Laundry spaces	8 l/s (30 m^3/h)	13 l/s (45 m^3/h)	17 l/s (60 m^3/h)	(a2)	(a2)

(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).
(a2) Unusual volumes in compartments of this type in relation to those recommended or sizing case in case you have the requirements mentioned above.

SPAIN						
2010			**2022**			
Minimum ventilation flow (l/s)						
	Per occupant	**Per m2 useful**	**Other parameters**	**0 or 1 BER**	**2 BER**	**3 or more BER**
BR	**5**	**-**	**-**	**8**	**8**	**8**
Rest of BER				**-**	**4**	**4**
LR and DR	**3**	**-**	**-**	**6**	**8**	**10**
Mini. flow (total/per local)				**12/6**	**24/7**	**33/8**
T and BR	**-**	**-**	**50 per room**	**-**	**-**	**-**
K	**-**	**2**	**-**	**-**	**-**	**-**
Storage rooms and common areas	**-**	**0.7**	**-**	**-**	**-**	**-**
			50 per room			
Car parks and garages	**-**	**-**	**120 per parking**	**-**	**-**	**-**
Waste warehouses	**-**	**10**	**-**	**-**	**-**	**-**

SWEDEN							
2010					**2022**		
Ventilation rates					**Ventilation rates (l/s per m^2)**		
			BR with WC (l/s)<!–Para Run-on–>				
The whole building (l/s per m^2)<!–Para Run-on–>	**K (l/s per person)<!–Para Run-on–>**	**Small kitchen (l/s)<!–Para Run-on–>**	**With window**	**No window**	**The whole building**	**Unoccupied dwelling**	**Occupied dwelling**
0.35	**4 (mini.10)**	**15**	**10–30 (high velocity)**	**15**	**0.35**	**0.10**	**0.35**

UNITED KINGDOM'S			
The ventilation rates between 2010 and 2022 are similar (See Figs. 2–4).			
For the entire building	LR and the VER	K	BR with a WC and only the WC
20 l/s	Rapid ventilation (with opening windows) 1/20 of the ventilation area of the floor with 8000 m2	Quick ventilation through a window that opens with ventilation of 4000 mm^2 and extraction of 30 l/s next to the worktop or 60 l/s elsewhere o PSV (pressure support ventilation).	With bottom opening of the window and an extract of 4000 mm^2 with a rate of 15 l/s o PSV (pressure support ventilation).

ABBREVIATIONS: (LR) Living room; (BER) Bedroom; (T) toilet; (BR)Bathroom (B) Bath; (K) Kitchen (DR) Dining Rooms.

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 rises 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 then 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.

Denmark has decreased in some point cases for technical reasons of other kinds (from 20 in 2010 to 0.3 l/s in 2022 in the kitchen and from 15 to 0.3 in the bathroom with WC).

Also in France, it decreased, for example, in the kitchen (from 20 to 21 in 2010 to 12.5 l/s in 2022), while the rest of the countries have maintained similar rates or have partially and slightly modified them generally before the pandemic for other reasons.

On the other hand, the referenced bibliography indicates that the living room is one of the areas with the highest risk of contagion between co-habitants.

So, although there exists the need for an envelope as hermetic as possible that I isolated from the outside (energy efficiency), is convenient for the countries with low rates (equal to or less than 1 l/s) in this room (Belgium, Czech Republic, Denmark, Finland, Netherlands, Germany, Portugal, Sweden) that reformulate their regulations to increase this rate. On the other hand, as already mentioned, 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.

This should also be done in bedrooms for countries such as Belgium, the Czech Republic, Denmark, Finland, the Netherlands, Portugal, and Sweden. Although it occurs occasionally (Denmark or Italy), it also happens in bathrooms and kitchens. However, in these cases, the risk is especially focused when they are shared and ventilation is reduced.

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.

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.

However, mandatory ventilation systems with control options (manual or automatic) should be included or at least pre-installation conditions.

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

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 Republic	Similar rates	Yes	No	Yes
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, especially in the bedroom and living room, although previously they were very low compared to other countries	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-García:** 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/the-history-of-ventilation-and-temperature-control.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 Centnerová, 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-García, J.J. Moyano-Campos, J.D. Bienvenido-Huertas, Distances of transmission risk of COVID-19 inside dwellings and evaluation of the effectiveness

of reciprocal proximity warning sounds, Indoor Air 31 (2021) 335–347, https://doi.org/10.1111/ina.12738.
[8] M.Y.Z. Abouleish, Indoor air quality and COVID-19, Publ. Health 191 (2021) 1–2, https://doi.org/10.1016/J.PUHE.2020.04.047.
[9] T. Sharpe, P. Farren, S. Howieson, P. Tuohy, J. McQuillan, Occupant interactions and effectiveness of natural ventilation strategies in contemporary new housing in Scotland, UK, Int. J. Environ. Res. Publ. Health 12 (2015) 8480–8497, https://doi.org/10.3390/ijerph120708480.
[10] B. Chenari, J. Dias Carrilho, M. Gameiro Da Silva, Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: a review, Renew. Sustain. Energy Rev. 59 (2016) 1426–1447, https://doi.org/10.1016/J.RSER.2016.01.074.
[11] Government of Spain, Decree 314/2006 of March 17, approving the Technical Building Code (Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación) H.S. Sanitation, HS Section 3 Indoor Air Quality. BOE 74, March 28, (2006) 11816-11831. https://www.boe.es/eli/es/rd/2006/03/17/314. (Accessed 6 April 2021).
[12] European Parliament, Directive (EU) 2018/844 of the and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance). Off. J. Eur. Communities. L 156 75-91 (2018). https://eur-lex.europa.eu/eli/dir/2018/844/oj. (Accessed 18 April 2021).
[13] A. Litiu, Introduction Ventilation system types in some EU countries, Rehab. J. 1 (2012) 18–23. https://www.rehva.eu/fileadmin/hvac-dictio/01-2012/ventilation-system-types-in-some-eu-countries_rj1201.pdf. (Accessed 11 April 2021).
[14] R.J. Lowe, Ventilation strategy, energy use and CO2 emissions in dwellings -a theoretical approach, Build. Serv. Eng. Technol. 21 (2000) 179–185, https://doi.org/10.1177/014362440002100306.
[15] N. Khan, Y. Su, S.B. Riffat, A review on wind driven ventilation techniques, Energy Build. 40 (2008) 1586–1604, https://doi.org/10.1016/J.ENBUILD.2008.02.015.
[16] T. Peters, A. Halleran, How our homes impact our health: using a COVID-19 informed approach to examine urban apartment housing, Archnet-IJAR. 15 (2021) 10–27, https://doi.org/10.1108/ARCH-08-2020-0159.
[17] L. Fang, C. McDaniel, Home hours in the United States and Europe, B E J. Macroecon 17 (2014) 1–27, https://doi.org/10.1515/bejm-2015-0031.
[18] T. Abdalla, C. Peng, Evaluation of housing stock indoor air quality models: a review of data requirements and model performance, J. Build. Eng. 43 (2021), 102846, https://doi.org/10.1016/J.JOBE.2021.102846.
[19] M.J. Limb, A review of international ventilation, airtightness, thermal insulation and indoor air quality criteria, Tech. Note AIVC. 55 (2001) 1–194. https://www.aivc.org/sites/default/files/members_area/medias/pdf/Technotes/TN55 REVIEW OF VENTILATION CRITERIA.pdf. (Accessed 5 April 2021).
[20] H. Yoshino, S. Murakami, S.I. Akabayashi, T. Kurabuchi, S. Kato, S.I. Tanabe, K. Ikeda, H. Osawa, T Sawachi, H. Hukushima, M. Adachi, Survey on minimum ventilation rate of residential buildings in fifteen countries, in: 25th AIVC Conference-Ventilation and retrofitting, AIVC, 2004, pp. 227–238. https://www.aivc.org/sites/default/files/AIVC_2004_CP25.pdf#page=239. (Accessed 2 April 2021).
[21] O. Seppänen, N. Brelih, G. Goeders, A. Litiu, Summary of European ventilation standards, their implementation and ventilation systems used in European buildings. REHVA – Federation of European Heating, Ventilation and Air-conditioning Associations (2012) 1-172. https://webgate.ec.europa.eu/chafea_pdb/assets/files/pdb/20091208/20091208_d05_oth5_en_ps.pdf. (Accessed 8 April 2021).
[22] C. Dimitroulopoulou, Ventilation in European dwellings: A review, Build. Environ. 47 (2012) 109–125. https://doi.org/10.1016/j.buildenv.2011.07.016.
[23] A. Asikainen, O. Hänninen, N. Brelih, W. Bischof, T. Hartmann, P. Carrer, P. Wargocki, The proportion of residences in European countries with ventilation rates below the regulation based limit value, Int. J. Vent. 12 (2016) 129–134, https://doi.org/10.1080/14733315.2013.11684007.
[24] D. Marín-García, Del COVID-19 -SARS-CoV-2- y su relación con la ventilación y climatización en edificios. From COVID-19 -SARS-CoV-2- and its relationship with ventilation and air conditioning in buildings, Aparejadores. CoaatSev. 87 (2020) 43–51. https://dialnet.unirioja.es/servlet/articulo?codigo=7993189&orden=0&info=link. (Accessed 2 April 2021).
[25] P. Aguilera Benito, C. Piña Ramírez, G. Viccione, E. Lepore, Ventilation for residential buildings: critical assessment of standard requirements in the COVID-19 pandemic context, Front. Built Environ. 7 (2021) 113, https://doi.org/10.3389/FBUIL.2021.656718.
[26] D. Lewis, Why the WHO took two years to say COVID is airborne, Nature 604 (2022) 26–31, https://doi.org/10.1038/D41586-022-00925-7.
[27] Z. Noorimotlagh, N. Jaafarzadeh, S.S. Martínez, S.A. Mirzaee, A systematic review of possible airborne transmission of the COVID-19 virus (SARS-CoV-2) in the indoor air environment, Environ. Res. 193 (2021), 110612, https://doi.org/10.1016/J.ENVRES.2020.110612.
[28] H.C. Burridge, R.K. Bhagat, M.E.J. Stettler, P. Kumar, I. De Mel, P. Demis, A. Hart, Y. Johnson-Llambias, M.F. King, O. Klymenko, A. McMillan, P. Morawiecki, T. Pennington, M. Short, D. Sykes, P.H. Trinh, S.K. Wilson, C. Wong, H. Wragg, M. S. Davies Wykes, C. Iddon, A.W. Woods, N. Mingotti, N. Bhamidipati, H. Woodward, C. Beggs, H. Davies, S. Fitzgerald, C. Pain, P.F. Linden, The ventilation of buildings and other mitigating measures for COVID-19: a focus on wintertime, R. Soc. A: Math., Phys. and Eng. Sci. 477 (2247) (2021), 20200855, https://doi.org/10.1098/RSPA.2020.0855.
[29] G. Berry, A. Parsons, M. Morgan, J. Rickert, H. Cho, A review of methods to reduce the probability of the airborne spread of COVID-19 in ventilation systems and enclosed spaces, Environ. Res. 203 (2022), 111765, https://doi.org/10.1016/J.ENVRES.2021.111765.
[30] D. Welle, DW, Coronavirus: what are the lockdown measures across Europe? *52905137 (2020)*. https://www.dw.com/en/coronavirus-what-are-the-lockdown-measures-across-europe/a-52905137. (Accessed 5 April 2021).
[31] M. Van Hoecke, Methodology of comparative legal research, Law Method 16 (2015) 1–35. https://biblio.ugent.be/publication/7145504/file/7145530. (Accessed 1 April 2021).
[32] World Health Organization (WHO), (2020), Coronavirus Disease (COVID-19): Ventilation and Air Conditioning, WHO, 2020. https://www.who.int/news-room/questions-and-answers/item/coronavirus-disease-covid-19-ventilation-and-air-conditioning. (Accessed 20 April 2021).
[33] A. Baka, O. Cenciarelli, P. Kinross, P. Penttinen, D. Plachouras, J. Semenza, C. Suetens, K. Weist, European Centre for Disease Prevention and Control. Heating (ECDC), Heating, Ventilation and Air-Conditioning Systems in the Context of COVID-19, ECDC, 2020, pp. 1–19. https://www.ecdc.europa.eu/sites/default/files/documents/Ventilation-in-the-context-of-COVID-19.pdf. (Accessed 12 April 2021).
[34] World Health Organization (WHO), Roadmap to Improve and Ensure Good Indoor Ventilation in the Context of COVID-19, WHO, 2021, pp. 1–25. https://www.who.int/publications/i/item/9789240021280. (Accessed 2 December 2021).
[35] P. Wargocki, T.H. Kuehn, H.E.B. Burroughs, C.O. Muller, E.A. Conrad, D.A Saputa, W.J. Fisk, J.A. Siegel, M.C. Jackson, A. Veeck, P.W Francisco, Position document on filtration and air cleaning, ASHRAE Am. Soc. Heat. Refrig. Air-Conditioning Eng. (2015) 1–22. https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd-feb.2.2021.pdf. (Accessed 4 April 2021).
[36] Belgisch Instituut voor Normalisatie (BIN), Standard NBN D 50-001:1991, NBN Shop, 1991. https://www.nbn.be/shop/en/standard/nbn-d-50-001-1991_1546/. (Accessed 11 April 2021).
[37] P. Charvat, Ventilation in the Czech Republic: Technical Note AIVC 63, Coventry, Air Infiltration and Ventilation Centre, 2008, pp. 1–20. http://www.aivc.org/sites/default/files/members_area/medias/pdf/Technotes/TN63_Ventilation in the Czech Republic.pdf. (Accessed 14 April 2021).
[38] Office of Technical Standardization, Metrology and State Testing, Czech Republic, ČSN 734301:2004/Z4 (73 4301) (2019), Technical standard | MyStandards. https://www.mystandards.biz/standard/csn-734301-2004-z4-1.8.2019.html. (Accessed 10 April 2021).
[39] Danish standards, DS418 (2011), 7. https://es.scribd.com/document/93342410/DS418-7th-Edition. (Accessed 6 April 2021).
[40] Danish standards, DS 418, Calculation of heat loss from buildings (2020). https://global.ihs.com/doc_detail.cfm?document_name=DS 418&item_s_key=00601926. (Accessed 10 April 2021).
[41] Government of Finland, Ministry of the Environment Housing and Building Department, Indoor climate and ventilation of buildings. Regulations and guidelines (2003). https://www.edilex.fi/data/rakentamismaaraykset/d2e.pdf. (Accessed 8 April 2021).
[42] Government of France, Ministre de l'urbanisme et du logement, Arrêté du 24 mars 1982 relatif à l'aération des logements - Légifrance (1982). https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000862344/. (Accessed 3 April 2021).
[43] H. Gottschalk, Ventilation concepts according to DIN 1946-6. More individual scope; Lueftungskonzepte nach DIN 1946-6 (2011), vol. 7, Mehr individueller Spielraum, 2011, pp. 12–16. https://www.osti.gov/etdeweb/biblio/21412558. (Accessed 6 April 2021).
[44] Verein Deutscher Ingenieure (VDI), VDI 2088:1976-12 Ventilating of dwellings. https://www.beuth.de/en/technical-rule/vdi-2088/1524279, 1976. (Accessed 18 April 2021).
[45] German Standards, DIN 18017-3 Lüftung von Bädern und Toilettenräumen ohne Außenfenster – ventilation of bathrooms and toilet rooms without outside windows – ventilation des salles de bains et des toilettes sans fenêtres extérieures – Inhalt (2020). https://www.baunormenlexikon.de/norm/din-18017-3/28e3c772-4e78-4e02-a3f2-24f67566f3a4. (Accessed 18 April 2021).
[46] Parliament, Greek, Law 1577/1985. General Building Regulation, Greek Official Gazette 210/A/18-12-1985, 1985. https://www.argohellas.net/gok1985.pdf, 2000. (Accessed 14 April 2021).
[47] Parliament, Greek, Law 2831/2000. Building Regulation. Official Government Gazette 140/A/13-6-2000. http://portal.tee.gr/portal/page/portal/SCIENTIFIC_WORK/arxeia_diafora/20000100140.pdf, 2000. (Accessed 19 April 2021).
[48] Parliament, Greek, Law 4067/2012. Building regulation. Official Government Gazette 79/A/09-04-2012. https://web.archive.org/web/20170716035715/http://www.ypeka.gr/LinkClick.aspx?fileticket=5nRUKLGlL8E%3D&tabid=506&language=el-GR, 2012. (Accessed 7 April 2021).
[49] L. Appolloni, M. Gola, M. Raffo, L. Capasso, G.G. Settimo, U. Moscato, A. Azara, M. Dettori, S. Capolongo, D. D'Alessandro, Towards an update of the Italian ministerial decree july 5th, 1975, Ann Ig 32 (2020) 66–84, https://doi.org/10.7416/ai.2020.3395.
[50] Normative sulla ventilazione domestica. https://www.ventolino.it/info/normative-sulla-ventilazione-domestica.html, 2021. (Accessed 20 April 2021).
[51] Government of Netherlands, Building regulations in The Netherlands | Business.gov.nl. https://business.gov.nl/regulation/building-regulations/, 2012. (Accessed 1 April 2021).
[52] Government of Norway, Building acts and regulations - direktoratet for byggkvalitet. https://dibk.no/regelverk/Building-Regulations-in-English/, 2013. (Accessed 12 April 2021).
[53] I.P.Q.-Instituto Português da Qualidade, NP 1037-1 2002 Ventilação e evacuação dos produtos da combustão dos locais com aparelhos a gás Parte 1: Edifícios de habitação. Ventilação natural. https://protecaocivil.sintra.pt/images/servico-

municipal-de-protecao-civil/legislacao/gaz/NP_1037-1_Ventilacao_produtos_combustao_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. Linde, 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. Kontonasiou, 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).