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Indoors ventilation in times of confinement by SARS-CoV-2 epidemic: A comparative approach between Spain and Italy

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ABSTRACT

With the arrival of the SARS-CoV-2 coronavirus, the scientific academia, as well as policymakers, are striving to conceive solutions as an attempt to contain the spreading of contagion. Among the adopted measures, severe lockdown restrictions were issued to avoid the diffusion of the virus in an uncontrolled way through public spaces. It can be deduced from recent literature that the primary route of transmission is via aerosols, produced mainly in poorly ventilated interior areas where infected people spend a lot of time with other people.

Concerning contagion rates, accumulated incidence or number of hospitalizations due to COVID-19, Spain, and Italy have reached very high levels. In this framework, a regression analysis to assess the feasibility of the indoor ventilation measures established in Spain and Italy, with respect to the European framework, is here presented. To this aim, ten cases of housing typology were and analyzed. The results show that the measures established in the applicable regulations to prevent and control the risk of contagion by aerosols are not adequate to guarantee a healthy environment indoors. The current Italian guidelines are more restrictive than in Spain, yet the ventilation levels are still insufficient in times of pandemic.

1. Introduction

In Wuhan (China), at the end of 2019, health officials began to investigate patients with viral pneumonia. In early January 2020, the Chinese authorities warned that they identified a new coronavirus (CoV), spreading quickly. According to WHO sources, it was initially thought that the outbreak did not constitute a public emergency at an international level, but in a short time, at the end of January, the same WHO declared that "COVID-19" is a global emergency (World Health Organization, Statement on the second meeting of the Emergency Committee of the International Health Regulations (2005) on the novel coronavirus outbreak (2019-nCoV), 2020c). The global situation worsened to the point a pandemic was declared worldwide because the population did not have immunity against it, along with a high level of contagion and a significant mortality rate (Qun Li, 2020). The first cases were registered in Europe at the end of January, though a recent study suggests the presence of the virus in Italy as early as November 2020 (Times, 2020; Tobías, 2020). The first 100 infections are counted as day zero, which in Italy corresponds to February 27th and in Spain to March 5th (Glass, 2020). Since then, Spain and Italy were among the most affected countries globally, after the United States (Alvaro Briz-Redón, 2020; Jordi Martorell-Marugán, 2021; Tobías, 2020).

From that moment on, different governments have taken measures such as the closure of airports, schools, commercial activities, restaurants, etc. (Borrelli, 2020; Generale, Ordinanza del Ministro della salute 30 gennaio, 2020b; Generale, Delibera del Consiglio dei Ministri 31
With the arrival of the COVID-19 pandemic, our habits changed, as well as the way we “live” in our homes. Suddenly, as a society, we had to face involuntary confinement. From one day to the next, we have been obligated to stay indoors much longer than usual and probably, to share spaces with one or more people, whether they are components of our nuclear family or not. Adults had to start working remotely from home, and both children and teenagers had to get used to online lessons.

We are facing aspects that can affect our quality of life, due to the fact that we are in times of a pandemic, considering the importance of indoor air quality and the difference that the space we have at home can make as something conditioning (Antony Aroul Raj V, 2020; Giacomo Chiesa, 2015; Hu, 2020; Megahed, 2020; Sannigrah, 2020). According to various studies, contagion is due to droplets that we expel when we speak, cough, or sneeze. However, the latest studies focus on the exposure of aerosols that dissipate the virus through the environment, minimizing this risk with a derived clean ambient air quality of good safety. Improving the indoor environment and its quality can be essential to improve the quality of life healthily, preventing the spread of the disease (Ballarini I., 2011; Ballarini I. C., 2011; Ballarini, 2017; Beatriz Gennai, 2020a; Jefatura del Estado, 2011; Zhang, 2020), affecting social health effects can be observed for CO₂ levels over 7000 ppm (Mairal, 2013; Persily, 2017). With the increase of CO₂ concentration indoors, where people’s breathing and related activities account for a more significant share due to the confinement, air exchange may turn to be insufficient, raising the risk of SARS-CoV-2 contagion.

2. Methodology

Due to the importance of ventilation in times of pandemic, this research focuses on the effectiveness of air change in homes, checking whether the corresponding values are in agreement with the new requirements and directives established by-laws to contain spreading contagion (Antony Aroul Raj V, 2020; Sun, 2020).

To discuss the merits of the ruling legislations, ten types of dwellings were conceived satisfying the minimum floor height set by each of the considered countries, hence representing typical dwellings. According to the parameters established by the Spanish, Italian, and European regulations, the flow rate and air changes per hour were calculated for them. A regression analysis was carried out to estimate the relationships between the above-obtained values and the ones derived with a one-way analysis of variance (ANOVA). ANOVA uses F-tests to test the equality of means statistically. The concentration of CO₂ allowed in homes by the different regulations was analyzed as well. An indoor CO₂ level of 1400 ppm provides good indoor air quality in most situations. Human

2.1. Minimum measures of floor area and height of the room(s) according to the Spanish and Italian regulations: study cases definition

For a comprehensive assessment of the air changes per hour, it was necessary to first evaluate the differences between construction regulations in Spain and Italy, with concern to the minimum floor area calculated per person and the minimum size of what makes up a house. In addition, the minimum heights of the room(s) in these two countries were checked.

In Spain, the dimensions of the houses are ruled by the Urban Regulations and the General Urban Planning (Normas Urbanísticas y Plan General de Ordenación Urbana). The floor area or the minimum free height can be slightly different, depending on the municipality, city, or region of pertinence. In Italy, the habitability of a residence certifies the suitability of the property to be used as a dwelling. The Italian law n. 457 of 05/08/1978 establishes the “Standards for residential construction” (Norme per l’edilizia residenziale) (Governo Italiano, 1978) and, in particular, the technical characteristics of buildings, according to which the net heights of the room(s) and auxiliary areas, are measured between floor and ceiling.

This study compared the regulations, with concern to building in Spain, currently used in Madrid, Barcelona, and Sevilla (Ayuntamiento de Madrid, 2009; Ayuntamiento de Sevilla, 2020; Generalitat de Catalunya, 2012), with major Italian cities such as Milan, Bologna, and Turin (Comune Bologna, 2020; Consiglio regionale del Piemonte, 2017). The minimum surfaces and heights in residential rooms in Spain and Italy are summarized in the following Table 1:

From Table 1, it is noteworthy that the minimum height of the room(s) in Italy is higher than the corresponding one set by Spanish regulations. The floor areas in Spain are also slightly smaller than what is established in Italy.

The building types being selected for the calculation and subsequent ventilation analysis, sketched in Fig. 1, with characteristics listed in Table 2, are the most representative dwellings in the Spanish and Italian real state (Ballarini I., 2011; Ballarini I. C., 2011; Ballarini, 2017; Beatriz

### Table 1

| Area               | SPAIN Measurements | ITALY Measurements |
|--------------------|--------------------|--------------------|
|                    | Minimum height (h) | Minimum area (m²) | Minimum height (h) | Minimum area (m²) |
| Main room (2 pers.)| 2.5                | 10.0               | 2.7                | 14.0               |
| Secondary room (1 pers.)| 2.5             | 6.0                | 2.7                | 9.0                |
| Secondary room (2 pers.)| 2.5             | 10.0               | 2.7                | 14.0               |
| Living room (plus kitchen)| 2.5           | 10.0 (14.0)        | 2.7                | 14.0               |
| Kitchen            | 2.2                | 5.0                | 2.7                | 5.0                |
| Main bathroom*     | 2.2                | 1.1                | 2.5                | 2.0                |
| Secondary bathroom **| 2.2              | 1.1                | 2.5                | 2.0                |
| Premises accessories| 2.2                | –                  | 2.4                | –                  |
| Studio (1 pers.)   | –                  | 25.0               | –                  | 28.0               |
| House 1 room (up to 2 pers.)| –          | 37.0               | –                  | 38.0               |
2.2. Regulations regarding ventilation in Spain, Italy, and Europe

The current legislation in Spain, Italy, and Europe is analyzed to calculate the main parameters needed to maintain healthy indoor air quality. The factors that most influence the improvement of health are air changes per hour, the minimum ventilation flow, and the concentration of CO$_2$ indoors, which will be studied according to the different legislation.

2.2.1. Minimum flow rate per house

2.2.1.1. For Spain and Italy. In Spain, according to CTE HS 3 "Indoor air quality", the amount of minimum flow in l/s, depending on the number of dry and humid areas present in the housing is taken into consideration (Table 3) (Ministerio de Fomento G. d., 2019).

In order to calculate the value of the minimum flow $q_v$ in l/s, it is necessary to consider the number of bedrooms and living rooms present in the housing (admission calculation) and the number of toilets and bathrooms (extraction calculation). The final result of the flow of the house will then be determined by the highest resulting value, whether of admission or extraction.

In the cooking zone of the kitchens, a system must be provided to extract the pollutants produced during use, independently of the general ventilation of the habitable premises. This condition is considered satisfied if a system in the cooking zone allows a minimum flow rate of 50 l/s to be extracted.

On the other hand, total floor area and overcrowding rate are considered for Italy to calculate the air flow. The following Tables 4 and 5 extracted from the UNI 10339 standard (Ente nazionale italiano di unificazione, 1995): "Hydraulic systems for welfare purposes: Generalization, classification and standard requirements" establish the reference for the design of ventilation installations.

Table 2
Characteristics of the selected homes in Spain and Italy.

| Housing | Nº. of total premises in the home | Nº. of dry premises | Nº. of humid premises | Spain | Italy |
|---------|---------------------------------|---------------------|-----------------------|-------|-------|
| House 1 | 3                               | 1                   | 2                     | 25.0  | 28.0  |
| House 2 | 4                               | 2                   | 2                     | 39.8  | 45.8  |
| House 3 | 5                               | 2                   | 3                     | 41.4  | 57.6  |
| House 4 | 5                               | 3                   | 2                     | 48.8  | 66.3  |
| House 5 | 6                               | 3                   | 3                     | 50.4  | 71.3  |
| House 6 | 6                               | 4                   | 2                     | 57.8  | 81.8  |
| House 7 | 7                               | 4                   | 3                     | 59.4  | 84.8  |
| House 8 | 7                               | 5                   | 2                     | 66.8  | 95.3  |
| House 9 | 8                               | 5                   | 3                     | 68.4  | 96.3  |
| House 10| 8                               | 6                   | 2                     | 75.7  | 108.8 |

Table 3
Minimum flow rate for constant flow ventilation in rooms. Source: CTE HS 3.

| Housing type | Minimum flow $q_v$ in l/s | Humid areas |
|--------------|---------------------------|-------------|
|              | Main bedroom              | Rest of bedrooms | Living room and dining rooms | Minimum in total | Minimum per area |
| 0 or 1 bedrooms | 8                         | –            | 6                          | 12               | 6               |
| 2 bedrooms    | 8                         | 4            | 8                          | 24               | 7               |
| 3 bedrooms or more | 8                         | 4            | 10                         | 33               | 8               |
2.2.1.2. For Europe. For further comparison, we consider the European standard EN 16798:2019 "Energy performance of buildings - Ventilation for buildings" (Comité Europeo de Normalización, EN 16798-1:2019, «Energy performance of buildings - Ventilation for buildings, 2019a; Comité Europeo de Normalización, EN 16798-2:2019, «Energy performance of buildings - Ventilation for buildings, 2019b») for Europe. The quality of the indoor environment by category (Table 6) is taken into account. The floor area and the people that can be set in case of non-residential buildings are considered.

As established by the EN-16792-2019, the air flow can be calculated according to the criteria based on predefined supplied ventilation air flow rates: total ventilation flow rate for case 1 and supplied air for cases 2 and 3 in residential buildings (Table 7).

Finally, combining the different options, the flow that presents the most restrictive data is chosen in the final analysis of the calculation.

2.2.2. Concentration of CO₂ for houses

2.2.2.1. For Spain and Italy. In Spain, as established by CTE HS 3 "Indoor air quality", a sufficient flow of outdoor air must be provided in the living areas of the houses so that the average annual concentration of CO₂ is less than 900 ppm and that the yearly accumulated CO₂ that exceeds 1600 ppm is less than 500,000 ppm per hour, at the same time (Ministerio de Fomento G. d., 2019).

Currently, there are no concentration limits of CO₂ provided by the Italian legislation for indoor residential environments, standards, etc., so they can be referred to as values present in the legislation of other countries or by analogy with other regulations or to values found in the scientific literature (Gaetano Settimo, 2016).

2.2.2.2. For Europe. According to the EN-16798-2 standard, the maximum concentration of CO₂ for each of the categories is shown in Table 8 (Comité Europeo de Normalización, EN 15251:2008, «Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics», 2008), referring to the premises and the outdoor concentration.

With reference to the UNE EN-171330 (Comité Europeo de Normalización, 2014) standard, showing the environmental quality indoors, a difference in the concentration of CO₂ of 500 ppm is established indoors with respect to the outdoor. In addition, it sets a maximum limit value of 2500 ppm.

2.3. Requirements established by different governments due to the pandemic

Due to the importance of eliminating the concentration of various pathogens in the air to minimize SARS-CoV-2 infections, various governments have published application guides with restrictions regarding the ventilation flow, air changes per hour, and the maximum concentration of CO₂ (ASHRAE, 2020; Bonadonna, 2020; Instituto para la diversificacíon y ahorro de energía, 2020; Rapporto Istituto Superiore della Sanità, 2020).

In Spain, recommendations for air conditioning systems and ventilation were issued to prevent the spread of the SARS-CoV-2. It is advised to keep the minimum outdoor flow rate to 12.5 L/s per occupant, which can be achieved by increasing ventilation or reducing occupation. In addition, an ACH of 2 air changes per hour is also indicated. Furthermore, it is recommended to make air flow checks, minimize air circulation in equipment, and increase natural ventilation to decrease contaminants diffusion (Ballarini, 2017). Regarding the CO₂ concentration, 500 ppm is indicated as an optimal value (Allen, 2020).

As for Italy, no official documents were found, indicating a minimum ventilation flow rate or air changes per hour, or even a maximum concentration of CO₂ in the indoor environment.

It is also essential to consider that the WHO advises controlling airborne transmission adequately, recommending a natural ventilation rate of at least 60 L per second, per person, and six air changes per hour (Dai, 2020; Gobierno de España, 2020; World Health Organization, 2020).
Consideraciones para la cuarentena de los contactos de casos de COVID-19, World Health Organization, Gestión de la COVID-19 en hoteles y otras entidades del sector del alojamiento.

3. Results

The analysis, next provided, shows the statistical results arisen from comparing the ventilation parameters, taking into account ten types of selected dwellings (Fig. 1). Summary tables and graphs are presented, showing whether the current regulations meet the new criteria established during the COVID-19 pandemic, including the relationship between Italian, Spanish, and European regulations.

3.1. Comparative analysis between the minimum flow regulations and the COVID-19 directives

To evaluate all the aspects mentioned above, the analysis with StarGraphics of the ventilation parameters in a generic residential building was carried out considering ten types of dwellings and a variable number of occupants.

3.1.1. For Spain and Italy

In Spain, the calculation of the minimum ventilation flow is carried out based on the number of dry and humid premises present in the house, according to the Spanish standard CTE HS 3 “Indoor air quality” (Ministerio de Fomento G. d., 2019).

3.1.2. Concerning the calculation of the air flow for Italy, the floor area of the housing and the rate of overcrowding are considered instead. The flow calculations per dwelling are made following the UNI 10339 (Ente nazionale italiano de unificazione, 1995) standard: “Hydraulic systems for welfare purposes. Generalization, classification and standard requirements”

The results, shown in Fig. 2, indicates that the Italian legislation is more restrictive than the Spanish one, obtaining the maximum difference in flows for house typology 2 and 3, with a percentage difference between the adopted regulations of 81%. In addition, in both regulations, it is observed that the most significant gap in the increase in ventilation is obtained between housing typologies 5 and 6, that is, when passing from two to three bedrooms. The recommended ventilation for times of pandemic is higher than that established in both legislations.

The one-way analysis of variance (ANOVA) showed that the Spanish regulations (Table 9) the results obtained are consistent with the European standard EN 16798 (Comitè Europeo de Normalización, 2017) along with the related interpretation of requirements contained in CEN/TR 16798-2:2019 (Comité Europeo de Normalización, 2019b). The percentage difference between the two categories is 15.4% and 35.3%, calculated by area and by person, respectively.

Comparing the results obtained with the European regulations with those of Spain and Italy, one can observe that the required values are higher in Italy, no matter the calculation is made by area or by person. In the case of Spain, the ventilation flow values are lower than those required by Europe, both for the calculation made by area or by person.

The analysis using one-way ANOVA indicated that applying the criteria of the European regulations for both countries, the ventilation criteria are considerably different, being F (4493) = 10.05, for p < 0.005.

3.2. Comparative analysis between the regulations on ACH and the COVID-19 directives

3.2.1. For Spain and Italy

According to the Spanish and Italian regulations, the calculations here are made by considering the European standard EN 16798 (Fig. 4) and the data on the minimum square footage for houses and bedrooms.

The highest data in the ventilation flow table were chosen as optimal. ACH was then calculated considering the height of the room(s), for the Spanish (2.5 m) and the Italian (2.7 m) cases. The ACH results turn out to be lower compared to the Covid-19 guidelines that establish a minimum of 2 ACH according to the government of Spain.

To quantify the ratio of the flow rate and changes per hour of ventilation air, we performed a statistical study on the data, using a simple regression model to compare both variables with the Italian and Spanish regulations (Table 9). The results obtained are consistent with the data shown in Figs. 2 and 3. The correlation coefficient between the flows largely explains the observed trend in these data. On the contrary,
in the air changes per hour of ventilation air, the corresponding value is close to 0, showing little correlation.

3.2.2. For Europe

In the case of Europe, EN-16792-2019 establishes an air changes per hour’s value of 0.7 for category I (the most restrictive) and 0.6 for category II. In the case of Spain, only typologies 2 and 3 remain below these levels. In Italy, no obtained values are below 0.6.

3.3. Comparative analysis between regulations on CO₂ concentration

This analysis is done with the criteria established by European regulation, Spanish guidelines, and recommendations against the COVID-19 regarding CO₂ concentration (Table 10).

The Spanish regulations present very restrictive CO₂ concentrations in the interior, being this of 900 ppm, provided that the annual accumulated CO₂ that exceeds 1600 ppm is less than 500,000 ppm⋅h. But according to the recommendation guide in times of COVID, it is suggested that the concentration is not greater than 500 ppm. However, the European regulations EN-16798-2 and EN-171330-2 present limit values depending on the internal concentration compared to the external one, having a maximum difference of approximately 550 ppm (depending on the category). It can be seen that they are very different criteria that should be unified for the dimensioning of ventilation in homes and the improvement of people’s well-being.

4. Conclusion

In light of the growing evidence of the risks of airborne transmission of the SARS-COV-2 virus, a need to reconsider the parameters established by law to ventilate spaces in residential buildings arisen. Within the general framework of European, Italian and Spanish regulations, this study then investigated whether the values of the parameters adopted for the design of ventilation in homes are sufficient to ensure adequate indoor air quality.

Natural ventilation is an affordable and sustainable method to achieve this goal, but it presents discrepancies in the calculation variables. We have shown that for Italy, the air flows required in the applicable regulations are more restrictive than in Spain, especially for larger houses. Significant differences in this sense have been observed for all types of considered housing solutions, except number 1, which is the one with the smallest surface area. However, the ventilation flow established by the Spanish regulations presents better results than the Italian ones, since an air flow of 12.5 l/s per person is foresees for the former case. As for the European regulations, the resulting air flows, both in terms of

Table 9
Correlation between Spanish and Italian regulations.

| FLOW          | ACH       |
|---------------|-----------|
| Correlation coefficient = | 0.8746   |
| R-squared =    | 74%       |
| Correlation coefficient = | 0.1748   |
| R-squared =    | 9%        |

Table 10
Comparison of CO₂ concentration results by the different regulations.

| CO₂ concentration | Spain | Spain | Europe | Europe | Europe |
|-------------------|-------|-------|--------|--------|--------|
| CTE HS 3 Spanish recommendation for Covid-19 | EN 16798-2 (Rooms) ΔCO₂ In-Out | EN-16798-2 (Living rooms) ΔCO₂ In-Out | UNE-EN-171330-2 ΔCO₂ In-Out |
| ppm | 900 | 380 | | | |
| ppm | 500 | 550 | | | 500 |
surface area and number of occupants, are much lower than those established by Spanish and Italian legislation.

Regarding the number of air changes per hour, the values are less than 2 ACH, both for Italy and Spain, yet somewhat higher for the latter country, as it features areas with lower volumes. This implies the need to increase the criteria established in the different regulations to gain 6 ACH, recommended by WHO. Regarding the CO2 concentration, the legislated values must not exceed a concentration difference between the indoor and outdoor environment of around 500 ppm. As a matter of fact, Spain presents a higher risk of excessive pollutant concentration due to the lower volumes in the different rooms of the houses, compared with the corresponding minimum dimensions established in Italy. The ventilation flows indicated by different standards are insufficient to comply with the number of air changes per hour recommended by WHO and, consequently, with decreasing levels of indoor CO2 concentration. Therefore, it would be appropriate to increase the minimum health measures in terms of inner ventilation, considering that it is a space where we spend more hours than before, as there are no laws that currently establish optimal measures that guarantee to avoid contagion via aerosol sprays.

As a result of this study, the need has arisen to update the legislation on ventilation, since the criteria established long ago are not currently adequate to avoid contagion by aerosols indoors. Under the proposed new paradigm, the air is supplied to building occupants for breathing, not for heating or cooling. For this reason, future efforts are also necessary to expand this research, in the general framework of natural and forced ventilation systems, comprehending other factors such as occupation, activity, weather conditions, energy efficiency, etc.

It should be noted that the obtained results are based on simplified assumptions, without taking into account many influencing factors such as temperature, humidity, evaporation of droplets, etc. Yet, this research can be considered a first step to understand the criteria required for ventilation in residential buildings to address the prevention of the transmission of infectious diseases.

Declaration of Competing Interest

None

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