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Ventilation time recommendation system incorporating local meteorological data

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Abstract

Since the airborne transmission of SARS-CoV-2 is the key in the spread of COVID-19, the interest in the quality of the air in enclosed spaces has become utmost importance. Natural ventilation is the first obvious option to improve epidemiological security, and general rules have been widely disseminated. Nevertheless, the changes in weather conditions greatly limit the validity of such rules. Here we present a system that, upon the introduction of basic parameters of a given space, its volume, location, orientation, architectural environment and average occupancy, yields optimized ventilation times on the basis of wind meteorological forecasts. It has been successfully implemented in the educative system of the Autonomous Community of Galicia (northwest Spain) and it is currently operative.

Keywords

Ventilation protocols, meteorological data, computational fluid dynamic techniques, online application implemented in Galicia (Spain), disease control, air quality, educational system

Introduction

The improvement of the air quality in indoor inhabited spaces is an obvious subject of interest.[1] Namely, high levels of CO_2 would lead to a series of undesired effects (decrease of attention, sleepiness, …) that are typically manifested in teaching environments,[2] and, therefore, a notable part of the focus has been directed to classrooms, by setting up strategies to assure good air quality there.

However, the COVID-19 (coronavirus disease 2019) outbreak has boosted the need for such studies since the airborne transmission of SARS-CoV-2 (Severe Acute Respiratory Coronavirus 2) has been understood. Evidence from superspreading events, where numerous people are infected at the same time, usually in a crowded indoor space, clearly pointed to airborne transmission.[3] Now, it is widely accepted that inhalations of SARS-CoV-2 represent a major route for the spreading of COVID-19.

When this new scenario was assumed by the scientific community, aerosols exhaled by infected individuals were observed to travel to a distance of more than 2 m.[4] This challenged the initial recommendation given by the World Health Organization,[5] based on the fact that the typical falling radius of droplets larger than 100 µm in diameter is around 2 m, and also based on the risk of transmission through contact with surfaces.[6] Due to this new paradigm, human exhaled aerosols can be accumulated in poorly ventilated air, leading to superspreading events[7] or, at least significantly increasing the risk of contagion. Therefore, as indicated by Prather et al.,[3] a key factor to control the spread of SARS-CoV-2 is the improvement of indoor air quality and, in this task, natural ventilation is the first option to be studied. Some authors suggested that improving the ventilation system is even more important than sterilizing surfaces.[8]

Besides specific solutions to be implemented by specialists, several general guides for ventilation have appeared since then in different formats, strategies and recommendations, with useful information and tips. Among the contents of such guides, schematic drawings recommending crossed ventilation or pointing to ideal geometries of

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windows and doors in classrooms are included. Of course, these are generic suggestions, that neglect the ubication and orientation and other specific characteristics of the classroom, and this alters notably the dynamics of the ventilation mechanism, simply because the wind conditions on the windows change completely the flow inside the considered volume.

Here we are presenting a system that after the introduction of simple data of indoor space and its environment, yields estimations of adequate ventilation times. The system automatically includes meteorological data from the local meteorological service. Its simplicity allows massive implementation and general use for non-skilled users. It is currently being applied to the whole system of primary and secondary education of the Autonomous Community of Galicia (Spain), which consists of around 1400 buildings with an estimate of around 20 000 classrooms. In this manuscript, we describe first the basic principles sustaining the method. Followed by the description of the implementation protocol considered, then, we analysed the first data after activating the application.

General considerations about the ventilation problem

There is a myriad of effects that intervene in the determination of the optimal conditions to ventilate a room and many of them are strongly dependent on the specificities of the building under consideration. The purpose of this paper is to present a simplified model that still preserves the most relevant factors in the problem and that still can be used as a guide to ventilate each of the 20 000 classrooms in the region. With this in mind, we can try to classify the different aspects involved in the problem as follows.

Thermal conditions in the classroom and spaces next to it

In the spirit of simplification of the problem, we considered that the classroom and the surroundings are at the same temperature and, thus, there are no convective flows due to temperature gradients or thermal sources (heating). Strictly speaking, even the body heat produced by occupants of the classroom should be taken into consideration. Nevertheless, we opted to neglect this effect as it was a piece of information impossible to acquire for all the 20 000 classrooms in the Galician educational system. This is, indeed, an oversimplification of the problem but keeps our considerations in the 'safe' zone. In fact, all thermal gradients present in the system would contribute to circulate the air in the room and facilitate the mixture and the ventilation. Thus, neglecting these effects would result in a more conservative scenario where the safety of the occupants is the first priority.

Wind and meteorological conditions in that particular location

This is the main effect considered in this proposal and it is a very important one for the particular location considered. Galicia is located in the northwestern corner of Spain and its climate is mild oceanic, characterized by relatively mild temperatures all over the year (the average temperature in Galicia is between an average of 7 degrees Celsius in January and 18 degrees in August) and a long rainy season (winter). Spring and Autumn seasons are characterized by mild temperatures (8–13°C) and important precipitations in form of rain almost everywhere in Galicia. Rainfall is usually abundant, exceeding 1000 mm per year almost everywhere, becoming close to 2000 mm along the west coast and on the west-facing slopes. The wind blows frequently and can be stormy in the cold season. From these climatological data two important facts can be inferred: a) it rains a lot and keeping the windows always open is not an option on many days; and b) the wind is a very important factor that is mostly present in almost all locations in Galicia (especially in the coast). The comfort level of occupants, measured by the average temperature of the classroom, is another parameter that is important to consider especially in the cold winter days, when keeping windows open at any time is not an option. The public meteorological service of Galicia (Meteogalicia) provides a twice daily detailed meteorological information with a spatial resolution of 4 x 4 km^2. This invaluable information is available for integration into any ventilation model upon request.

Environment location

This effect considers the type of artifacts (additional buildings, tall trees, etc.) in the close vicinity of the ventilation areas of each classroom. Classrooms with windows facing an internal patio or a narrow street are obviously less likely to feel the effect of the wind than a classroom facing an open space. This type of information is relevant and is considered in the model.

The occupation of the classroom and the use of CO_2 concentration as a proxy of air quality

CO_2 detectors are widely available, and the measure of its concentration is an accepted indicator of air quality in buildings and of the effective outdoor air supply rate in occupied rooms.[9] With this in mind, the number of students in the classroom and the type of activity developed by the occupants may determine the amount of CO_2 produced and the quality of the breathable air in the room. The exhaled CO_2 is also a proxy of COVID-19 infection risk for indoor activities.[10]

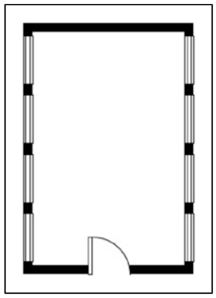

Figure 1. Scheme of a classroom with a configuration of doors and windows optimal for ventilation.

Table 1. Values of the parameters used in the balance equation.[11] $\boldsymbol{C_{out}}$ is the typical concentration of CO_2 in the fresh air in Galicia. The X's indicate the average volumes of CO_2 exhaled per unit time and per person (m^3/h).

Parameter	Value
$\boldsymbol{C_{out}}$	380 ppm
$\boldsymbol{X_{teacher}}$	0.0221 m^3/h
$\boldsymbol{X_{primary}}$	0.0112 m^3/h
$\boldsymbol{X_{secondary}}$	0.0148 m^3/h

Geometrical properties of the classroom

The distribution of the space inside the classroom and the actual relative location of doors and windows is important as it would determine the effectiveness of the ventilation. Clearly, a room with a small window located in a corner and the door close to it would need more time to completely renovate the air inside than a room with windows covering opposite sides of the classroom. Unfortunately, the typology of classrooms is highly variable and there is no simple systematic way to include this effect in the models without analysing each of the 20 000 classrooms individually. In the following, we consider a classroom configuration that ensures optimal ventilation (see Figure 1 for an example of a classroom configuration with optimal ventilation). Nevertheless, we present some recommendations (based on detailed analysis of several standard configurations) at the end of the paper that aim to resolve this problem and make our results of general applicability.

Variations of CO_2 in a room: CO_2 balance equation

In the COVID-19 pandemic context, the contagion risk in a given room would increase with the amount of exhaled air and, accordingly, with the amount of CO_2 expelled by its occupants.[4,10] Thus, there are two factors that contribute to variations to the CO_2 concentration in the room. On one hand, the CO_2 produced by all occupants in the classroom (which is always a positive contribution) and, on the other hand, the fresh clean air exchanged with the exterior through open windows and/or doors. In this case, equation (1), the balance equation describing these effects, as follows[11]:

$$V_{class}\frac{d\,C}{d\,t} = \phi\, C_{out} - \phi\, C + G \tag{1}$$

where C is the CO_2 concentration in the room (units are typically given in ppm, parts per million, although for this equation we used parts per unit), V_{class} (m^3) is the total volume of air (that it is specific of each classroom and should be provided by each educational institution), ϕ (m^3/s) is the flow of fresh air entering the room that, for continuity, equals the flow that leaves the place, C_{out} is the concentration of CO_2 in the fresh air coming from outside the classroom and G (m^3/s) is the volume of CO_2 generated by occupants in the classroom per unit time. The value of ϕ never equals zero as some windows may not close tightly, or due to cracks or more importantly, the classroom door is always open (as mandated by the local authorities during the pandemic crisis). The intensity of this infiltration is considered to be dependent also on the wind intensity as during a windy day the infiltration of fresh air is significantly larger than on a calm day. The percentage of infiltration during the closed-windows period were estimated by comparing with experimental measurements and was set equal to 5% of the airflow entering the classroom with open windows. This value was estimated from

Table 2. Example of wind velocity values provided by the local forecast service in Galicia (MeteoGalicia) at a height of 10 m. U is the component of the wind velocity in the E-W direction with positive values facing E and V is the orthogonal N-S component of the wind velocity with positive values pointing *N*. An equivalent set of values is provided for each of the locations of the different classrooms considered, twice per day, all days of the week. These values should be multiplied by a factor of 0.4 in order to extrapolate the results to a 4 m height.

Date	uj (m/s)	vj (m/s)
30/01/2021 08:00	2.20	8.66
30/01/2021 09:00	3.29	10.17
30/01/2021 10:00	2.98	8.21
30/01/2021 11:00	2.65	9.27
30/01/2021 12:00	3.12	9.87
30/01/2021 13:00	1.02	12.06
30/01/2021 14:00	0.33	8.18
30/01/2021 15:00	0.79	8.54
30/01/2021 16:00	0.37	8.93
30/01/2021 17:00	−0.34	8.74
30/01/2021 18:00	0.10	8.34
30/01/2021 19:00	−0.79	8.70
30/01/2021 20:00	−1.79	6.88
30/01/2021 21:00	−2.10	7.78
30/01/2021 22:00	−2.36	6.71

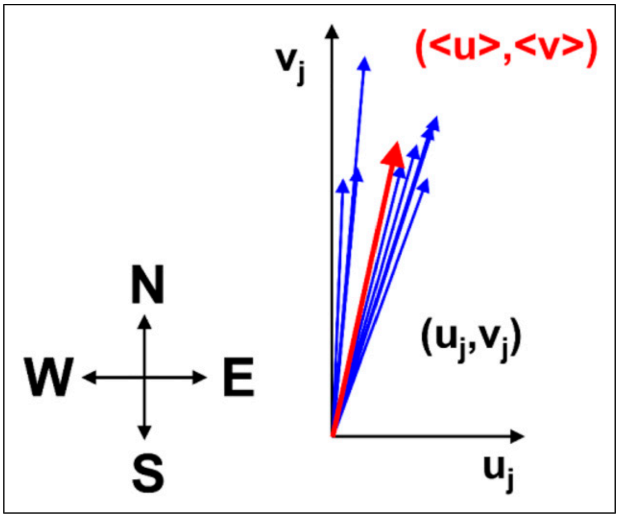

Figure 2. Representation of typical values (morning period, from 8:00 until 15:00, taken from Table 2) of the wind velocity for a particular location. For the calculation, MeteoGalicia uses a square tessellation of Galicia with a step of 4 km inside. The red arrow represents the average value of the wind velocity for the morning period assigned to the square surface of 4 x 4 km^2.

the empirical observations done in some classrooms. This is, indeed, a rough estimation as its actual value may strongly vary from class to class, Nevertheless, 5% seems a reasonable value. All these factors allow some permanent flow of air in and out of the classroom independently of whether windows are open or not.

The value of C_{out} changes from one location to the next as it is strongly influenced by the contamination levels in the area. Galicia is one of the cleanest regions in Spain due, in part, to the significant rainfall along most of the year that cleans the air and the lack of high-contaminant industries. Another factor is the dispersion of the educational institutions across the territory (in the same way that the population is distributed).[12] with many located in predominantly rural areas where the air quality is exceptionally clean. Thus, a reasonable value for Galicia is $C_{out} =$ 380 ppm (parts per million),[13] (see Table 1).

As indicated below, we considered that the fresh air entering the room is forced by the wind conditions in the particular location. In order to determine the flow of fresh air into the classroom, we used the expected average value of the velocity (provided by the twice-daily forecast given by MeteoGalicia). The classrooms were considered to only have external ventilation (i.e., there are no air conditioning units, which is the case for the vast majority of classrooms considered) and the exchange of air is only with the outside and the corridor that it is supposed to be well ventilated at any time (following the norm dictated by the local educational authorities).

In that case, the fresh air flow entering the room per unit time (that equals the flow leaving the room) is given by equation (2):

$$\phi = A_{vent} v_{\perp} \tag{2}$$

where A_{vent} is the total area open to the exterior used by the air to flow into the room. $v_{\perp}$ is the component of the wind velocity perpendicular to the ventilation surface (this value is provided by the weather forecast). In order to determine the effective ventilation area, A_{vent}, we provide the schools with some schematics with the most common types of windows and examples to calculate the effective area based on geometrical considerations.

As mentioned before, the local weather forecast service (MeteoGalicia) provides with hourly predictions of the wind intensity and direction at any location in the framework of a square tessellation of 4 x 4 km^2 of Galicia (see Table 2 for an example). This forecast corresponds with the values of the wind velocity at 10 m height and, thus, should be corrected before incorporating them into the calculations. As most of the educational facilities considered are typically three-storey buildings, we extrapolate these values to a generic height of 4 m by multiplying the values of the predicted velocities by 0.4. This linear approach is, indeed, a rough estimation as the real profile is determined by the Atmospheric Layer (ABL) which is a non-trivial problem that also takes into consideration the nature of the terrain.[14,15]A detailed analysis of the problem shows that the linear approximation that was taken always considers smaller values for the velocity than the realistic values given by ABL (see the Appendix for details). As one of the leading factors in this project was to keep the safety inside the classrooms, we considered the linear approximation, as the effective ventilation is always going to be better than our estimate. Also, considering a simple 0.4 factor multiplying the values of the velocity given by MeteoGalicia added simplicity to all the calculation processes, but always keeping the safety of students and the quality of the air inside as a priority. The effect introduced by the type of environment surrounding the classroom is considered below.

We considered two school shifts. The first period was from 8 a.m. till 3 p.m. and the second shift was from 3 p.m. till 10 p.m. (10 p.m. can be the closing time of several secondary schools in the night shifts of adult educational programs). For each of these two periods, we estimated the average value of both components of the velocity and the standard deviation, which would provide an indication of the fluctuation in the wind intensity for that period. Figure 2 plots the velocity values for a random morning period (in blue) and the average (in red). Table 2 is an example of a list of typical values provided by the meteorological service.

The effective value of $v_\perp$ is positive if the wind blows in a direction opposite to the windows. In that case, the application considered that the ventilation due to the wind effect is negligible and the standard ventilation recommendation was given by the education authorities. The quality of the air in the corridor is guaranteed as it was mandatory that all corridors in the educational system must be permanently ventilated at all times.

The last term in equation (1) is G, defined as the volume of CO_2 generated by occupants of the classroom per unit of time. In order to calculate this term, we need to know the amount of CO_2 expelled by each individual. In general, it can be evaluated using equation (3):

$$G = NX_{student} + X_{teacher} \tag{3}$$

where N is the typical number of students in the classroom, $X_{student}$ is the volume of CO_2 produced by a single student per unit time and $X_{teacher}$ is the volume of CO_2 produced by the teacher in that time (units are m^3/h). The units of G are, thus, m^3/h. We differentiated the amount of CO_2 expelled by the teacher from the students as usually her/his role is more active (mostly because of the speech) and, thus, the value of $X_{teacher}$ is larger. Also, as the value of $X_{student}$ depends on the age of students in the classroom, we differentiated (following)[11] between students in primary education (typical ages ranging from 6 to 11 years) and students in secondary education (with typical ages ranging from 12 to 18 years). We adhered to the reference average values[1] listed in Table 1. These values (Table 1) were measured[11] by other authors and we used them in our calculations.

There is an additional factor lately introduced in the classroom dynamics due to the existence of the COVID-19 pandemic: the wearing of facial masks. Their use has proven to be determinant in controlling the spread of the pandemic as they prevent the dissemination of little droplets containing the virus.[16] Some authors measured the levels of CO_2 inside the masks and determined that under some circumstances they may reach non-comfortable levels.[17] This can be a problem, but it does not significantly modify the amount of CO_2 expelled into the classrooms, although the number of droplets expelled by each individual is significantly reduced. In fact, some reduction of the total CO_2 expelled could be expected but due to metabolic changes triggered by the continuous inhalation of excessively concentrated CO_2 in air. In any case, and always trying to be on the more conservative side, this is not a factor that should be included in the equations.

From the dynamics explained, some characteristic times can be estimated. First the configuration of a closed classroom (thus $\phi = 0$) was considered with students inside under normal conditions. From equation (1) the variation of CO_2 concentration is given by equation (4):

$$V_{class}\frac{d\,C}{d\,t} = G \Rightarrow t = \frac{(C - C_{out})\ V_{class}}{G} \tag{4}$$

This equation tells the time needed to reach a particular CO_2 level starting from a basal configuration with an initial CO_2 concentration equal to C_{out}. An interesting value is the time needed in that particular classroom to reach a level of CO_2 equal to $C = 1000\ ppm$ (values of CO_2 above the range 800–1000 ppm are considered inappropriate).[18,19] We defined this value by equation (5):

$$T_{close} = \frac{(1000\ ppm\ -\ C_{out})V_{class}}{G} \tag{5}$$

and gives information about the characteristic time for a particular classroom to reach large values of CO_2. The infiltration is not included in the calculation of T_{close}, thus, the actual values of CO_2 in the room can be significantly smaller than 1000 ppm depending on the meteorological conditions.

The other characteristic time is related with the time needed to renew the air in a classroom due only to the wind blowing at the windows. ϕ, by definition, is the volume of fresh air per unit time flowing into the classroom and through the windows (this flow, as calculated above with equation (2), considers the ventilation surface and the local meteorological conditions). ϕ times the time the windows are open gives the total volume of fresh air entering the

Table 3. Different generic surrounding landscapes. First column is just a label to refer to each class of configurations. The last column gives the ratio of wind (K) actually reaching the windows of a classroom with that particular configuration.

Category	Description	K
A	Classroom facing a small street or inner courtyard with no ventilation	0.0
B	Windows open to a broad street with buildings located at 20 m or more (average urban context in Galicia)	0.2
C	Windows open to a large space with some disperse obstacles such as tall trees or some isolated constructions	0.65
D	Classroom facing an extension of land with no obstacles and almost unlimited vision	1.0

room, that should equal the volume of the classroom, as defined by equation (6).

$$\phi T_{open} = V_{class} \Rightarrow T_{open} = \frac{V_{class}}{\phi} \quad (6)$$

In practical situations, the total time needed to completely refresh the air in a classroom might be longer due to mixing processes with the pre-existing air, etc., thus, we define this reference time with a factor 2 to account for these effects as given in equation (7).

$$T_{open} \equiv 2\,\frac{V_{class}}{\phi} \quad (7)$$

Due to the form of equation (1) the CO_2 decaying curve is expected to be exponential with a decaying exponent given by $\frac{\phi}{V_{class}}$. Thus, the value of T_{open} defined in equation (7) corresponds with the time needed to reduce the CO_2 concentration inside the classroom by a factor $e^{-2} \approx 0.13$. This is still an approximation as it considers that the incoming air mixes perfectly with the existing air which is not usually the case. Nevertheless, we considered it a good approximation in the context of the present work and always trying to keep things simple.

Also, the air inflow given by ϕ depends linearly on the wind velocity at the windows and for this velocity we have a mean value and a standard deviation. Thus, we have a maximum and a minimum wind velocity blowing through the windows, and this allow us to calculate a minimum and a maximum (respectively) period of ventilation that are the recommendation for that particular case.

These two characteristic times defined by equations (5) and (7) were used to define the ventilation protocol.

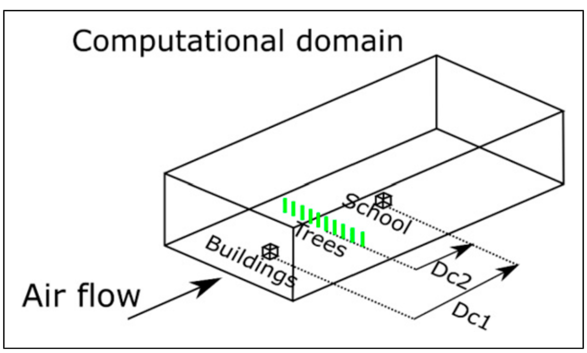

Figure 3. General scheme of the computational domain. Dc1 indicates the distance considered in the configuration in category B (from buildings to school) and Dc2 in the category C (from trees to school) as explained in Table 3 below. Buildings were designed as blocks with dimensions 10 x 10 (base) x 15 m^3 height and the façade of the school where fluid flow was computed has dimensions 50 x 10 m^2.

Numerical simulations using computational fluid dynamics techniques

Numerical simulations were carried out in order to characterize outside wind conditions under different school environments and, also, analyse air circulation inside the classroom and the variations it might introduce in the ventilation time. We use Star-CCM+ software[20] to design the geometries, build the mesh, solve the governing equations (Navier-Stokes) using finite volume method (FVM)[21] and postprocess the results.

Navier-Stokes equations (conservation of mass and momentum) governing fluid flow are as given in equation (8),

$$\begin{aligned} &\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = 0 \\ &\frac{\partial \rho u_i}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \end{aligned} \quad (8)$$

where u_i are the wind velocity components (u, v, w), ρ is air density, μ dynamic viscosity and t is the time.

In order to characterize the fluid flow, Realizable k-epsilon turbulent model was considered as suitable for numerical simulation of wind flow around buildings[22] and air circulation inside a room.[23] In addition, a two-layer approach[24] was used in order to gain added flexibility of an all -y^+ wall treatment.

Table 4. Mesh test performed to preserve the accuracy of the numerical method still minimizing the computational times.

	Number of faces	Effective mass flow on the facade of the school located 10 m away from the tree line (category C configuration)	Variation %
Mesh 1	4 201 038	62 %	***
Mesh 2	4 625 980	61 %	0.50%
Mesh 3	5 125 896	62 %	0.70%

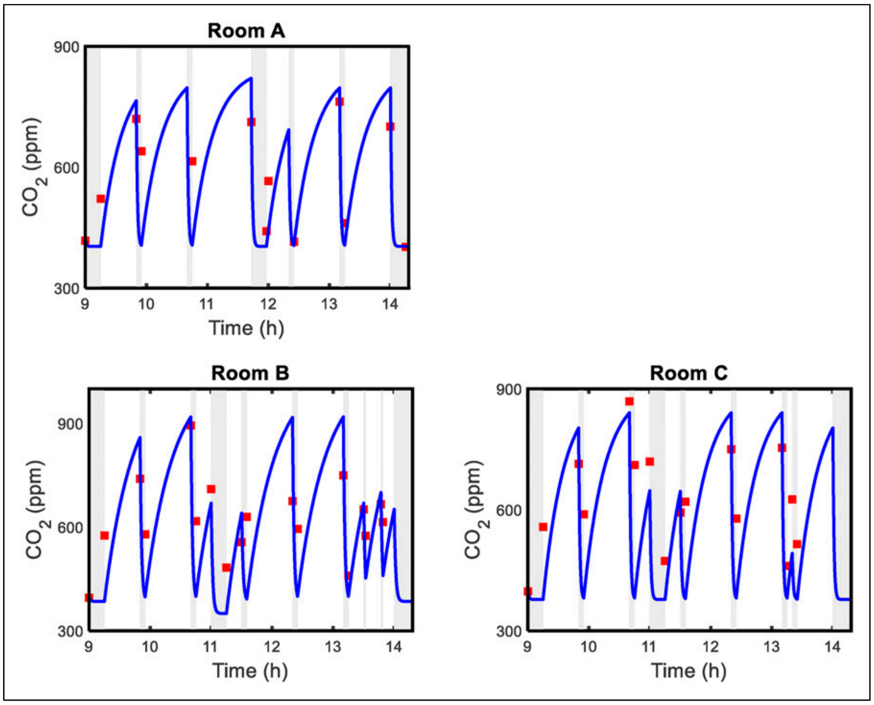

Figure 4. Experimental measurements of CO_2 concentrations (full squares in red) compared with CO_2 concentrations as predicted by the model (continuous blue line). Areas in grey mark the periods of ventilation with all the windows open as well as the door leading to a well-ventilated area. A residual opening is always considered equal to 5% of the total opening in the classroom. Model parameters for Room A: $N = 15$, $V_{class} = 141\ m^3$, $A_{vent} = 3.8\ m^2$, $v_\perp = 0.6$ m/s. Model parameters for Room B: $N = 17$, $V_{class} = 141\ m^3$, $A_{vent} = 2.7\ m^2$, $v_\perp = 0.6$ m/s. Model parameters for Room C: $N = 18$, $V_{class} = 141\ m^3$, $A_{vent} = 3.8\ m^2$, $v_\perp = 0.6$ m/s.

The transport equations for the kinetic energy k and the turbulent dissipation rate ε are as given in equation (9):

$$\frac{\partial}{\partial t}(\rho k)+\nabla\cdot\left(\rho k\overrightarrow{v}\right)=\nabla\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\nabla k\right]+P_k-\rho(\varepsilon-\varepsilon_0)$$
$$+S_k\frac{\partial}{\partial t}(\rho\varepsilon)+\nabla\cdot\left(\rho\varepsilon\overrightarrow{v}\right)=\nabla\cdot\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\nabla_\varepsilon\right]$$
$$+\frac{1}{T_e}C_{\varepsilon 1}P_\varepsilon-C_{\varepsilon 2}f_{2\rho}\left(\frac{\varepsilon}{T_e}-\frac{\varepsilon_0}{T_0}\right)+S_\varepsilon \tag{9}$$

where $\overrightarrow{v}$ is the mean velocity, μ is the dynamic viscosity; $\sigma_k = 1$, $\sigma_\varepsilon = 1.2$, $C_{\varepsilon 1} = 1.44$ and $C_{\varepsilon 2} = 1.9$ are model coefficients and P_k and P_ε are production terms defined by equation (10):

$$\begin{aligned} P_k &= f_c G_k + G_b - \gamma_M \\ P_\varepsilon &= f_c S_k + C_{\varepsilon 3} G_b \end{aligned} \tag{10}$$

with $C_{\varepsilon 3}$ is a model coefficient that is, following,[25] using $C_{\varepsilon 3} = tanh\frac{|v_b|}{|u_b|}$ where v_b and u_b are velocity components parallel and perpendicular to the gravitational vector g. f_c is the curvature correction factor calculated as in.[26] G_b and G_k are buoyancy and turbulent production. γ_M is compressibility modification.[27] $f_2 = \frac{k}{k+\sqrt{\nu\varepsilon}}$ is a damping function. S_k and S_ε are user-defined source terms. Air density was set equal to 1.20 kg/m^3 and viscosity equal to 1.82 10^{-5} Pa·s[28].

In the following subsections, we describe the specific details of the simulations to determine the effect of the environment of a school and those describing the air circulation inside the classroom.

Numerical simulation of wind flow outside the school

Geometry. A computational domain with dimensions 600 x 400 x 150 m^3 was considered. These dimensions were chosen so that the domain is large enough compared with the dimensions of the buildings and in order to avoid reflection of the fluid streams and other unwanted effects caused by the proximity to the boundaries. Dimensions were set according to AIJ.[29] (Architectural Institute of Japan) standard, H being the height of the highest structure in each configuration, lateral and top boundaries were set as 5H or farther away from the structure and outflow boundary was set as more than 10H behind it. Buildings were designed as 15 m height blocks with a 10 x 10 m base area

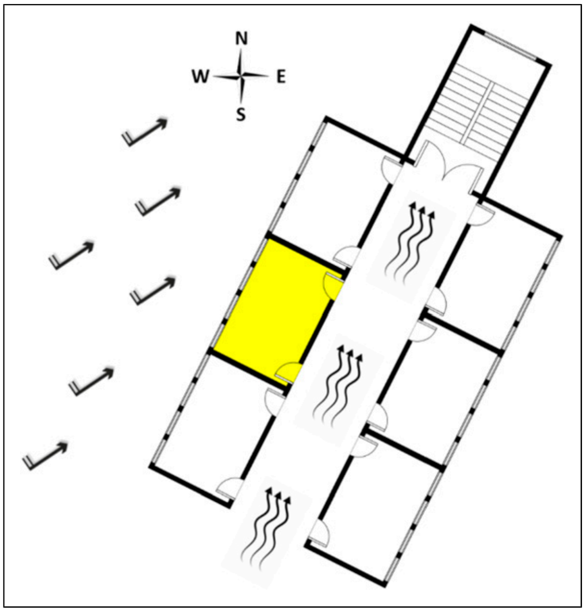

Figure 5. Different classroom configurations were analysed considering typical distributions of doors and windows. (a) t = 0 s, (b) $t = 12.5$ *s*, (c) $t = 25$ *s*, (d) $t = 37.5$ *s*, (e) $t = 50$ *s*, (f) $t = 62.5$ *s*.

whereas the trees were designed as a system of blocks with a small separation between them in order to simulate the loss of wind velocity when crossing them. Different configurations were taken into account along the simulations considering additional buildings of trees partially blocking the air from reaching the classroom windows as summarized in Table 3 below. A general scheme of the computational domain is described in the Figure 3.

Mesh. In order to solve the governing equations of the flow, the computational domain is discretized in a mesh with small polyhedral elements. The mesh was built using a module embedded in StarCCM+ with an auto-generation volumetric mesh tool and volumetric controls to ensure the desired shape and type of refinement. All the meshes considered have a special refinement near the buildings and the school in order to capture all the local phenomena that affect the ventilation of the school. This refinement is more significant in configurations compatible with category C (4 201 038 faces) that in category B (3 135 614 faces) and was set considering hexahedral layers with a stretching ratio of 1.3 and a minimum of 10 grids around each structure. In this way, it assures that the phenomena around the small blocks (simulating the trees) were still fully captured and were according to AIJ[29] (Architectural Institute of Japan) and COST[30] (European Cooperation in Science and Technology standards). To ensure that the results do not depend on the mesh, three different meshes were built for each configuration with an increase factor in the number of faces of 1.1. Table 4 shows the results obtained for category B.

As the difference in the results is less than 1% between different meshes, we opted to perform all the simulations using Mesh 1 in order to optimize the computation time.

Boundary conditions and numerical models. The inlet velocity was fixed as the boundary condition and its value was set equal to 4 m/s which is a typical value in Galicia. This value actually changes depending on the location, day and time but this value provides a characteristic value. In order to obtain an accurate description of a particular classroom, we should include all the specific information for that place including the actual wind conditions. However, this was unrealistic when 20 000 classrooms were considered. Only 12 generic configurations (suggested by the academic authorities as the most common in our educational system) were analysed to provide a reference.

Atmospheric pressure was set as the outlet boundary condition and the symmetry condition was used in the other walls that delimit the computational domain. SIMPLE algorithm was used for pressure-velocity coupling and second-order upwind discretization schemes were used for the conservation of mass and momentum equations.

Air circulation inside the classroom

Mesh. The interior space of the classroom was divided into polyhedric elements in order to describe the fluid (air) inside and its dynamics by solving the Navier Strokes equations. The mesh has approximately 1 100 000 faces with slight variations depending on the classroom configuration. A similar test to the previous subsection was performed (not shown) in order to verify the independence of the results with respect to the mesh size.

Boundary conditions and numerical models. As before, atmospheric pressure was set as outlet condition (door), the velocity equals 4 m/s as inlet (windows) and no-slip conditions in the walls.

Empirical data to validate the equations

In order to validate the balance equations, direct CO_2 measurements were done in an actual classroom during normal teaching activities. The results presented in Figure 4(a) correspond with a classroom (Room A) occupied by 15 students in 3rd grade (primary) plus the teacher during the regular activities. A CO_2 sensor was placed inside the room at different times. The total volume of the classroom is 141 m^3, with four windows located on one of the walls (1.38

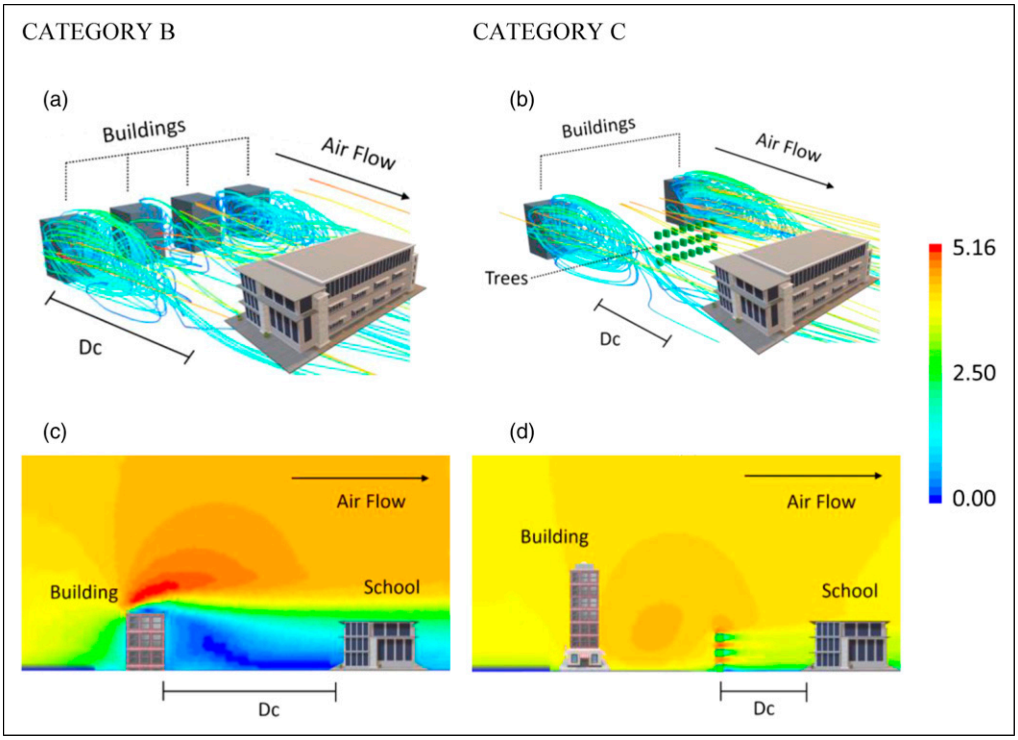

Figure 6. CFD (Computational Fluid Dynamics) simulations for different configurations within the categories B and C. (Dc indicates the distance between the buildings and the school) (a) Wind streamlines in the region immediately behind the tall buildings partially blocking the ventilation (category B). Some turbulent zone can be observed in the proximity of these buildings. (c) Velocity contours plotted on a plane perpendicular to the school facade. These velocity contours show just the strong reduction of the velocity values after interacting with the buildings. (b) and (d) are the equivalent plots for the configuration C. Here the wind flow is just partially blocked by some tall trees. Details of the CFD simulations are in CFD techniques section.

x 0.69 m^2 each) and the entrance door located at the opposite wall (similar configuration as (j) in Figure 7). Measurements were taken 22 Oct. 2020 with a relative humidity at the exterior that ranged from 60% up to 80%, with an exterior temperature within the range of 11 - 18°C, and with a temperature inside the room that varied within the range of 17 - 21°C during the observation period. Wind velocities were recorded right outside the windows, and they varied within the range of 0.28–0.9 m/s. All these measurements were taken using an air conditioning case TESTO (ref. 141/0768). A CO_2 probe (TESTO 0632 1240 with a 3% accuracy) was connected to the meteorological case for the CO_2 recordings. Only one CO_2 sensor was placed in the classrooms analysed. It was installed at a central position not close to the sources of CO_2 or the main ventilation streams at a height of 1 m. The door was always kept open following the standard procedure used in the manuscript.

Direct observation of Figure 4(a) shows some differences between the recorded values and the predictions obtained from the simulations of the equations given in the previous section (the blue line in Figure 4 is just the numerical integration of the balance equations in the previous section using Euler method). Some of the differences can be attributed to the use of one single sensor located in a specific location in the classroom, but the general trend is well reproduced as well as the maximum and minimum values achieved. Several other classrooms with different levels of occupancy and ventilation protocols were also analysed and the results are equivalent (some examples are shown in Figure 4(b) and (c)). From these results, the values obtained by numerical simulations with the balance equation can be inferred to be in good agreement with those recorded experimentally and this model becomes a good tool to estimate the levels of CO_2 in a classroom.

Adequation of the problem to the galician case

The next step is to approach this model to the specificities of the Galician case. The project is to provide information on the ventilation procedures personalized for each of the 20,000 classrooms in the educational Galician system. For this, some minimal information from the different schools was needed in order to feed the model. After some

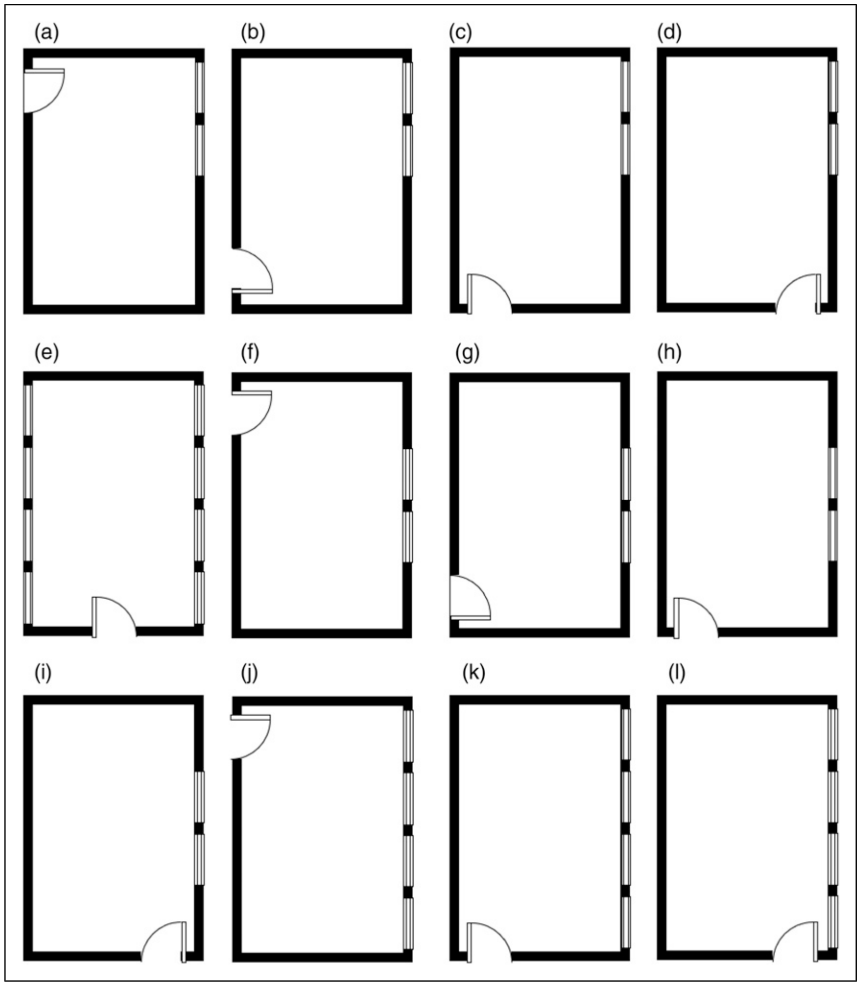

Figure 7. Scheme of a typical classroom with the ventilation-related most relevant parameters.

discussions with educational representatives, it became apparent that, as we were dealing with a massive number of classrooms and people, the most convenient was to minimize the information requested from the schools. Obviously, the more information we get the more accurate the recommendations would be. On the other hand, an excess in the demand of data may result in a lack of interest from the teachers and principals, a non-meticulous introduction of the data and, in general, failure to participate in the program. Finally, a realistic consensus was found to reduce the number of parameters to the following:

1. The location of the school is available to the educational authorities and this information is incorporated directly into the system. The location is, then, correlated with the wind velocities for the corresponding square 4 x 4 km^2 sector in which MeteoGalicia divides the region for the calculations.
2. Basic geometrical information of the classroom: number of students, area, height and total area of opened windows. This information is provided by the educational institutions at the URL https://ventilacion.usc.es, created by us to be the reference for the procedure. Each centre has its own individualized access password. Upon inserting the password, our system identifies the ubication of the centre.
3. The main orientation of the windows. This information, given also by the teachers or principals, is important in order to calculate the total wind blowing in that direction.
4. An important factor of the problem is the landscape surrounding the classroom, which modifies the wind flow reaching the windows. The type of constructive elements, surrounding orography or natural items (e.g., trees) act as obstacles in the close vicinity of the windows used to ventilate. This information, given by the teachers/principals, is, therefore, crucial in determining the effective amount of fresh air that can enter the classroom through the windows.
5. The internal distribution of the space inside the classrooms as well as the relative location of the

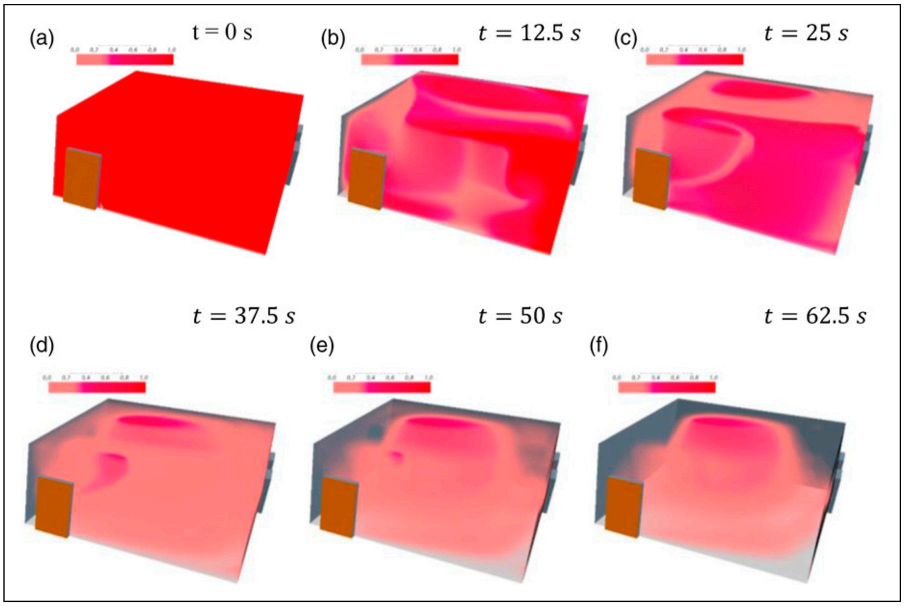

Figure 8. Evolution of the spatial distribution of CO_2 concentration in a classroom with configuration (h). (see Figure 6). Initially the whole room is filled with CO_2 and then, the windows and door just open. As time goes by, fresh air enters through the windows and renovates the air inside. Model parameters: room dimensions, 8 m x 7 m x 3 m; total open surface at the windows, 2.4 m^2 distributed in 2 windows; door area, 2.4 m^2; perpendicular wind velocity on the windows, 4 m/s.

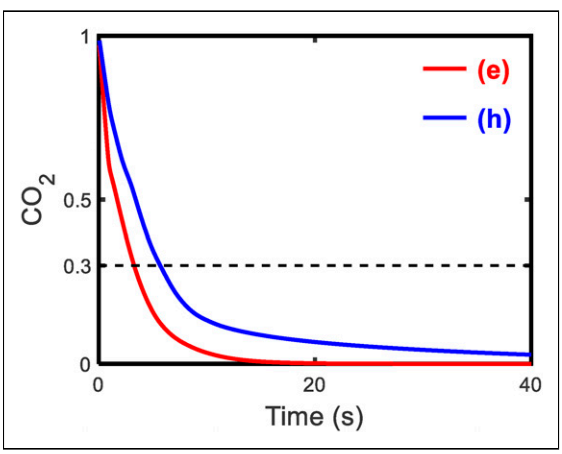

Figure 9. Evolution of the CO_2 concentration during the ventilation process in a classroom with configuration (h) (blue line) compared with the configuration (e) (standard case with the red line). Same model parameters as in Figure 8.

doors and windows, to be chosen by the teachers/ principals among some representative configurations.

Figure 5 shows a scheme of a typical classroom with the ventilation-related most relevant parameters. Summarizing, the first item is a direct parameter that was provided by the educational government authorities; the rest were provided by the teachers, principals and representatives of each educational centre. The last two items require some additional discussion in the following sections.

Effect of the surrounding landscape on the ventilation parameters

The surrounding landscape of a classroom is supposed to have an influence on the ventilation conditions inside the classroom via the partial attenuation of the wind blowing at the windows. A limiting case of a set of windows facing an inner narrow courtyard or a narrow street could completely block the wind to blow through the windows. In this case, the effective wind at the classroom windows should be zero. The other limiting case is a classroom facing an extension of land with no obstacles and almost unlimited vision. The effective wind blowing at the windows could be predicted by the meteorological service. In between these two cases, almost any configuration is possible. In order to organize all these possible situations, we have grouped them in a set of basic configurations. For each configuration, we performed numerical simulations using Computational Fluid Dynamics (CFD) techniques (as described above) and characterized the effective wind that actually arrives onto the windows of that particular classroom with this particular configuration for the surrounding landscape.

After analysing typical landscapes and urban environments characteristic for Galician schools, four different

Table 5. Correction factors for each classroom category in Figure 7, as measured from the CFD simulations.

Classroom Category	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
Correction factor	3.0	1.6	1.6	1.2	1.0	1.8	1.8	1.7	1.4	1.0	1.0	1.0

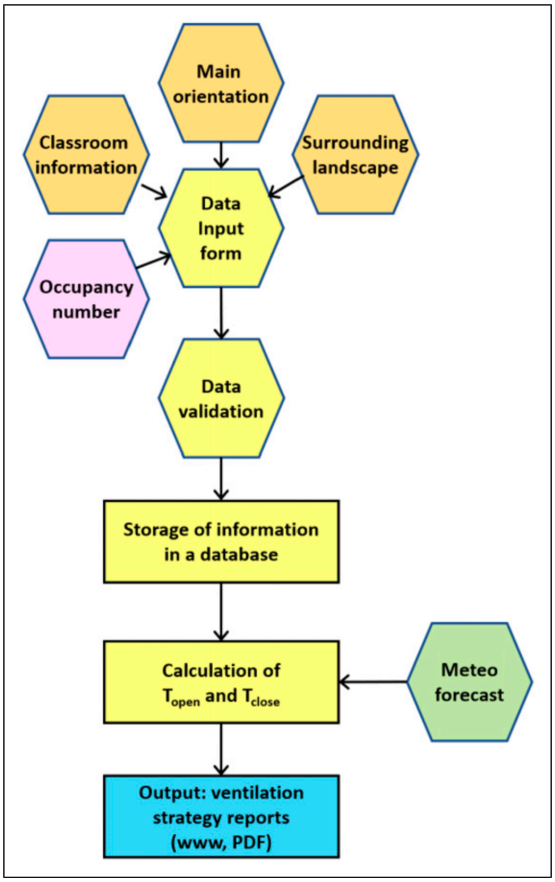

Figure 10. Flow diagram of the on-line application that provides ventilation recommendations.[32]

generic configurations for the surrounding landscape were considered and are listed in Table 3. These four configurations were chosen in agreement with the educational authorities as representative. Of course, additional cases may describe more accurately the real situations but might introduce confusion among the users of the application and also require additional effort from the principals. Thus, the representatives of each school were only asked to choose, from the four previous categories, which landscape described better the surrounding landscape of each of his/her classroom windows.

Within each of the categories considered, we performed multiple numerical simulations considering different configurations and using techniques presented in the previous section and measured the percentage of wind actually reaching the windows of the considered classroom. The average values of the wind ratios reaching the windows in each category are listed in the last column in Table 4. These factors, K, were multiplied by the values of $v_\perp$ (in equation (2)) to determine the effective wind velocity at the classroom window. Some examples of the different simulations are shown in Figure 6.

In the classrooms of category A, the ventilation of the room does not depend on the meteorological conditions and should follow the default protocols provided by the local authorities that typically involve more time of ventilation (windows open).

Effect of the internal distribution of the space inside the classrooms

As described, the internal distribution of the space inside the classroom, as well as the relative location of doors and windows, could influence the effectiveness of the ventilation process. It is impossible to consider all the different configurations available in detail but, from a generic point of view, there are some general categories that can be considered where most of the actual configurations lay. The calculations presented so far consider a situation of optimal conditions for ventilation such as the one in Figure 1. We elaborated and analysed 12 different configurations of the internal distribution of classrooms that reproduce the most characteristic configurations observed in real situations (see Figure 7, where all the configurations are depicted). This is done, obviously, to allow teachers/principals to select which one compares better with their actual classroom. For these configurations, we performed numerical modelling using CFD techniques and calculated the evolution of the total concentration of CO_2 inside the classroom. These simulations were aimed to determine the time needed to completely renovate the air inside the classroom for each different configuration. In this sense, initially, the room was considered to be full of 'contaminated' air (red coloured in the pictures) and we observed the variation of its concentration with time due to the fresh air (colourless) entering through the windows. Figure 8 presents the evolution of the concentration of CO_2 in a configuration such as (h). At time $t = 0\ s$, the room is filled with CO_2 ('contaminated' air) and, as time evolves and fresh air enters through the open windows, the amount of CO_2

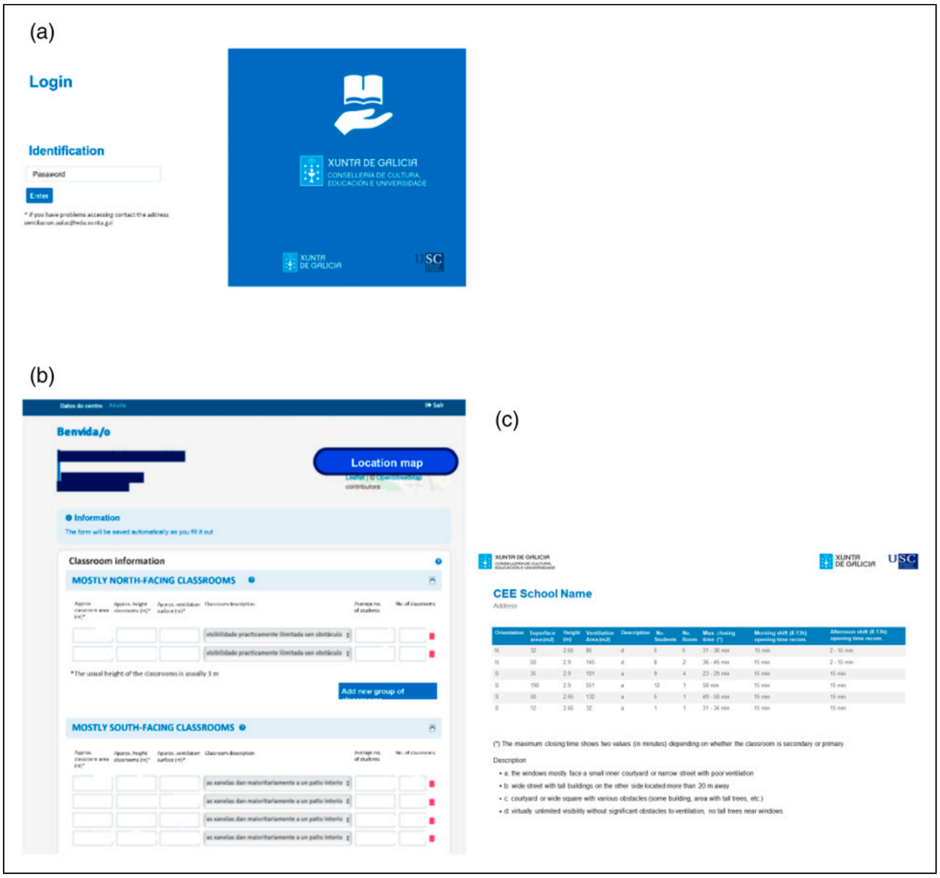

Figure 11. Images of the application as seen by the users. (a) Welcome and identification page. (b) Introduction of the data. (c) Example of the report with the ventilation recommendations. The main legends of the application in these images are translated from Galician into English.

inside the room diminishes until it is completely clean. An animation of one of these simulations has already been presented.[31] Figure 9 presents the evolution of the CO_2 concentration in this simulation versus time. The dashed line in this figure marks the level at which 70% of the CO_2 has been replaced by the fresh air. The red line marks the evolution of the CO_2 concentration in a room configuration considered as 'standard' (configuration e) for comparison. This type of simulation also allows to determine areas in each classroom that are more difficult to ventilate (Figure 8).

These simulations were reproduced for all the spatial configurations as shown in Figure 7. For each simulation, we recorded the time needed to renew the air in the room up to 70%. These values are normalized by the minimum (corresponding with configuration (e), which is the most efficient configuration in terms of ventilation). The values are shown in Table 5. These values constitute a good estimate of the number of additional times necessary to completely ventilate a room compared with the optimum configuration (e). Based on this, any recommendation to open windows during a given period of time is to be multiplied by the corresponding factors in Table 5, depending on the actual distribution of the windows and doors in the classroom.

The results presented in Table 5 are quite robust and do not strongly dependent on the 70% cutoff considered. In fact, equivalent values were obtained for a significantly large range of cutoffs.

Implementation as an on-line application.

Along this paper, we have developed all the necessary aspects needed to provide a ventilation recommendation on a daily basis specific for each of the classrooms in the system. The information flow is schematized in Figure 10.[32] Figure 11 presents some pictures showing the different stages of the application. The welcome page (Figure 11(a)) allows each school to register into the application via the specific password that was given in advance. Once inside, the system incorporates the information of the school and

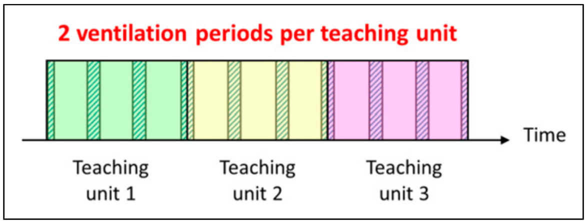

Figure 12. Timeline with the schematics of the ventilation regime considered in an ideal classroom. This example shows two ventilation periods per teaching unit in addition to the mandatory 5 min between units. The large teaching period was considered for an arbitrary classroom. Each colour corresponds with each one of the three teaching units. The hatched areas correspond with the ventilation periods while the blank ones are for the closed-windows periods.

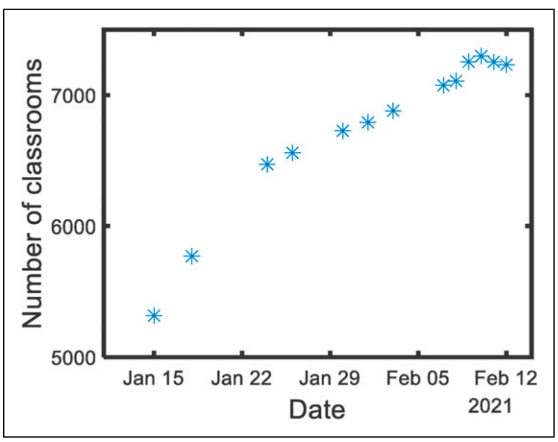

Figure 13. Number of classrooms incorporated into the application versus time.

location and, thus, able to acquire the meteorological data specific for that location. The next page requires from the user (teachers, managing teams of the schools or authorities) all the information (as described earlier in this manuscript) about all the classes wanted to be included in the system (see Figure 11(b) as an example). The last stage combines the information acquired with the local meteorological forecast to provide ventilation recommendations singularized for each classroom in the form of a report accessible via web or pdf (see Figure 11(c) as an example).

Once all the information is uploaded into the application, each school receives every morning the specific ventilation strategies for the morning and afternoon shift (see the report in Figure 11(c) as an example) for each one of the classrooms considered once the meteorological data is acquired from MeteoGalicia.

Strategies for the Galician educational system and analysis of the application data

The educational system in Galicia organizes the teaching units in periods of 50 min each. The maximum number of teaching units without a long break is three. The standard protocol during the COVID-19 pandemic was to thoroughly ventilate before and after these three teaching units to ensure that the air quality is optimum and equivalent to the outside air. Between two consecutive teaching periods, there is a mandatory 5 min ventilation period. Doors are supposed to be always open and the corridors well-ventilated. In order to avoid abrupt changes in ventilation protocols that might hinder acceptance from the teachers, we adequate the recommendations to mimic the already existing procedures; therefore, the application recommends a number of ventilation periods, with a duration time calculated by the system, during each teaching unit. An example of the ventilation dynamic is plotted in the timeline in Figure 12.

The application was implemented and made available to the whole primary and secondary education system of the Autonomous Community of Galicia (population: 2.7 million) at the beginning of 2021. By mid-February, more than 7200 classrooms had introduced the basic information and were receiving the daily ventilation recommendation (see the evolution of the number of classrooms incorporated into the application in Figure 13). Figure 14 presents histograms of the basic information provided for each classroom that shows the large diversity of teaching spaces. Specific daily ventilation recommendations were provided for this large diverse set of classrooms.

With the minimal set of parameters initially introduced in the application, we can calculate T_{close} and T_{open} as defined in equations (5) and (7). For sufficiently large values of T_{close} the recommendation is one ventilation period during each teaching unit for the period of time given by T_{open} (this number is to be corrected by the corresponding coefficient selected from Table 3, that accounts for the specific distribution of doors and windows in each classroom). The application actually provides a range of time to ventilate corresponding with the values calculated using the maximum and minimum wind velocities blowing at the windows. Smaller values of T_{close} trigger a recommendation of two ventilation periods during each teaching unit for the period of time. Given the equation controlling the evolution of the CO_2 concentration, equation (1), the evolution of the CO_2 levels in each one of the classrooms can be estimated in the system. A typical example is shown in Figure 15. For each classroom and shift (morning and afternoon) two recommendations were provided, considering the room occupied by primary students or secondary students as shown in Figure 15. The results shown confirm that the ventilation recommendation is appropriate and provides a

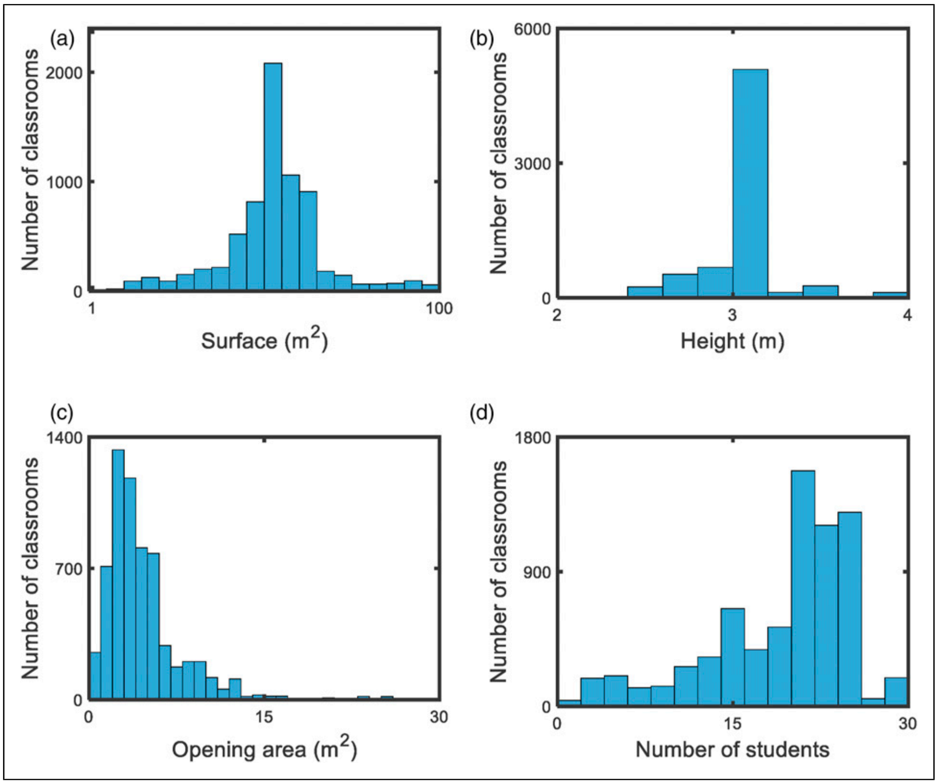

Figure 14. Distribution of the different parameters for the classrooms considered. (a) surface, (b) height, (c) opening area and (d) number of students.

good level of CO_2 in the room during the whole teaching period. The provision of these recommendations, the time the windows are closed can be optimized, which is a critical factor in winter in order to also optimize the degree of comfort (basically thermal) for the occupants.

Figure 16 presents an overview of the behaviour in all classrooms participating in the program as predicted from our model. For both shifts (morning and afternoon) as well as for primary and secondary occupancy, a histogram of predicted CO_2 average levels is presented for a typical day (9 February 2021). Each plot shows in the horizontal axis the average CO_2 concentration and in the vertical axis the number of classrooms in the educational system presenting those CO_2 values. The estimated levels of CO_2 (in the horizontal axes) are well into the safe zone, with values around 600 ppm in average. Just a few cases are observed to present significantly larger values of CO_2. These cases correspond in most of the occasions with errors during the introduction of the basic information, that are being corrected. The software has been improved to discard anomalous values and to warn the users about erroneous introduced parameters.

Just in a handful of cases these values are correct and correspond with some 'pathological' classrooms (usually spaces that were not originally conceived as classrooms and are used for some specific activities) that require some additional intervention to improve the ventilation system (i.e., install air-conditioning units, etc.). In fact, the application of this system is helping in the identification of those problematic spaces. This analysis is being repeated for different days under different weather conditions and the results are consistent with the ones presented here.

Discussion and conclusions

Students spend many hours in classrooms with relatively small interpersonal distance and, therefore, such indoor environments could be the focus of maximum potential risk of contagion in the framework of the COVID-19 pandemic. Values of exhaled CO_2 can be used as a proxy of infection risk and, in principle, a direct and certified measurement system of this gas could be an optimal solution. Nevertheless, it is impossible in practice to install such detection systems in a massive and valid way with standardized procedures in a network of more than 20 000 spaces in a short period of time. In order to improve their security in these spaces while still maximizing the comfort levels, we have developed a system to indicate specific ventilation rules for every classroom, based on a minimum amount of

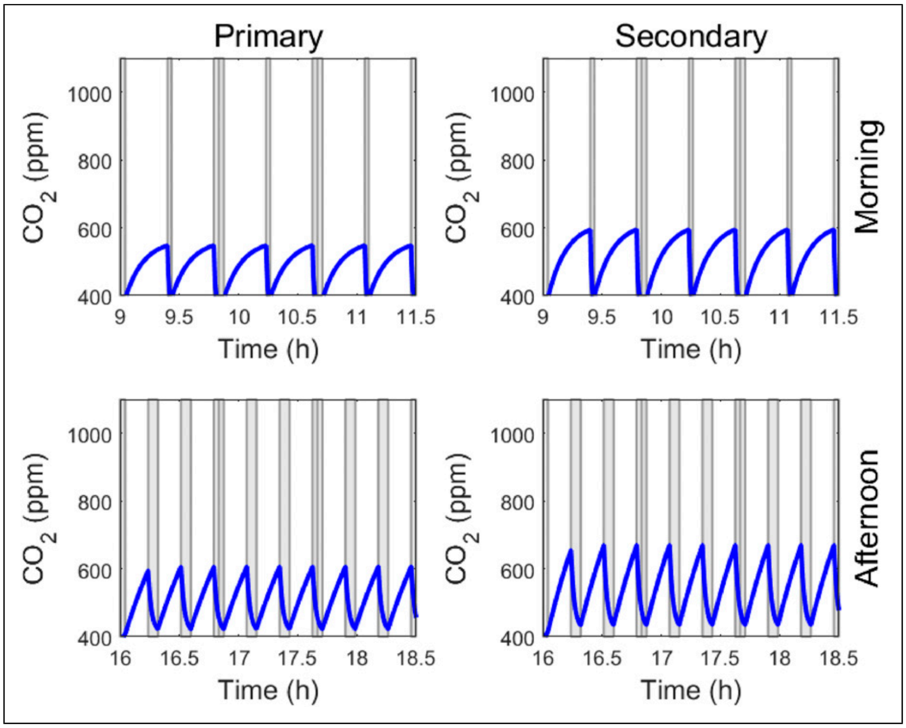

Figure 15. CO_2 levels in a typical classroom for the two shifts (morning or afternoon) and occupancy of primary or secondary students. Date 10 February, 2021.

information and meteorological predictions. This web-based system is easy-to-use by a large number of agents and, therefore, it can work widely and be deployable massively in a few days. There is no straightforward method to accurately define comfort levels for all classrooms in Galicia, instead, we can compute the total time the windows are closed and, thus, the period of time wind and rain stays out of the rooms, which could significantly improve the living conditions. Our system helps optimize such parameters and, thus, the comfort for each room.

This system has been implemented in the non-university education system of the Autonomous Community of Galicia (Northwest Spain, a population of 2.7 million), which means that it is directly influencing a very large number of habitants of that region[33]: 58 997 children in infant school (3–6 years), 134 093 of primary school (6–12 years), 94 664 of compulsory secondary school (12–16), 31 371 of high school (16–18) and 31 366 of professional training centres. Add to these figures an additional 27 058 students of special adult education and 38 789 students of art and language centres and other special regimes. This makes a total of 416 045 students that are users of classrooms to which this system can be applied. To this, we have to add a total of 45 293 teachers that are working in these classrooms. The total population directly affected by this system is 461 338, certainly a very high number, that means 17% of the total population of Galicia. This system is going to have, therefore, an important role in the sanitary situation of this region.

Moreover, the implementation of this system of ventilation coincided with the maximum impact ever of the COVID-19 pandemic in Galicia.[34] The accumulated incidence (number of new infections over a 14-day period) peaked on 1 February 2021, with a proportion of 780 cases per 100 000 habitants. To put this in context, take into account that values above 250 cases per 100 000 inhabitants are considered "epidemiological extreme risk".[35] Certainly, this has subjected the system to an unexpected pressure level: the best test to verify its reliability. Despite this extremely adverse circumstance, by mid-February 2021 the number of closed classrooms in the whole system due to sanitary reasons was only 107, and only 2 centres were closed.[36] These closures are simply preventive, once a significant number of cases is detected in the students of the same classroom, and this does not mean that contagions took place within the classrooms. Anyway, if we put them in the context of 1322 centres which contain more than 20 000 classrooms, and that by mid-February the system covered around one-third of the spaces, it seems that the system is behaving in a robust way.

It provides a useful tool to recommend ventilation strategies (not only for the current COVID-19 crises, but also to improve air quality in future years) but it also can be used to detect some 'pathological' spaces with poor

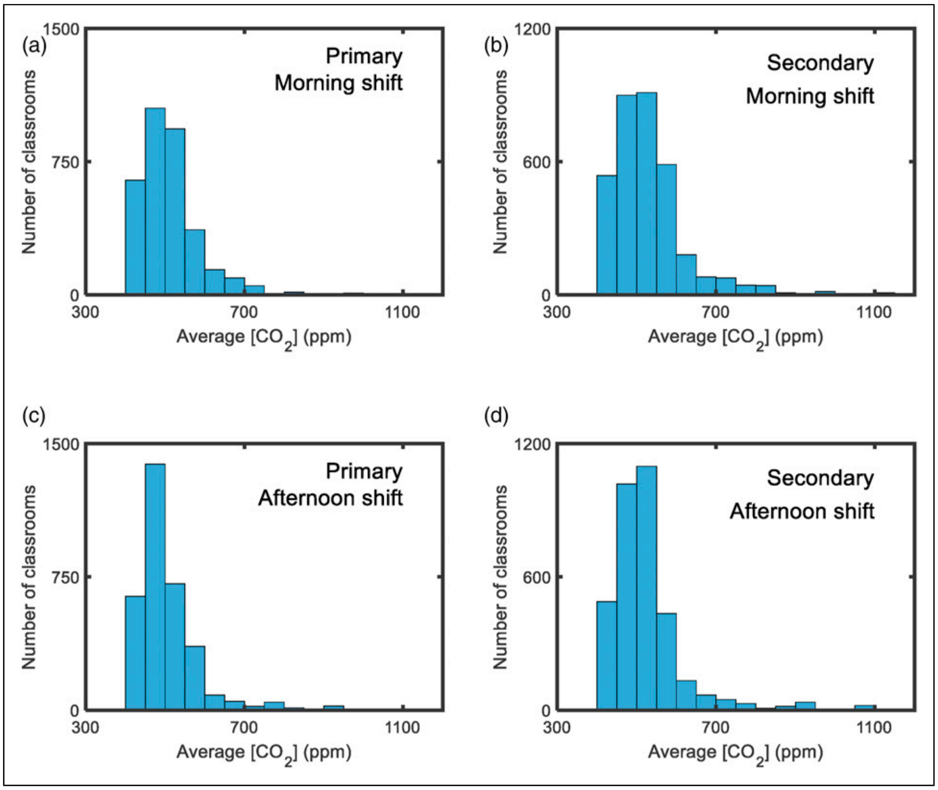

Figure 16. Histogram distribution of the average levels of CO_2 in all the classrooms participating in the project. (a) Morning shift, primary students' occupancy. (b) Morning shift, secondary students' occupancy. (c) Afternoon shift, primary students' occupancy. (d) Afternoon shift, secondary students' occupancy. (Date: 9 February 2021).

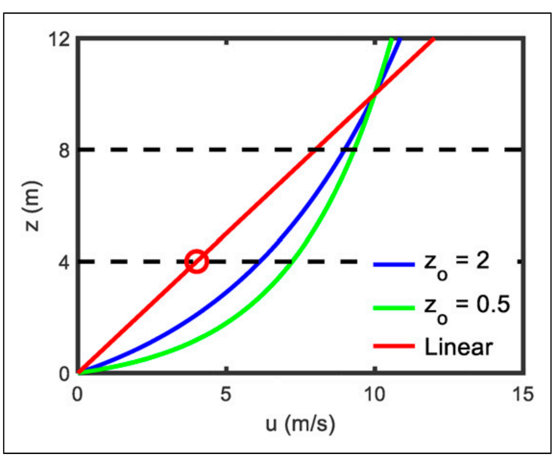

Figure 17. Velocity profiles calculated using the ABL and a value of $z_o = 2$ (blue line), $z_o = 0.5$ (green line) and the linear interpolation (red line). The two horizontal dashed lines mark the height $z = 4\ m$ and $z = 8\ m$ resp. ($u_{ref} = 10\ m/s$ for a height $H_{ref} = 10\ m$).

ventilation parameters and, thus, alert the authorities to take action. The continuous ventilation strategy does not apply in the Galician context as the adverse weather conditions prevent from keeping windows open for most of the time.

The system that we hereby propose and describe can be easily implemented to suggest ventilation recommendations for other spaces used for completely different purposes such as libraries, concert halls, churches or in general, gathering places.

The type of CFD techniques used can also be used to model restaurant spaces and, thus, to provide with adequate distribution and number of hosts as well as adequate ventilation protocols. More tests and refinements can be incorporated, but the present system is being implemented with reasonable success in a high number of real cases.

Declaration of conflicting interests

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Author contributions

APM and JM designed the project, participated in the discussions and wrote the manuscript. AOC performed the CFD simulations presented in the text.

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Appendix

Atmospheric Boundary Layer

We evaluated the realistic velocity profile in the atmospheric boundary layer and compared with the linear interpolated values considered in the application. The basic approach to the ABL problem,[37] the velocity profile in the ABL is logarithmic as a function of height (z) and can be approximated by equation (11):

$$u(z) = \frac{u^*}{K} log\left(\frac{z + z_o}{z_o}\right) \quad (11)$$

where K is the von Karman constant (usually in the range of 0.40 ± 0.02); z is the height; z_o is the aerodynamic roughness length that depend on landscape (some values are $z_o = 0.0002$ for sea or lakes; $z_o = 0.5$ for large vegetation such as farms or scattered assemblies of trees; $z_o = 2$ or higher for urban environment). u^* is the friction velocity, given by equation (12):

$$u^* = K \frac{u_{ref}}{\log\left(\frac{H_{ref}+z_o}{z_o}\right)} \quad (12)$$

where u_{ref} is the reference velocity (in our case, given by Meteogalicia) and H_{ref} the height where this velocity was measured.

Figure 17 presents the velocity profiles calculated following this procedure considering a typical velocity value of $u_{ref} = 10\ m/s$ for a height $H_{ref} = 10\ m$. Blue line shows the velocity profile considering the ABL and a value of $z_o = 2$ (i.e., urban landscape), green line is also the ABL velocity profile considering $z_o = 0.5$ (i.e. the school is surrounded by large vegetation and isolated groups of trees). The straight red line is the linear approximation. The red circle shows the chosen value for the velocity for the calculations presented along the manuscript. Horizontal dashed lines mark the height $z = 4\ m$ and $z = 8\ m$ corresponding with a second floor or the bottom of a fourth floor. The predicted values considering the ABL with different landscapes and even different heights always produce significantly larger values of the estimated wind velocity. We considered in all the calculations in the manuscript the linear value marked with the red circle as this is translated into a more conservative ventilation times, i.e., periods of ventilation larger than the time is really needed as the actual wind velocity blowing at the windows is always larger. In this way, the safety of the classrooms and the quality of the air inside is always prioritize.