Impact of Affordable Blown Mechanical Ventilation on CO_2 and PM2, 5 to Improve Air Quality in Schools

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Abstract: ***Background**: Young children are part of the most vulnerable segment of the population. They spend a huge part of their lifetime at primary school. Several studies have already been conducted in schools, showing that a poor Indoor Air Quality is linked to a wide range of discomforts and health problems, such as asthma, allergies, lack of focus and decline in cognitive functions. **Methods**: Concentration of carbon dioxide (CO_2) was assessed in three rooms in a French primary school, with no ventilation system. A Blown Mechanical Ventilation (BMV) was installed in the school and new CO_2 concentration was assessed consecutively, as well as the concentration in fine particle matter with aerodynamic diameter ≤2.5 µm (PM2.5). **Results and conclusions**: CO_2 concentration was significantly reduced after installing BMV (maximum values measured over a month decreased from 3072ppm to 1500ppm) Moreover, it was demonstrated that BMV prevents outside PM2.5 from entering the classes. The affordable cost and easy installation of BMV are key factors to allow a fast deployment, even in developing countries.*

Keywords: Indoor air quality (IAQ), carbon dioxide (CO_2), particle matter (PM), school, blown mechanical ventilation (BMV), children.

Abbreviations
Indoor air quality (IAQ),
Carbon dioxide (CO_2),
Particle matter (PM),
Particle matter with aerodynamic diameter ≤2.5 µm (PM2, 5),
Mechanical ventilation system (MVS),
Blown mechanical ventilation (BMV).

Highlights
- Children in classrooms are often subjected to excessive levels of CO_2.
- Opening the windows or using classic mechanical ventilation systems (MVS) lets outdoor particles matters (PM), dust, humidity and too cold or too hot air enter the classrooms.
- The solution we evaluated: Blown Mechanical Ventilation (BMV), that filters and blows outdoor air inside the room.
- Blown Mechanical Ventilation (BMV) provides particle free renewed indoor air.
- After installing a Blown Mechanical Ventilation (BMV) in the primary school, CO_2 levels were significantly reduced in each classroom, without big investments or works.

1. Introduction

The quality of the air we breathe is of utmost importance, as it brings to our bodies the essential oxygen our cells need to live and carry out their activities: oxygen is thus the main contribution to our daily energy.

However, the attention paid to air quality, in particular to Indoor Air Quality (IAQ) in the places we live and work, is still too slight due to a public ignorance of the issues and risks of poor air quality and/or excessive cost of efficient double flow ventilation systems[1].

And yet, it has been proven that within buildings, air quality is often worse than outside, condensing in confined spaces pollutants such as Particle matter (PM), Volatile Organic Compound (VOC), carbon dioxide (CO_2) accumulation[2 - 3].

Vulnerable groups, such as young children, are especially affected by poor air quality[4], notably poor inside air quality as they spend a large part of their time at home or at school.

Several studies have been conducted and have shown that the presence of PM, VOC and other pollutants inthe air is directly related to children's health problems such as asthma, allergic rhinitis[5 - 11], or increase in blood pressure[12].

Other studies have proven that high CO_2 levels, notably in confined spaces such as classrooms, impact learning abilities of children, decreasing their ability to focus[13 - 14]and causing fatigue and discomforts such as headaches[15].

Moreover, the recent COVID - 19 pandemic has created an opportunity to carry out further studies that have shown a relation between confined rooms and high levels of air pollutants, bacteria and fungi[16]. A common recommendation has been to open the windows. But this is a real problem when it is too cold or too hot outside, for instance cold enters and heating calories are lost.

Implementing a ventilation system in a building has been proven to be an effective solution to decrease CO_2 levels and reduce symptoms, whether it be a natural ventilation[17 - 18] or a mechanical ventilation system[19 - 21]. As reviewed[22], adequate ventilation is an important condition for a healthy school environment.

In this paper, we investigate the efficiency of ventilation using insufflation principle, called Blown Mechanical Ventilation (BMV), to measure its impact on providing fresh, healthy and particle free air to children, without big investments or works in the building to install the ventilation system.

2. Materials and Methods

2.1 Sensors

In this study, three UHOO air monitoring devices[23] were used to measure the quality of the air in three rooms and to establish an initial assessment of the situation in the primary school. Various parameters were monitored**:** carbon dioxide **(**CO_2**),** fine particle matter with aerodynamic diameter ≤2**.5** µm **(**PM2, 5**),** temperature**,** humidity**,** Volatil Organic Compounds **(**VOC**),** carbon monoxide **(**CO**),** nitrogen dioxide **(**NO_2**),** ozone **(**O_3**).**

Sensors in the device were calibrated to measure these parameters within a specific detectable range, which are presented in the following table.

Table 1: Detectable range for sensors and ideal range of parameters

Sensor	Detectable range	Ideal range
CO_2	400 – 10000 ppm	< 1000 ppm
PM2, 5	0 – 200 µg/m^3	< 15 µg/m^3 (24h)
Temperature	- 40° – 85°C	19 – 24 °C
Humidity	0 – 100 %	40 – 60 %
VOC	0 – 30000 ppb	*Case by case*
CO	0 – 1000 ppm	< 4 µg/m^3 (24h)
NO_2	0 – 1000 ppb	< 25 µg/m^3 (24h)
O_3	0 – 1000 ppb	< 100 µg/m^3 (8h)

The ideal range corresponds to the limit values recommended by World Health Organization (WHO) for PM2, 5, CO, NO_2 andO_3, and other standards, without being strict regulations[24].

Please note, that for CO_2, the current regulatory and normative limit values usually vary from 1000 to 1500 ppm. A widely accepted standard is the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 62[25]. Within the framework of this standard, CO_2 concentrations are recommended to be maintained at — or below — 1, 000 ppm in schools[26].

Above 2000 ppm, recent studies have shown that the blood shows inflammatory changes and leakage of fluid from blood vessels into brain tissue in mice[27], and 15% above normal range, sleepiness, headaches and irregular heart rate[28].

2.2 Initial assessment

The initial assessment lasted one month. A monitoring device was installed in three rooms where it operated day and night, both when children were present in the rooms and when they were absent and during weekends and holidays. The present study focused on CO_2 and PM levels within the three rooms, to principally study the confinement degree of the rooms.

We retrieved the results of the assessment and extracted and analyzed the data, in order to check the impact of a Blown Mechanical Ventilation (BMV) solution to the primary school.

2.3 Blown mechanical ventilation (BMV)

2.3.1 Principle of operation

It was decided to install a Blown Mechanical Ventilation (BMV) in the three rooms and to observe the impact of the ventilation on the CO_2 concentrations.

A BMV works as follows: outside air is taken in through a single air vent, located high up the ventilator to avoid ground pollutants. The air is then filtered with HEPA filters to eliminate particle matter (PM). The air could be preheated if the air is colder than the inside temperature of the building.

High efficiency Particulate Air Filters, known as HEPA filters are widely used in the field of air ventilation and/or air conditioning. These filters remove from the air that passes through at least 87% of particles whose diameter is equal to 0, 3µm. The filtration efficiency increases for particle diameters greater than 0, 3µm such as 2, 5µm (96, 7%) or 10µm (99, 3%).

The BMV then blows the filtered (and possibly preheated) air into the desired rooms, which are connected by tubing to the BMV.

The new fresh air replaces the stale air by expelling it through air outlets located around windows or doors.

The light overpressure created in the rooms makes it possible to evacuate all eventual indoor pollutants (CO_2, particles, moisture, odors, COV…). Indoor air is then constantly renewed and replaced by healthy fresh air.

Figure 1: Operation principle of a BMV

The school was equipped with BMV systems with a flow rate ranging from $100m^3/h$ to $220m^3/h$. Two different BMV systems were used: VMI cube from VentilAir Sec (France) [29] andVPE - expert 125 from Econology (France) [30]. They were placed in the attic above the roofs as indicated in Figure1. They give similar results.

2.3.2 Difference with respect to a classic mechanical ventilation system (MVS)

The BMV works by insufflation. This operating principle is the opposite of that of a classical mechanical ventilation system (MVS) that works by suction.

Indeed, a MVS takes in stale indoor air at several points, usually in the bathroom and kitchen, through air vents using air suction principle and expels it outside.

Air suction creates a light air depression in the rooms, that causes outside air to automatically enter through air vents located above doors and windows.

Certainly, with this classic MVS, odors, humidity and CO_2 are ejected outside, but inside air is replaced by unfiltered outside air. Thus, outdoor pollutants such as particle matter (PM), can enter in the rooms, contributing to a globally polluted air[31].

Moreover, incoming air is at the same temperature as outside air, which implies that cold (respectively heat) enters easily into the rooms in cold (respectively hot) periods, requiring an even higher energy expenditure to warm up (respectively cool down) the entire volume of the rooms.

Concerning double flow mechanical ventilation, entering outdoor air is filtered and there is a calorie swap with outgoing polluted air. Thus, entering air is preheated and particle free as with a BMV. But its price is very high, so it is rarely installed in buildings, particularly in developing countries. As with a classical MVS, the building is under light air depression, which implies that each time a door or a window is opened, it makes it possible for PM or dust to enter. There is no possible filtration at this step.

On the contrary, the BMV, with the little overpressure created in the rooms, is advantageous to prevent outside pollution from entering inside. This principle is by the way well known for clean rooms in the microelectronic industry and for operating rooms in hospitals.

2.4 Place

In the primary school, several rooms were equipped with the BMV: 3 classrooms for children, 1 room for teachers and a resting room for children.

The following figure shows a map of the school for calculation of the different rooms.

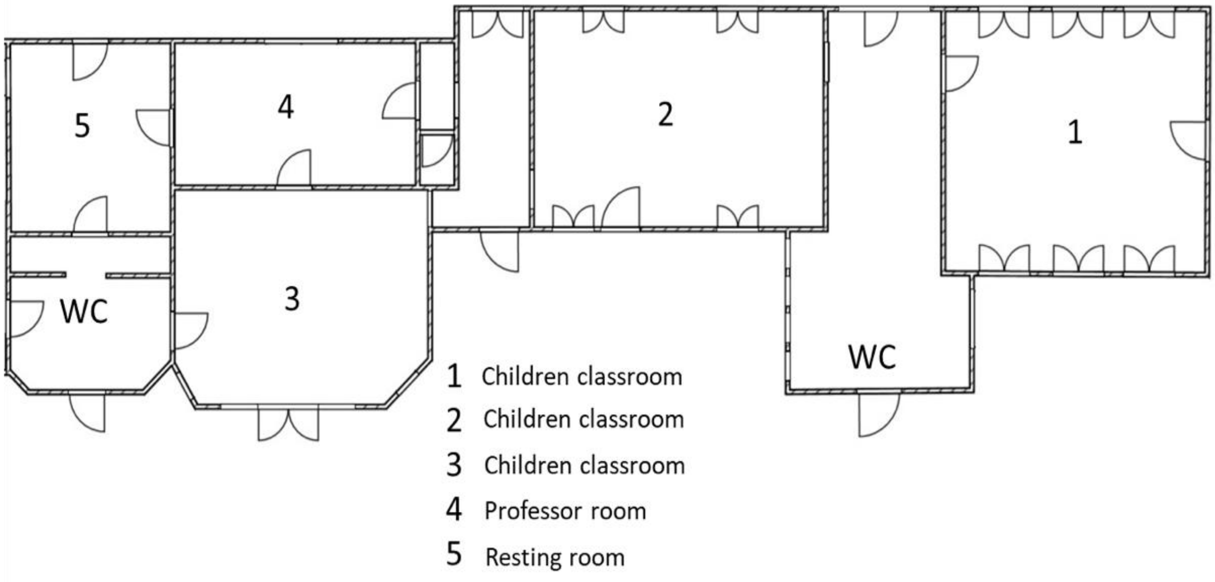

Figure 2: Map of the school for measurement of the surface and the volume of the rooms

The ventilation system installed in the school is based on the principle of positive ventilation. Thus, it is a key point to inject more air inside than the air openings can eject outdoor. In addition, it is mandatory to renew ½ of the total volume of a given room every hour.

For instance, for a room with a dimension of 7, 9m x 6, 8m, corresponding to a surface of 55m^2 and a height of 3m62, the global volume is 200m^3. Thus, a minimum of 100m^3 of stale air per hour must be removed. The air input flow rate was selected to 150m^3/h and the total air openings were chosen to allow 130m^3/h of ejected air. Ideally the air openings could be several window trickle vents with permanent opening flow at 10, 20 or 30 m^3/h. If it is not possible to use window trickle vents, it is possible the air opening could be a small space (around 1cm) between the lower part of doors and the floor. It is also possible to use adjustable flow rate air vents in the roof if there is an attic above the roof connecting to the outside.

Additionally, in each room, the air paths necessary to implement the renewal of air in an optimal way were studied, and the locations of the air vents for insufflation of fresh filtered outside air and the air outlets strips for exhaust of the stale inside air were consequently decided in order to have an optimum flushing of the rooms.

2.5 Final assessment

A final assessment was made during one month in the primary school, in the same conditions as the initial assessment. We focused on CO_2 levels within the different rooms, to compare it with the levels found during the initial assessment and also on fine particle matter (PM2, 5) concentration, in order to prove that the ventilation system did not contribute to letting outside particles enter the rooms.

Again, the results of the assessment were extracted and analyzed, in order to observe the impact and benefits of the ventilation system.

3. Results and discussion

3.1 CO_2

3.1.1 CO_2 results of the initial assessment (without BMV)

The initial assessment showed that the CO_2 levels in all the three chosen classrooms were much too high, especially when the children were inside the classrooms.

On the figure 3a, which is an overview of the results in classroom n°2, days are indicated below the curve as “m, t, w, t, f, s, s” for “Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday”. We can note obvious peaks of CO_2 on Monday, Tuesday, Thursday and Friday, i. e. school days.

Within each peak, we note two smaller peaks that correspond to the presence of children in the morning, and then in the afternoon. CO_2 levels generally did not decrease sufficiently between the two half days to drop below 1000ppm.

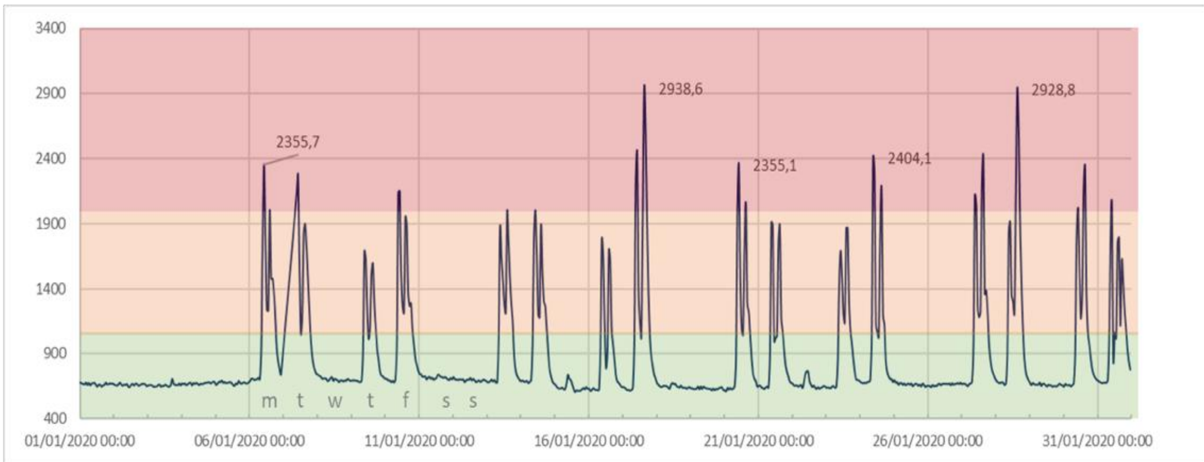

Figure 3a: $C0_2$ measured during the initial assessment without operating BMV

The table below shows the maximum CO_2 values reached during the assessment period, in different rooms.

Table 2: Maximum value of CO_2 measured during the initial assessment

	Classroom n°1	Classroom n°2	Restroom
Maximum CO_2 level registered during initial assessment	3072 ppm	2938 ppm	1316 ppm

These values are well beyond the recommended limit value of 1000 ppm in schools.

We explained these high values by:

- The presence of the children and teachers breathing all together,
- The lack of ventilation,
- No opening of the windows because the primary school was next to a road and the teachers did not want to let the outside pollution and traffic noise come inside.

3.1.2 CO_2 results of the final assessment (with BMV)

After installing the Blown Mechanical Ventilation (BMV), the final assessment made it possible to observe a great decease in CO_2 levels in all rooms.

As shown on the figure 3b, which is an overview of the results in classroom n°2, the average level of CO_2 when the children are inside the classroom is around 1000ppm and drops below 800ppm each time the children go out, notably between the morning and the afternoon.

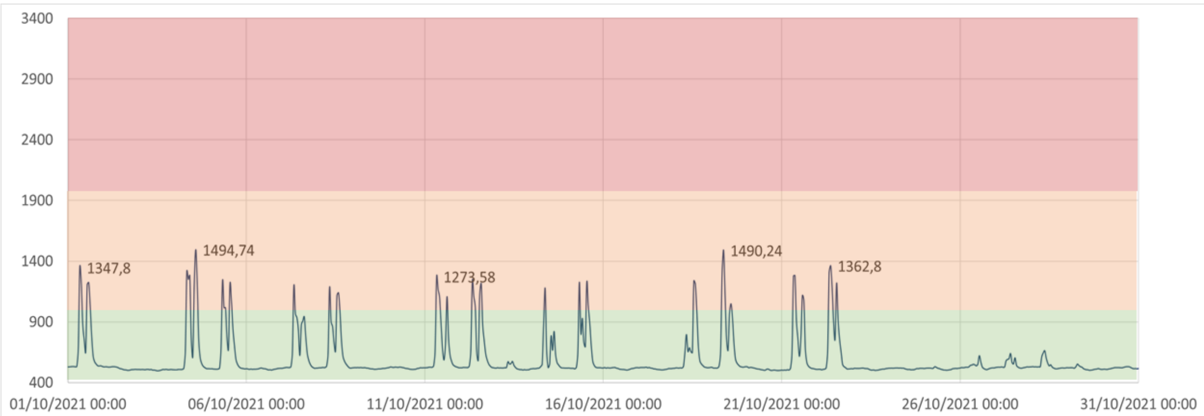

Figure 3b: CO_2 measured during the final assessment with operating BMV

Maximum values reached in this classroom n°2 are below 1500ppm, i. e. twice less than the previous maximum value of 2938ppm reached during the initial assessment (see table 2).

Therefore, we can say that the BMV which was installed in the primary school is an efficient ventilation system to renew inside air and avoid CO_2 accumulation.

The final assessment showed that the concentration of fine particle matter (PM2, 5) in the classrooms was low, close to zero, below the recommended limit value of 15 $\mu g/m^3$.

It can be seen on the figure 4 as the blue curve, which is an overview of the results in classroom n°2.

We can note some double peaks, as in the curves for CO_2 (see figures 3a and 3b), which materialize in the moments the children are present in the classroom.

The orange curve represents the concentration of outside fine particle matter (PM2, 5) provided by the air quality analysis service provider (named ATMO in France). This concentration is higher and the curve shows some narrow and intense peaks of particle pollution, certainly due to outdoor conditions such as dense traffic, street work, fires, sandstorm. . .

What to remember from this graph is that the inside PM2, 5 concentration is much lower than the outside PM2, 5 concentration. The BMV then effectively filters the particles when taking air from the outside to blow it inside.

The inside concentration of PM2, 5 shows a constant pattern, independent from the outside PM2, 5 concentration variations (notably the narrow and intense peaks). The small increases in the classroom are certainly due to children and teachers bringing dust in with them from the outside, moving, etc. The relation between the children's presence, in particular during some activities such as painting, gluing and drawing, and ultrafine particle concentration inside was already reported[32].

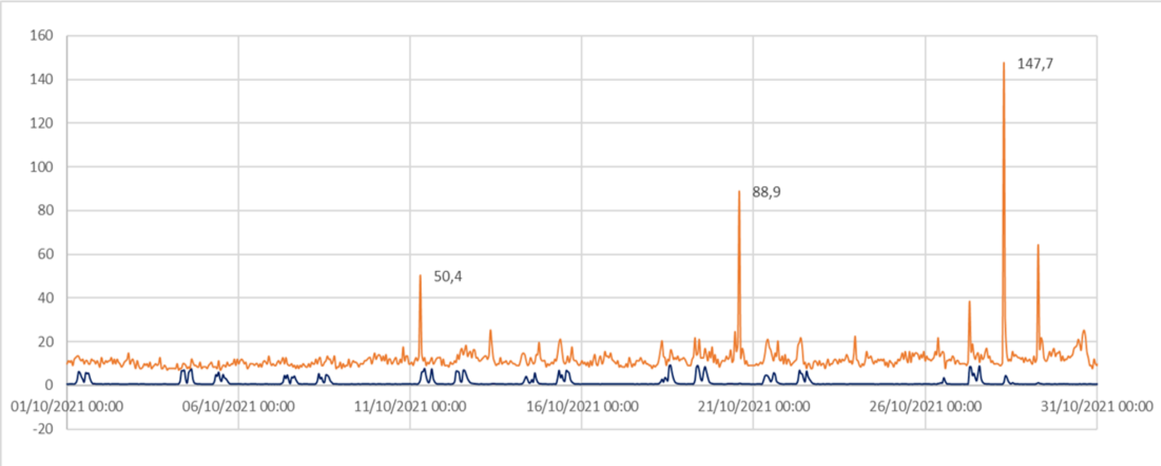

Figure 4: PM2, 5 measured during the final assessment with operating BMV (10.2021)

Consequently, we can say that the BMV which was installed in the primary school is efficient to filter outside fine particle matter (PM2, 5). BMV is reliable to provide particle free, fresh and healthy air within the rooms without big investments.

4. Conclusions

This study made it possible to show that a Blown Mechanical Ventilation (BMV) is a reliable and effective ventilation system which permits to disperse CO_2 accumulation in order to provide children with renewed air that complies with the recommended limit values of $C0_2$.

Moreover, this study showed that a Blown Mechanical Ventilation (BMV) is adapted to provide fresh air, taking it from outside, without introducing harmful particles into the rooms and complying with the recommended limit values of fine particle matter (PM2, 5).

The simplicity of BMV installation and the interesting impact to improve air quality for children, even if the outside air is polluted by fine air particles, could be easily duplicable in any other indoor areas such as offices, retirement homes. The affordable cost and easy installation of BMV in existing buildings are key factors for fast deployment anywhere in the world in order to improve air quality, thus life quality.

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

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