Numerical assessment of mechanical ventilation filtration.

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Abstract. The improvements in living standards and air-conditioning have widely been applied, however, the health effects of indoor air pollution have been increasing, especially in the last three years with the coronavirus. To get clean air through the building, filtration is one of the most efficient strategies to optimize indoor air quality. In this regard, a comparative study was done in a classroom at ENTPE laboratory to emphasize filtration's importance and to test the efficiency of analyzed type PM10_50. The results highlighted allows us to see the impact of control strategy on the efficiency of filtration (air conditions and ventilation systems performances). The numerical feedback has also been analyzed and the results allowed us to find an efficient filter and draw recommendations for their use.

1. Introduction

The building sector represents 44% of the energy consumption in France and annually emits more than 123 million tons of carbon dioxide CO_2 [1]. Indoor air quality is one of the biggest environmental challenges of our time. Indeed, it is one of the most important issues that must be considered along with improving environmental quality.

Thus, ventilation and air-conditioning considerations are increasingly important for improving indoor air conditions, especially in terms of pollutant removal.
The purpose of most ventilation systems is to provide thermal comfort and acceptable Indoor Air Quality (IAQ) for occupants.
In another context, according to World Health Organization statistics, 4.9 million people die each year from diseases due to poor air quality, especially during the pandemic (covid-19) [2]. The coronavirus infection could spread more rapidly through air-conditioning systems, or even through draft ducts.

The air contains a group of pollutants due to the potentially detrimental effects that Volatile Organic Compounds (VOCs), particulate matter including allergens and molds, and combustion gases, viruses, and bacteria that affect and destroy human life, exposure to pollutant particles causes health conditions having a particular impact on pulmonary and cardiovascular disease. Indeed, the indoor environment offers a great diversity in situations of exposure to numerous physical agents and microbiological or chemical contaminants, whose consequences on health vary in particular according to the pollutants' nature, the exposures' characteristics, etc.

Different sources can be responsible for pollutants in indoor air: sources specific to the building, its environment, its equipment, or the behavior of its occupants.

In order to solve this problem through the building and to reduce COVID-19 spread, the air filter plays a major role as an important component in air conditioning systems. The filter selection depends on the purpose for which it is used. Impurities may be classified according to their size, fine particles require a deep filter, which forms a high resistance to airflow and, therefore, it may require high fan energy.

A new international standard Test for Ventilation ISO 16890 (2017) [1] was introduced to determine filter requirements in order to get a uniform and consistent method to classify filters. This standard replaces the European standard NF EN 13779 (2012) and American ASHRAE 52.2.

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The classification according to ISO 16890 reflects the efficiency to be expected from the filters according to the criteria that is used to qualify the air quality: concentrations in PM_1 , $PM_{2.5}$, and PM_{10}.

This standard only deals with aerosols containing particles with aerodynamic diameters between 0.3 µm and 10.0 µm. It is therefore important to study the performance of mechanical filters, according to their characteristics and their use over time for polydisperse particles smaller than 300 nm in order to simulate their real conditions.

The overall objective of this study is to evaluate the efficacity of filtration used by means of different strategies of indoor parameters and mechanical ventilation.
With this aim, this study presents a numerical study of the indoor air quality conditions of an office room under mechanical ventilation using three different strategies.

2. Methods

2.1 The methodology adopted

In order to evaluate the efficacity of filtration, a methodology was developed in this article based on the numerical modeling of an office room. The model we developed considers the types of pollutants present in the building and the types of filters. Through this model, the indoor concentration of pollutants was calculated inside the building based on three simulation conditions. In the following sections, we present a description of the office room and the different simulation scenarios.

2.1.1 Presentation of Office room case study

The selected room is an experimental test cell called HYBCELL sitted up at ENTPE-LTDS laboratory (figures 1 and 2). The dimensions of the cell are 3.17 m and 5.01 m with a height of 2.6m.

Figure 1 illustrates that the HYBCELL is composed of two rooms, room A and room B, in our case study we worked only on room A.

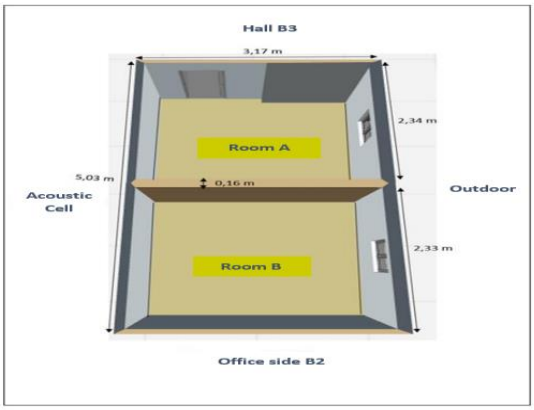

Figure 1: Representation of the current layout of the HYBCELL experimental cell [3].

Figure 2: Indoor and outdoor views of HYBCELL Test cell A [3].

2.1.2 Type of tested Particles:

There are various types of pollutants present within buildings, which vary in terms of particle size and emission sources. They can penetrate deep into the lungs, and cause respiratory problems such as asthma and heart disease. These particles can come from various sources and can include household dust, combustion particles, textile fibers, pollens, mold spores, and vehicle emissions. viruses, bacteria, mold spores, dust mites, and pollens.
The PM (equivalent Particulate Matter) index is used to measure the concentration of fine particles in indoor air. The main types of pollutants within buildings with their PM index include:

- PM_1: fine particles with a size of less than 1 micron, which may include viruses, bacteria, mold spores, dust mites, and pollen.
- $PM_{2.5}$: fine particles with a size of fewer than 2.5 microns, which may include; combustion particles, household dust, textile fibers, pollen, and mold spores.
- PM_{10}: fine particles with a size of fewer than 10 microns, which include household dust, combustion particles, textile fibers, pollen, mold spores, and vehicle-emitted particles.

This study focuses specifically on the filtration of particles less than 10 microns Indice PM_{10}.

2.1.3 Filter Selection: Comfil filtre 1 (30/30*)*

An PM_{10} (Particulate Matter 10 microns) air filter is a type of filter used to remove fine airborne particles, such as PM_{10}(particles smaller than 10 microns in diameter). PM_{10} air filters use an electret filter material that attracts fine particles with a static electrical charge. This static charge creates a force that draws the particles to the filter material, where they are trapped and held. They are particularly useful for reducing fine particle levels in enclosed spaces such as classrooms, offices, and living areas.

Comfil filter 1 (30/30) is a general-purpose air filter, designed to capture suspended particles in the air. It is classified as MERV 8 in the United States and has an ISO16890 efficiency of PM_{10}-50, indicating a minimum particle capture efficiency of 75% for particles ranging from 3 to 10 microns in diameter. It is commonly employed in general ventilation applications, HVAC and refrigeration systems, clean room ventilation systems, air handling units, and industrial applications.

2.1.4 Mean concentration of a pollutant in a Uni-zone confined space

A prediction model of indoor air quality consists in writing for each pollutant the differential equations that translate the conservation of mass in the building:

$$\frac{d(\rho.V.C)}{dt} = \rho.V.\frac{dC\,(t)}{dt} \quad (1)$$

Mean concentration of a pollutant in a Uni-zone Confined space expressed by the following equation:

Variation of concentration = Emitted Polluan + Pollutants entering - Pollutants leaving - Removed Pollutants

$$\frac{dC\,(t)}{dt} = \frac{G}{V} + \lambda Cext \; - \lambda C\,(t) - \lambda Cext\,\varepsilon \quad (2)$$

That, given that the air exchange rate is $\lambda = Q/V$, where Q (m^3/h) is the volume.
The formulation of the Concentration of a Pollutant in an Indoor Space can be resolved numerically, will give:

$$C^{t+dt} = (1-(dt+\varepsilon)\frac{Q}{V} + Ct + \frac{G}{V}dt + \frac{Q}{V}\,Cext \quad (3)$$

C^{t+dt} The vector of pollutant concentrations p at instant t+dt.
C, mean instantaneous concentration of the pollutant (mg/m^3).
C_{equi}, the total concentration of pollutants takes into account both internal generation and the infiltration of outdoor pollutants.
G, generation of pollutants inside the compartments (mg/h).
ρ **:**
V, room volume (m^3).
λ, the air exchange rate (h^{-1}).
C_{ext}, outdoor concentration (mg/m^3).
Q, the flow rate through the filter (m^3/h).
ε, the efficiency of filtration.

this equation and climate data were employed and in conjunction with data from the HYBCELL space to model the concentrations of pollutants and CO_2 via Matlab Simulink.

2.1.5 Modeling and Simulation Conditions

A building model based on finite differences (envelop model) and pressure code (airflow model) has been developed and validated by Mohamed EL mankibi [6]. This model has been developed under Matlab-Simulink environment and within the framework of this paper, we added pollutant model using S-functions and added control strategies as described below. Figure 3 shows an overview of developed model and control strategies implemented in Simulink.

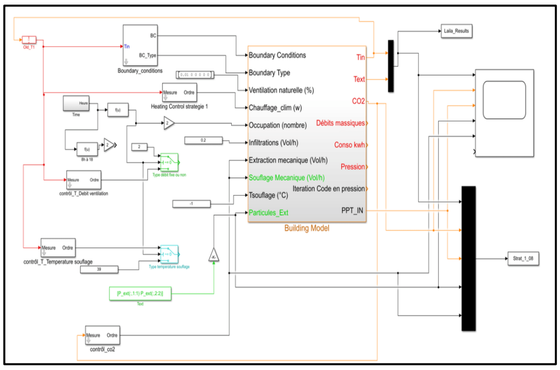

Figure 3: The interface of model room A using control strategy 1 in Matlab Simulink.

The filter performance was simulated under different strategies to evaluate their filtration. These simulation conditions include parameters such as airflow rate, temperature and humidity, particle loading, and pressure drop, filtration efficiency.
In this study, we evaluate internal pollutant concentration taking into account the presence of two individuals in the office. We considered the absence of internal generation and the simulation was conducted during the first five days of January.

2.1.6 Control strategies

In this case study we adopted the three most common used control strategies in order to assess their effects on filtration performance; the first one is focusing on thermal comfort and indoor air quality (Strategy 1) based on controlling temperature by means of electrical resistance and controlling CO_2 by ventilation with external temperature as inlet temperature. The second strategy (Strategy 2) the is focusing on thermal comfort and is based on controlling temperature by means of ventilation with heated inlet air. Finally, the third strategy (Strategy 3) is based on regulatory airflow for indoor quality and heated ventilation inlet air for thermal comfort. The mechanical ventilation airflow is fixed using France's standard of ventilation.

In the first strategy: ventilation was used to control_the temperature and the electrical resistance to control the CO_2 using the PID command. The temperature setpoint was set at 20 °C and the CO_2 indoor concentration setpoint was at 1000 ppm. And for all control strategies indoor air setpoint temperature was set to 20 °C.
As of the second strategy, it was divided into two parts: (for these two parts we kept the setpoint temperature equal to 20 °C through PID command).

1. Occupant presence (8h/12h-14h/18h)

we have maintained the ventilation flow rate at the minimum regulation flow rate which is equal to 2 Vol/h and we have varied the insufflation temperature with the PID command, the variation of the flow rate must not be higher than 4 vol/h.

2. The occupation's absence (18h/8h-12h/14)

If the office is not occupied, the indoor temperature is controlled using mechanical ventilation (fixed insufflation temperature of 39 °C), and the variable airflow is controlled using PID controller with a maximum of 4 vol/h.
And finally, the third Strategy is based on controlling temperature by electric resistance, of which the setpoint temperature was fixed at 20 °C through PID command and the insufflation temperature was equal to the external temperature. Using the regimental flow rate of 2 Vol/h during the occupation.
For these three strategies, at first, we considered an efficiency of filtration at 0.7 and then, we increase the efficiency at 0.8. So, we compared it with the regulation of ventilation in France (without any filtration) to determine the impact of the change accurately.

3. RESULTS AND DISCUSSION

The obtained results by means of simulation during the ten winter days under Lyon climate conditions are shown in Figures 4 and 5:

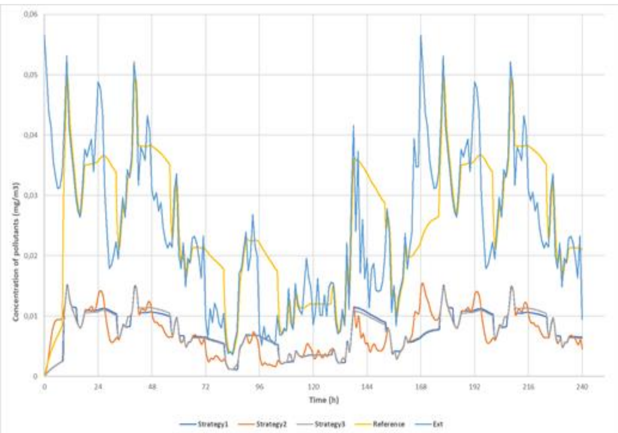

Figure 4: the variation of the concentration pollutants (PM_{10}), according to the three different strategies using 0.7 as an efficiency of filtration.

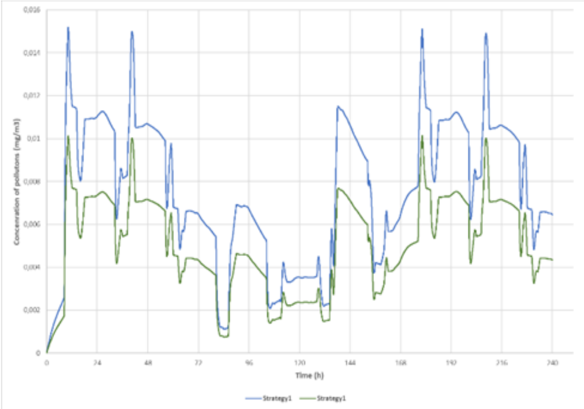

Figure 5: the variation of concentration of pollutants (PM_{10}), using strategy 1 with two efficiencies of 0.7 and 0.8.

As a reference, we added a simulation using France regulation mechanical ventilation airflow with no filtration.
The results showed that if we compare the three strategies with the general strategy applied in the buildings (by adapting the French regulatory reference) and by fixing the efficiency of filtration at 0.7, we obtained the maximum concentration of the pollutants from the outside per unit, due to the absence of filtration. The absence of filtration in our reference case leads to the concentration of pollutants inside the building being equal to the concentration of pollutants outside, one reason for this; is that without filtration, even with the presence of a mechanical ventilation system (VMC), pollutants from outside the building, such as dust, pollen, and car exhaust, can easily enter the building through open windows or doors, or through cracks in the walls or roof, additionally, sources of pollution inside the building, such as cleaning products, building materials, and air fresheners, can contribute to the concentration of pollutants. These indoor pollutants can accumulate over time, and without proper filtration, they can become concentrated.

We observed also, that When we applied the filtration, according to the three strategies using an efficiency of 0.7, the concentration is reduced with a gap of 0.0012 mg/m³ and the peaks and their duration differ according to the used strategy.
We also can notice that the first strategy and the third strategy have the same peaks and the same variation of concentration of the pollutants as a function of time, but the second one has a different behavior and a shift of pikes. As shown in figure 3 even if we increase the filtration efficiency from 0.7 to 0.8, the behavior of the concentration variation does not change due to the simulation in the same conditions, the spikes here present the presence of occupants (8/12-14/18). But we can clearly see that the concentration of internal pollutants decreases with a difference of 0.073 mg/m³.

Thus, the use of filtration efficiency equal to 0.8 achieves significant improvement compared to filtration efficiency equal0.7 in terms of indoor air quality.

By comparing these strategies, we found that the first strategy allows for having an optimal concentration of pollutants inside the building compared to other strategies. In terms of efficiency, if we compared the first strategy (thermal - indoor air quality) with an efficiency equal to 0.7, we found the average variation of concentration inside the building equal to 0.0071 mg/m³, and the difference between this strategy and the reference strategy without filter (reference) equal to 0.0088 mg/m³ in terms of concentration. On the other hand, if we apply the same strategy with an efficiency equal to 0.8, the average variation of concentration inside the building is equal to 0.005 mg/m³ and the difference between this strategy and the reference strategy without a filter is equal to 0.0012 mg/m³.

Conclusion

The main objective of this study was to evaluate the concentration of pollutants using three strategies and to test the efficiency of these strategies; first, one controlling temperature by electric resistance and ventilation, second one was controlling temperature by ventilation, and the last one was controlling temperature by electric resistance than, we have tested these strategies on efficiency values of 0.7 and 0.8.

We conclude that if we increase the filtration efficiency, the concentration decreases with a difference of 0.0075 mg/m³. This means that the more we increase the efficiency, the more the concentration decreases; The more the filter efficiency increases, the more it is able to retain a greater quantity of particles, thus reducing the concentration of these pollutants in the air. This can have positive consequences for air quality, as well as for the health and safety of people exposed to these pollutants.

It was also found that the change in the filter efficiency does not affect the various behavior of the pollutants inside the building due to the same simulation conditions.
The evaluation of the data presented in this work leads to recommend the use of the first strategy, which allows to filter well the pollutants inside the building, and to have a concentration of pollutants with an optimal value compared with the other strategies.

As a continuation of this study, the HYBCELL test is being equipped and adapted to experimentally validate our conclusions and lead further investigations with Canadian IRRST.

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