CHOOSING AIR FILTERS FOR GENERAL VENTILATION BY ENGINEERING CALCULATIONS

Luca Berardino – **luca.berardino@polito.it**
Politecnico di Torino, www.polito.it
Wili Colozza Hoffmann – **wili.hoffmann@anthares.eng.br**
Anthares, www.anthares.eng.br
Paolo Tronville – paolo.tronville@polito.it
Politecnico di Torino, www.polito.it

S2 - Equipamentos e Componentes de Ar Condicionado, Ventilação e Aquecimento

Abstract. *The WHO global air quality guidelines published in 2021 and the recent COVID-19 pandemic have shown that air quality is a public health issue. Indoor Air Quality should be an imperative aspect in designing air conditioning systems for indoor environments where people spend most of their time. The greatest concern regarding harmful effects on human health is* $PM_{2.5}$*. Considering the concentration of* $PM_{2.5}$ *present in outdoor air in most urban centers it is obvious the need to clean outdoor air, which seldom meets the values prescribed by the WHO. Therefore, devices to purify the air of particulate matter are becoming increasingly important, and their selection is one of the critical aspects of indoor air conditioning system designs. Calculating the essential components to guarantee indoor air quality can be done by carrying out a mass balance of the contaminants of concern. This calculation becomes more complicated in the case of particles due to the size dependence of behaviors and properties. However, it is possible to calculate the* $PM_{2.5}$ *concentration after fixing the particle size distribution and thus reducing its representation to a single number. ABNT NBR ISO 16890-1:2018 standard offers the designer the possibility of selecting filters and calculating airflow rates, sizing the ventilation system by choosing the battery of filters capable of meeting the project's objectives. The draft revision of ABNT NBR 16401-3 takes advantage of this important advance to calculate the internal concentration of particles, an essential parameter for guaranteeing a healthy indoor environment.*

Keywords: *Air filter,* $PM_{2.5}$*, IAQ, Ventilation system, IS0 16890, Indoor Air Quality.*

1. INTRODUCTION

Air pollution is a complex mixture of particulate matter (PM), gases, and other pollutants released into the atmosphere due to various human activities, including industrial processes, transportation, and agriculture. Also, building construction materials and indoor activities can generate pollutants within the buildings, increasing concerns about indoor air quality (IAQ). Air pollutants can be gaseous (for example, NO_x, SO_x, CO, and volatile organic compounds), liquid, and solid (particulate matter).

Exposure to air pollution has severe implications for human health, affecting respiratory, cardiovascular, and overall well-being. Vulnerable populations, such as children, the elderly, and individuals with pre-existing health conditions, are particularly susceptible to the health impacts of air pollution. The World Health Organization (WHO), in its Air Quality global guidelines (2021), estimates that millions of premature deaths occur annually due to outdoor and indoor air pollution exposure.

Gaseous pollutants like nitrogen dioxide and ozone can irritate the respiratory system, exacerbating existing conditions and reducing lung function. Nitrogen dioxide causes increased susceptibility to respiratory infections (Logue et al., 2012). Particulate matter, especially $PM_{2.5}$ or smaller, can penetrate deep into the respiratory system. $PM_{2.5}$ is toxic, and several studies (Dockery et al., 1993) demonstrate its negative impact on human health. The inhalation of $PM_{2.5}$ causes respiratory diseases such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Additionally, fine particles can enter the bloodstream, contributing to cardiovascular problems such as heart attacks, strokes, and hypertension.

$PM_{2.5}$ definition is not as straightforward as it could look. $PM_{2.5}$ and PM_{10} rigorous definitions differ from the total particles below 2.5 µm and 10 µm, respectively. US Federal Reference Method (FRM) 40 CFR Appendix J and L to Part 50 (Office of the Federal Register, 2001) (Office of the Federal Register, 1999) and European Standard EN 123419 (EN 12341: 2014, 2014) define PM_{10} and $PM_{2.5}$ as the PM penetrating a size-selective inlet with 50% efficiency at 10 µm and 2.5 µm aerodynamic diameters, respectively. The aerodynamic diameter is the diameter of the spherical particle of standard density with the same settling velocity as the actual particle of interest. Nevertheless, not all particles can be characterized correctly by aerodynamic diameter. For smaller particles (below 100 nm), the impact of gravity is negligible. Therefore, it is better to use the physical diameter (Tronville et al., 2023). Terms like $PM_{0.3}$ or $PM_{0.1}$ have no clear meaning if not defined properly by those using these terms.

The COVID-19 pandemic showed that air quality is a public health issue, emphasizing the relevance of focusing on its control. Efforts to mitigate the health impacts of air pollution involve regulatory measures, technological advancements in emission controls, and public awareness campaigns. Understanding the intricate relationship between air quality and human health is crucial for developing effective strategies to address this global public health challenge, according to Pope III et al. (2002).

We can, therefore, acknowledge the importance of controlling $PM_{2.5}$ indoor concentration. Indoor exposure to contaminants is more important to human health than outdoor exposure because people spend most of their time in confined environments. The goal is to ensure good indoor air quality even when the external environment contains $PM_{2.5}$ higher than WHO limits. The most recent value of the WHO limit for the annual average $PM_{2.5}$ concentration is 5 $\mu g/m^3$. Hence, more than 95% of the places on the Earth do not respect this limit, and outdoor air could sometimes be more polluted than indoor air, carrying $PM_{2.5}$ inside the occupied environment. Even if it is not easy to completely satisfy the WHO requirement, we should do our best to get as close as possible to the lowest $PM_{2.5}$ concentration outdoors and indoors to minimize adverse health effects.

For this reason, IAQ standards like ANSI/ASHRAE in standard 62.1 define acceptable indoor air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction". IAQ is not just about the bad smell of the air but also includes health effects. To control and maintain good IAQ, we should consider the following approaches:

- To control the $PM_{2.5}$ source inside a confined environment (e.g., no smoking allowed);
- To dilute the $PM_{2.5}$ concentration with outdoor air if it is clean enough;
- To remove $PM_{2.5}$ from outdoor air and inside the environment by employing air cleaning technologies.

The goal is to achieve comfort and productivity for the human occupants and minimize adverse health effects through a calculation and proper choice of the ventilation system and its components.

Removing $PM_{2.5}$ from outdoor air and inside the environment requires a careful air conditioning system design to clean the outdoor and indoor air. HVAC designers are used to evaluate the thermal load through energy balances and calculate the cooling and heating loads to size the components and the supply airflow rate to satisfy thermal requirements in the environment. Sizing the air conditioning system requires knowledge of the physical laws governing the heat transfer mechanisms and fluid dynamics to achieve the desired temperature and relative humidity.

Similarly, to achieve the desired $PM_{2.5}$ concentration levels, HVAC designers should understand the underlying physical, chemical, and biological mechanisms that drive pollutant emission, transport, and control. Similarly to the case of thermal design, the designer can use a mass balance of contaminants to determine the components' performance to achieve the design targets, i.e., the acceptable IAQ. The aim is to achieve the limits of airborne particulate pollution in terms of PM mass concentration set by cognizant authorities worldwide (e.g., WHO).

We can illustrate this concept by analogy between the thermal and the contaminant load design. The mass flow of generated and removed contaminants is similar to the heat flux, the temperature difference is similar to the difference of contaminants concentration, and we can compare the particulate mass flow rate collected by an air filter to the thermal power provided by a heat exchanger. However, the air ventilation system design may be more challenging due to the particle size dependence of $PM_{2.5}$ behavior and properties.

The proposed revision of Brazilian standard ABNT NBR 16401-3 (2023) and the current standard ABNT NBR ISO 16890-1:2018, which replaced ABNT NBR 16101:2012, can fulfill this gap. These two documents help design the ventilation system by proposing a transparent model and using the particle size-resolved efficiency integrated over a typical urban aerosol particle size distribution (PSD).

To design the ventilation system, calculate the airflows, and choose the proper air-cleaning equipment, the designer needs to know the particle size distribution in the outdoor air and the ability of each device to remove the PM associated with such an aerosol. The purpose is to obtain the PM concentration downstream of each filter, knowing the PM concentration upstream and the air filter's efficiency as a function of particle size. This value is the penetration through the air cleaning device. If the PSD does not change drastically inside the ventilated environment, the designer can use the same value also for the cleaning device, if any, placed in the recirculation duct. Otherwise, the designer should use the proper PSD of the aerosol generated inside the environment to calculate the penetration through the air filter placed in the recirculated air duct.

Luckily, aerosol physics determines the PSD in outdoor air. The PSD of urban aerosols is similar in every city worldwide (Seinfeld & Pandis, 2016). What changes from one place to another is the mass concentration, which is much higher in more polluted areas. Inside and near cities, anthropogenic sources determine the PSD of urban aerosols. We can effectively represent the PSD of urban aerosols as a bimodal distribution. We are especially interested in the distribution of mass (or volume if we fix the particle density) as a function of particle size to calculate the ability of a cleaning device to remove the PM fraction under control.

ABNT NBR ISO 16890-1:2018 introduced a new approach, providing data immediately useful for choosing the proper filter for each application. The focus shifted from product-only to application-oriented calculations. For instance, ABNT NBR 16101:2012 could not immediately answer the question: how much $PM_{2.5}$ does an F7 filter remove? On the contrary, ABNT NBR ISO 16890-1:2018 can immediately provide an estimate to answer this question considering the aerosol's characteristics.

Moreover, and most importantly, ABNT NBR ISO 16890-1:2018 is a flexible tool because the user can change the PSD according to his application data. Hence, the designer can calculate the PM removal efficiency on different size intervals and with different PSDs. However, ABNT NBR ISO 16890-1:2018 uses a reference particle distribution to provide a classification system (ePM$_1$, ePM$_{2.5}$, and ePM$_{10}$ values) and allow easy and meaningful comparison of filters. It uses two reference particle size distributions: the urban one for obtaining the ePM$_{2.5}$ and ePM$_1$ values and the rural one for ePM$_{10}$ values. The absolute value of the PM concentration depends on local conditions and will impact the filter service life. For instance, filters with the same *e*PM$_x$ class get clogged faster in more polluted environments. Finally, the spreadsheet attached to the official copy of the standard drives the *e*PM$_x$ calculation and avoids calculation errors.

Standard ABNT NBR ISO 16890-1:2018 classification uses only the filters' initial efficiency in removing *e*PM$_1$, *e*PM$_{2.5}$, and *e*PM$_{10}$ atmospheric aerosol fractions. On the contrary, ABNT NBR 16101:2012 used unrealistic efficiency values for classification using data obtained during the synthetic dust loading process. Moreover, ABNT NBR ISO 16890-1:2018 obtains the initial efficiency as the average fractional efficiency curve of the filter in clean and discharged conditions (Tronville & Rivers, 2016) to consider the efficiency drop of electrostatically charged media exposed to ultrafine or oily particles.

Another powerful tool that makes the ventilation system design and air filter choice process easy is the proposed revision of the ABNT NBR 16401-3 (2023). It defines the minimum outside air for ventilation, the minimum levels of air filtration, and technical requirements for systems and components related to indoor air quality. Annex E illustrates calculating the air filter minimum efficiency to achieve the desired contaminant concentration for different ventilation systems.

This paper shows how to apply and use the proposed revision of standard ABNT NBR 16401-3 (2023). This approach is suitable for designing any ventilation system, regardless of the publication stage of the proposed standard. We present some ventilation systems with different configurations, listing the main assumptions and equations to calculate the PM$_{2.5}$ concentration over time. We took some examples from the proposed revision of standard ABNT NBR 16401-3 (2023). After that, we derive and apply the model below to six different ventilation systems serving a typical environment (e.g., a classroom). We summarize the calculation results in a table to show how the PM$_{2.5}$ concentration changes with the ventilation system type, the airflow rates, and the filters' efficiency.

2. CONVENTIONAL AIR-CONDITIONING SYSTEMS WITH RECIRCULATION (CONFIGURATION 1)

The air conditioning system sketched here below (Fig. 1) mechanically ventilates a room. The air enters the room and exits mainly through the return duct and partly leaks out because of exfiltration. We calculate the PM$_{2.5}$ concentration as a function of time (any other pollutant would follow the same procedure) inside the occupied space. We assume the pollutant concentration to be uniform in the room (zero-dimension model). The assumptions made for this study are:

- Mixing fresh air with a fraction of the return air before supplying it into the environment is possible.
- The environment is over-pressurized, and some air exfiltrates out.
- In the room, there is a pollutant source (e.g., cigarettes).
- Filters 1, 2, and 3 have a certain *e*PM$_{2.5}$ efficiency.

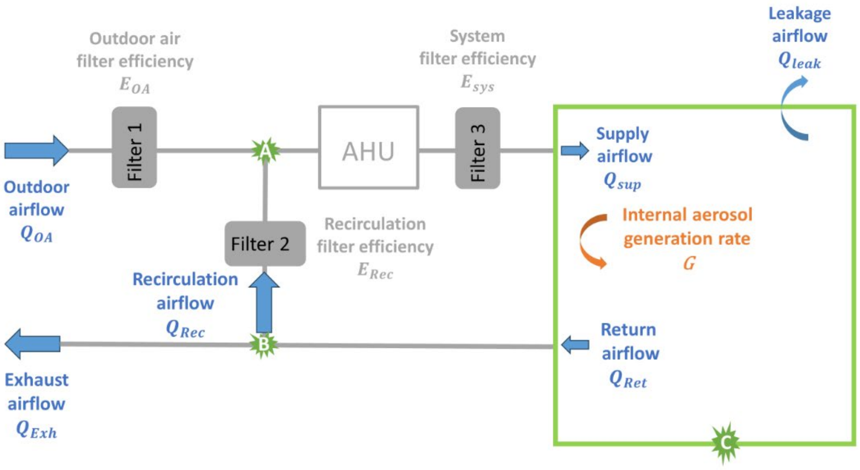

Figure 1 – Air-conditioning System Configuration 1

Generally, the amount of air supplied in the environment is input data. The ventilation system designer chooses the supplied airflow based on the activity performed by the occupants, thermal load, and the air diffusion strategy. For simplicity, we will express the airflow with the value of the number of air changes per hour (n):

$$Q_{sup} = n \cdot V \quad [m^3/h] \tag{1}$$

Then, we can define a set of equations from the airflow balance in the main nodes of the system:

$$Q_{sup} = Q_{OA} + Q_{rec} \tag{2}$$

$$Q_{sup} = Q_{leak} + Q_{ret} \tag{3}$$

$$Q_{ret} = Q_{exh} + Q_{rec} \tag{4}$$

$$Q_{leak} = 0{,}04 \cdot Q_{sup} \tag{5}$$

The leak rate depends on the pressure difference between the room and the size of the window and door gaps. The engineer must consider it in the project. This study considers it as 4% of the supply flow. We use this percentage to show how to perform the calculation. However, the engineer should evaluate it case-by-case.

Where:
V = Environment volume [m^3]
Q_{Exh} = Exhaust airflow [m^3/h]
Q_{Leak} = Leakage airflow [m^3/h]
Q_{OA} = Makeup airflow (outdoor fresh air) [m^3/h]
Q_{Ret} = Return airflow [m^3/h]
Q_{Sup} = Supply airflow [m^3/h]
Q_{Rec} = Recirculation airflow [m^3/h]

The supplied airflow also controls the temperature and relative humidity inside the environment. The amount of outdoor air depends on the number of occupants. They are both input data. Starting from this information, we can split the return airflow into recirculation (to be mixed with the outdoor airflow) and exhaust airflow. After obtaining the various flows, we can study the concentration of a specific pollutant in the air and its trend versus time. To do that, we calculate the contaminant mass balance in the environment:

$$G - Q_{leak} \cdot C + (Q_{ret} - Q_{exh}) \cdot C \cdot P_2 \cdot P_3 + Q_{OA} \cdot C_{OA} \cdot P_1 \cdot P_3 - Q_{ret} \cdot C = \frac{dC}{dt} \cdot V \tag{6}$$

Where:
G = mass flow rate of pollutant emitted inside the environment [g/s];
P = filter penetration ($C_{downstream}/C_{upstream}$) [-];
E = filter particle removal efficiency (1-P) [-];
C = average pollutant concentration inside the environment [mg/m^3].

Let us gather some terms and label them to make the equation more readable:

$$a = G + Q_{OA} \cdot C_{OA} \cdot P_1 \cdot P_3 \tag{7}$$

$$b = Q_{ret} \cdot (P_2 \cdot P_3 - 1) - Q_{exh} \cdot P_2 \cdot P_3 - Q_{leak} \tag{8}$$

Then mass balance equation becomes:

$$a + b \cdot C = \frac{dC}{dt} \cdot V \tag{9}$$

We obtain a differential equation with separable variables.

$$\int_0^t dt = \int_{C_0}^{C} \frac{V}{a+b \cdot C}\, dC \tag{10}$$

Solving for C:

$$C = \frac{1}{b}\left[-a + (a + b \cdot C_0) \cdot e^{\frac{b \cdot t}{V}}\right] \tag{11}$$

Finally, for the steady-state condition, we consider time as infinite, and we obtain the following:

$$C = -\frac{a}{b} \tag{12}$$

3. CONVENTIONAL SYSTEMS WITH RECIRCULATION (CONFIGURATION 1.B)

This scheme is very similar to the previous one. The only change is in the absence of the filter cleaning the recirculation air (Fig. 2). Therefore, there is no pre-filtration of the recirculated airflow, leading to a further load for filter 3. The equations are similar to the previous case with the only assumption of P_2=1.

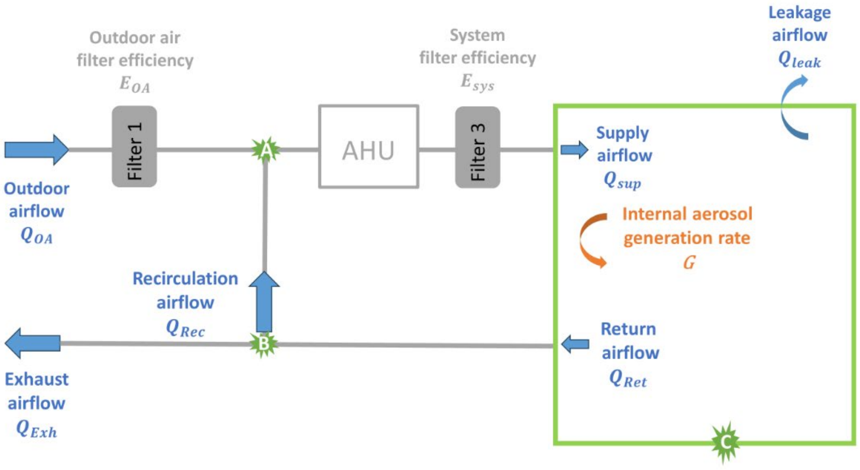

Figure 2 - Air-conditioning System Configuration 1.b

In this case, the mass balance equation is:

$$G - Q_{leak} \cdot C + (Q_{ret} - Q_{exh}) \cdot C \cdot P_3 + Q_{OA} \cdot C_{OA} \cdot P_1 \cdot P_3 - Q_{ret} \cdot C = \frac{dC}{dt} \cdot V \qquad (13)$$

4. AIR CONDITIONING WITHOUT RETURN AIR (CONFIGURATION 2)

In this configuration (Fig. 3), the supply airflow rate is 100% external air, i.e., it comes from outdoors. The only filter present needs to remove more particles. Thus, it will clog faster if it has the same efficiency as Configuration 1.

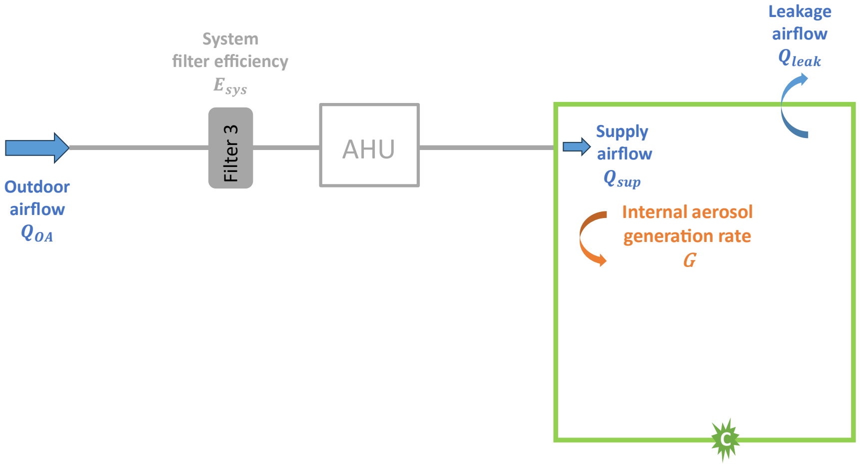

Figure 3 - Air-conditioning System Configuration 2

In this configuration, the main assumptions are:

P_1=1

P_2=1

$Q_{OA} = Q_{sup} = n \cdot V$

Recirculation factor = 0

$Q_{ret} = Q_{exh} = 0$

$Q_{sup} = Q_{leak}$

The balance equation becomes:

$$G - Q_{leak} \cdot C + Q_{OA} \cdot C_{OA} \cdot P_3 = \frac{dC}{dt} \cdot V \tag{14}$$

5. AIR CONDITIONING WITH RECIRCULATION WITHOUT EXHAUST AIR (CONFIGURATION 3)

Similarly to the previous configuration, the difference lies in the recirculation airflow (Fig. 4). The filter selection considers the proportions of the external and recirculated airflow.

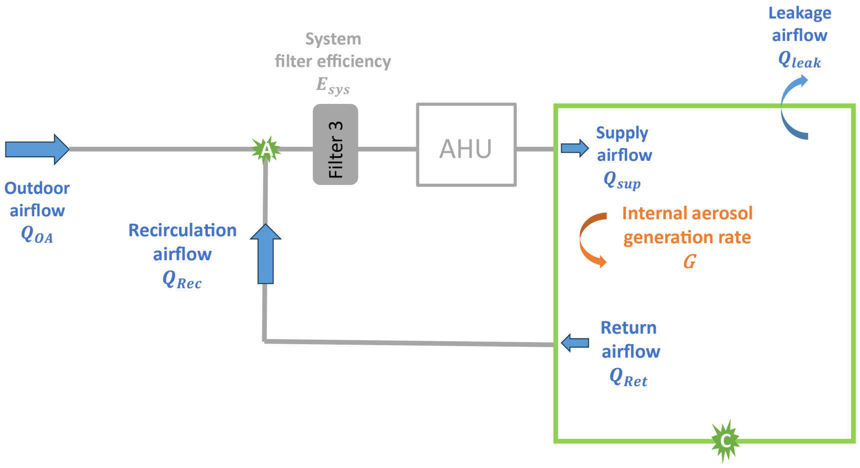

Figure 4 - Air-conditioning System Configuration 3

In this case, the main assumptions are:

P_1=1

P_2=1

$Q_{exh} = 0$

$Q_{rec} = Q_{ret}$

$Q_{ret} = Q_{sup} - Q_{OA}$

$Q_{leak} = Q_{sup} - Q_{ret}$

The balance equation becomes:

$$G - Q_{leak} \cdot C + Q_{OA} \cdot C_{OA} \cdot P_3 + Q_{ret} \cdot C \cdot (P_3 - 1) = \frac{dC}{dt} \cdot V \tag{15}$$

6. AIR CONDITIONING WITHOUT RETURN AIR AND WITH ROOM AIR CLEANER (RAC) (CONFIGURATION 4)

This configuration (Fig. 5) represents a case without mechanical ventilation. The air enters the room without any filtration by natural ventilation (e.g., open windows). In this case, we need a room air cleaner to improve the IAQ, especially if outdoor air is polluted. The room air cleaner can recirculate the air inside the room, filtering out the particles. Its efficiency depends on the Clean Air Delivery Rate (CADR), the product of the airflow rate processed by the filter's efficiency. The effectiveness of room air cleaners relies also on the amount of airflow processed: the higher the flow rate, the better the air cleaning effect. In terms of mass balance, the inlet airflow rate equals the outlet airflow rate. We assumed the air change rate with natural ventilation to be half of that with mechanical ventilation.

Furthermore, if there is no room air cleaner and, thus, no air cleaning is present, the configuration results in a new layout (Configuration 0). This case could be useful for analyzing and investigating the effect of internal aerosol generation in the room without filtration.

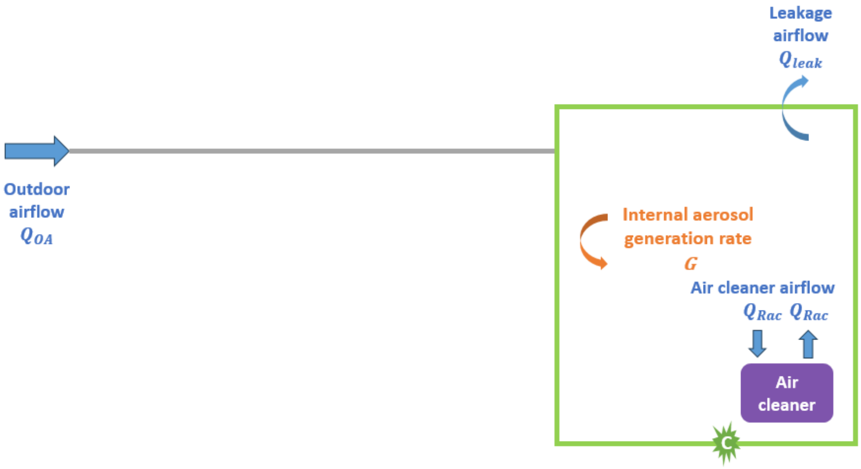

Figure 5 - Air-conditioning System Configuration 4

The balance equation for configuration 4 becomes:

$$G - Q_{leak} \cdot C + Q_{OA} \cdot C_{OA} - Q_{RAC} \cdot \eta \cdot C = \frac{dC}{dt} \cdot V \tag{16}$$

Where:
Q_{RAC} = airflow rate passing through the room air cleaner;
η = efficiency of the filter inside the room air cleaner;
$Q_{RAC} \cdot \eta$ = the so-called CADR.
In configuration 0, the equation (16) remains still the same without the term related to the room air cleaner:

$$G - Q_{leak} \cdot C + Q_{OA} \cdot C_{OA} = \frac{dC}{dt} \cdot V \tag{17}$$

7. CONVENTIONAL SYSTEMS WITH RECIRCULATION AND ROOM AIR CLEANER (CONFIGURATION 5)

This configuration is the most general and complete configuration that we modeled (Fig. 6). Both the ventilation system and the room air cleaner can clean the air in the room. In this case, following the example shown in Configuration 1, the assumptions are the same, and the balance equation is:

$$G - Q_{leak} \cdot C + (Q_{ret} - Q_{exh}) \cdot C \cdot P_2 \cdot P_3 + Q_{OA} \cdot C_{OA} \cdot P_1 \cdot P_3 - Q_{ret} \cdot C - Q_{RAC} \cdot \eta \cdot C = \frac{dC}{dt} \cdot V \tag{18}$$

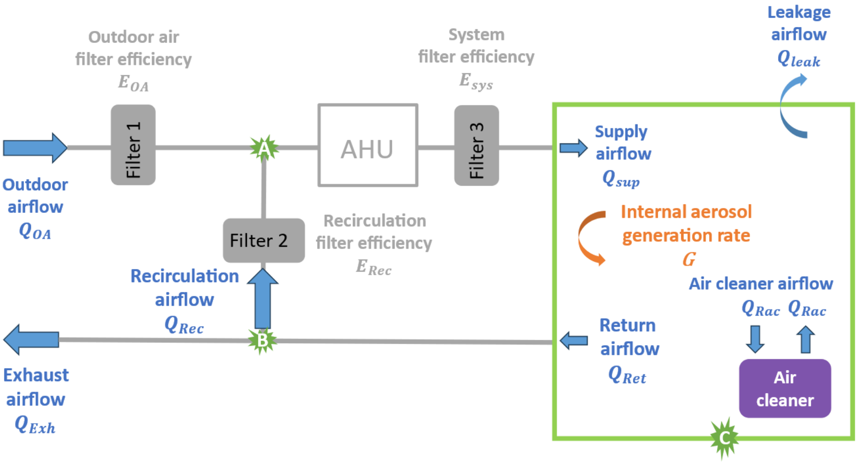

Figure 6 - Air-conditioning System Configuration 5

8. RESULTS

We implemented all the previous configurations to evaluate the $PM_{2.5}$ concentration as a function of the filtration system and airflows. In addition, we calculated the $PM_{2.5}$ concentration with natural ventilation and without air cleaning (also called configuration 0) to calculate the contaminant concentration when designers neglect IAQ calculations. Tab. 1 shows the input data for the calculation procedure. Table 2 reports the results expressed as the $PM_{2.5}$ concentration after 5 minutes (300 s) and in steady-state conditions. The calculations consider an internal aerosol generation rate of 1,38 µg/s, i.e., coherently with the value suggested by ABNT NBR 16401-3 (2023). However, to provide some more realistic conditions, we divided Configuration 0 into Configuration 0.a, where the internal aerosol generation rate is equal to the one provided by the draft Brazilian standard, and Configuration 0.b, where the contaminant generation is due to the smoke of one cigarette per hour, with a generation of 20 mg per cigarette of $PM_{2.5}$.

Table 1 - Technical input data

Number of people in the room	30
Room overall volume V [m^3]	400
Room area [m^2]	100
$PM_{2.5}$ concentration outdoors C_{OA} [µg/m^3]	50
Average 24h WHO limit for $PM_{2.5}$ concentration [µg/m^3]	15
Air change per hour (ACH) mechanical ventilation	3
Air change per hour (ACH) natural ventilation	1,5
Outdoor airflow Q_{OA} [dm^3 / (s·person)]	8
Internal aerosol generation rate [µg/s] according to NBR 16410-3 (50 [µg/(h·m^2)] for 100 m^2 floor area)	1,38
Internal aerosol generation rate [µg/s] if smoking 1 cigarette per hour (20 mg/h)	5,56
e$PM_{2.5}$ efficiency of room air cleaner filter [%]	80
Airflow rate of room air cleaner (Q_{RAC}) [m^3/h]	610

Table 2 - Calculation results

	Efficiency F1 – OA; Efficiency F2 – Rec; Efficiency F3 – Sys [%]	**Supply airflow [m^3/h] µ**	**CADR [m^3/h]**	**C_{300s} [µg/m^3]**	**C_{steady} [µg/m^3]**
NV no filtration – 0.a	-; -; -	600	-	51	58
NV no filtration – 0.b	-; -; -	600	-	54	83
VS complete – 1	50; 50; 80	1200	-	41	8
VS complete no F2 – 1.b	50; -; 80	1200	-	41	8
VS OA only – 2	-; -;80	1200	-	42	14
VS OA + Rec (F3 only) – 3	-; -;80	1200	-	42	12
NV with RAC - 4	-; -; -	600	488	46	32
VS complete with RAC - 5	50;50;80	1200	488	37	6

Configurations 1, 1.b and 5 are very similar, although configurations 1 and 5 include an additional filter in the air return. The end result is very similar; they can be dispensable in most cases. They would be important in environments with a lot of $PM_{2.5}$ generation. The results show that it is possible to estimate the indoor $PM_{2.5}$ concentration for facilities with air conditioning systems. However, calculating the concentration for environments with air purifiers and ventilation systems is also possible.

For configuration 5 with an air purifier and similar to configuration 1 without the air purifier, the influence of the cleaner is very small and may not be justified.

9. SENSITIVITY STUDY

Using this calculation method, we can observe in Table 3 the relationship between the concentration of $PM_{2.5}$ as a function of the variation in the supply airflow after 300 s ($C300_s$) of the HVAC system having been turned on, in the steady state condition (Csteady) and the time taken for the environment to reach a concentration of 15 µg/m^3, keeping the other variables the same as in the study above for configuration 1.b.

The airflow greatly influences the time elapsed until the installation reaches a concentration of 15 µg/m^3, which would be the concentration with no influence on the occupant's health.

Air Change per hour -ACH [1/h]	3	4	5	6	7
Qsup [m^3/h]	1200	1600	2000	2400	2800
C300 [µg/m^3]	41	38	36	33	31
Csteady [µg/m^3]	8.0	7.2	6.6	6.2	5.9
Time [s] to reach limit of of 15 [µg/m^3]	2310	1615	1240	1010	855

Similarly, Table 4 shows the variation in $PM_{2.5}$ concentration after 300 seconds of the installation being turned on (C_{300s}), in the steady state condition (C_{steady}) and the time elapsed for the environment to reach a concentration of 15 µg/m^3, varying the Internal aerosol generation rate (G_int). We keep the other variables as in the study above for configuration 1.b.

We can note that the internal generation of $PM_{2.5}$ greatly influences its final concentration, and the desired concentration may not be achieved at any time.

G_int [g/s]	1.38889E-06	2.78E-06	5.56E-06	5.56E-05	1.11E-04
C300 [µg/m^3]	41	42.15	44	77.41	114.52
Csteady [µg/m^3]	8	12.64	21.47	180.37	356.92
Time [s] to reach limit of of 15 [µg/m^3]	2310	3500	not	not	not

10. CONCLUSIONS

This work provides HVAC designers with practical examples to design a ventilation system to manage indoor air quality. ABNT NBR ISO 16890-1:2018 and the proposed revision of ABNT NBR 16401-3 (2024) provide the background for the design calculations. ABNT NBR ISO 16890-1:2018 classifies air filters based on their *e*$PM_{2.5}$ efficiency in removing a typical urban aerosol after fixing a specific particle size distribution. Starting from the filter classification, designers can easily choose proper filters for their system based on the model proposed in the revision of ABNT NBR ISO 16890-1:2018, which shows how to calculate the concentration of contaminants over time.

Furthermore, this work suggests that air filter selection is fundamental. The choice depends on the air filter's performance data, which allows one to evaluate the interaction with other variables, such as supply airflow, the proportion of external air, the concentration of outdoor $PM_{2.5}$, and the generation of indoor $PM_{2.5}$ by the process and type of occupancy, in the final result during occupancy.

It also shows the need for research to determine the generation of internal $PM_{2.5}$ for each type of activity or process, given its influence on the final result.

The proposed revision of ABNT NBR 16401-3 (2024) provides information on the best filter choice based on a desired $PM_{2.5}$ concentration within the environment. Furthermore, this algorithm proves to be an important calculation tool for air conditioning and ventilation system designers in the search for the best indoor air quality.

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ESCOLHA DE FILTROS DE AR PARA VENTILAÇÃO GERAL POR CÁLCULOS DE ENGENHARIA

S2 - Equipamentos e Componentes de Ar Condicionado, Ventilação e Aquecimento

Abstrato. As diretrizes globais de qualidade do ar da OMS publicadas em 2021 e a recente pandemia de COVID-19 demonstraram que a qualidade do ar é um problema de saúde pública. A Qualidade do Ar Interior deve ser um aspecto imperativo na concepção de sistemas de ar condicionado para ambientes interiores onde as pessoas passam a maior parte do tempo. A maior preocupação em relação aos efeitos nocivos à saúde humana são as $PM_{2,5}$. Considerando a concentração de $PM_{2,5}$ presente no ar exterior na maioria dos centros urbanos é óbvia a necessidade de limpar o ar exterior, que raramente cumpre os valores prescritos pela OMS. Portanto, os dispositivos para purificar o ar de partículas estão se tornando cada vez mais importantes, e sua seleção é um dos aspectos críticos dos projetos de sistemas de ar condicionado internos. O cálculo dos componentes essenciais para garantir a qualidade do ar interior pode ser feito através da realização de um balanço de massa dos contaminantes em questão. Este cálculo torna-se mais complicado no caso de partículas devido à dependência do tamanho dos comportamentos e propriedades. Porém, é possível calcular a concentração de $PM_{2,5}$ após fixar a distribuição granulométrica e, assim, reduzir sua representação a um único número. A norma ABNT NBR ISO 16890-1:2018 oferece ao projetista a possibilidade de selecionar filtros e calcular vazões de ar, dimensionar o sistema de ventilação escolhendo a bateria de filtros capaz de atender aos objetivos do projeto. A minuta de revisão da ABNT NBR 16401-3 aproveita esse importante avanço para calcular a concentração interna de partículas, parâmetro essencial para garantir um ambiente interno saudável.

Palavras-chave: Filtro de ar, $PM_{2.5}$, IAQ, Sistema de ventilação, IS0 16890, Qualidade do ar interno.