Liquid air filtration and continuous monitoring: customized indoor air quality

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Abstract. Air treatment in environmental air conditioning systems exposes the system to gases, contaminants, and often biological pollutants that cannot be solved by traditional mechanical filtration, motivating decision-makers to diagnose challenges and develop innovative strategies to mitigate the problem. More and more, in environments with high turnover of people (e.g., hospitals, hotels and shopping centers), fresh air ventilations are avoided and replaced by closed windows air purifier solutions to account for undesirable saturation of the atmosphere and the presence of pollutants such as PM10, PM2.5, PM1.0, nitrogen, and carbon oxides. The consensus is that polluting gases render the most efficient traditional filters ineffective. The ANSI/ASHRAE 62.1 and EN13779 standards reveal the absence of air treatment technologies that use the wet route in air conditioning systems. This work discusses the liquid air multi-venturi centrifugation technology of hydrodynamic precipitator purifiers in association with the synchronized and continuous monitoring of parameters (PM10, PM2.5, PM1.0, CO_2) in the external urban environment and internal environments of a shopping center. It evaluates the performance of the wet route for the physical-chemical and biological treatment of air. Efficiency for retaining particulate matter in a single step without disposable filter reached levels above F9 (85-95% PM2.5), with a reduction of 82.4% for CO2. Wet route technology extends the air conditioner's life, reducing external air flows and energy consumption by up to 13%, making IAQ a manageable and customizable variable. Among the conclusion of the investigation, the authors believe that the migration of industrial pollutant control technologies, such as liquid filtration promoted by gas scrubbers and hydrodynamic precipitators, should be considered as a first choice option due to the high efficiency achieved in the three types of pollutants to be controlled. That is micrometric particulate matter such as anthropogenic PM1.0 capable of reaching the lung alveoli, chemicals such as carbon dioxide and nitrogen, and biological assets such as viruses and bacteria that showed the vulnerability of HVAC-R systems during the COVID pandemic that rendered windowless corporate buildings unusable.

1 Introduction

Catastrophic natural events have become routine worldwide, including gigantic forest fires on the American West Coast, hailstorms in Rio de Janeiro in the middle of summer, and torrential rains summing hundreds of mm of water in a few hours in Europe. They place climate change as a central theme for many nations and groups defending the planet as a dystopian planet, a lousy place to live, even despite inertia and environmental resilience.

“Two new concepts are closely linked: inertia and environmental resilience, underlining the ability to resist environmental pressures. These terms are somewhat related and are probably best exemplified by climax communities, an ecological community in the final phase of succession, in which the species composition remains relatively stable until a disturbance such as pollution occurs. These environments can withstand changes in environmental pressures (resilience) but, at the same time, are slow to change in response to changes (inertia). Both properties are a function of biodiversity in a climax community. The greater the diversity, the more stable the community. Temperate forests are generally more diverse than grasslands, so their resilience and inertia would be greater.” [1].

2 Materials and methods

The typical IAQ contaminants (PM10, PM2.5, PM1.0, and CO2) were continuously monitored during the realization of a busy (25,000 visitors) event in a Convention Center located in a modern shopping center in the city of São Paulo over four consecutive days. As expected, the "quality radiography of the air" confirmed a sinusoidal function with variable amplitude directly dependent on the number of visitors. This behavior started from the base just before the public entered, with the air quality in compliance with the recommended standards. The function peaked at 6:00 pm, exhibiting indices for PM2.5 and CO2, much higher than recommended. Worryingly, the resuspension effect of the particulate matter accumulated on the carpets, raising the contaminant's maximum levels as the event progressed. The central location of the two MCQA sensors applied certainly brought results representative of reality; the air is now visible, and the IAQ information became available to managers of the Convention Center.

In response to this critical situation, one expects that designers of HVAC-R systems be more conscious about their responsibilities in changing this scenario by using BADCT ("Best Available Demonstrated Control Technology") technologies to guarantee physical-chemical quality biological air in indoor environments.

Air quality is online on the Microsoft Climate computing platform, continuously updated with the collective support of users, openly broadcasting free information. Figs 1, 2, and 3 illustrate, respectively, typical screens of this application, suggesting for different cities (Milano; São Paulo, Seul) the closing of windows and the strict use of air purifiers to overcome the depletion of the atmosphere by pollutants such as PM10, PM2.5, PM1.0, ozone, nitrogen oxides, and carbon.

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Fig. 1a. Milano-IT PM2.5: 41μ/m³, Poor

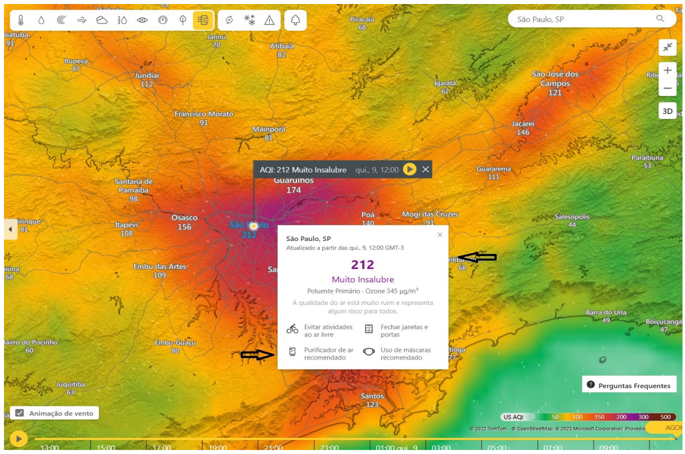

Fig. 1b. São Paulo-BR O$_3$: 345 µg/m³, Very unhealthy

Fig. 1c. Seul-KR PM2.5: 44μ/m³, Poor

Figure 1. Air quality (measured on 01/12/2024) in three cities around the world.

Table I, transcribed from the reference indicated in the legend, presents internationally agreed criteria on air quality, known as the AQI Air Quality Index.

Table 1. AQI-Air Quality Index.

Source: (https://www.msn.com/pt-br/clima/mapas/airquality).

AQI	*Health implications*
0 - 50	*Good*
50 - 100	*Moderate*
100 - 150	*Unhealthy for sensitive groups*

AQI	*Health implications*
150 - 200	*Unhealthy*
200 - 300	*Very unhealthy*
300 - 500	*Dangerous*

Table 2 summarizes the new air quality guidelines (WHO AQG), reflecting the large impact that air pollution has on global health, aiming for annual mean concentrations of PM2.5 not exceeding 5 µg/m^3 and NO_2 not exceeding 10 µg/m^3, and t peak season mean 8-hr ozone concentration not exceeding 60 µg/m^3 [2].

Table 2. Air Quality Guidelines AQGs. "Source: WHO, 2021)".

Pollutant	Averaging Time	2005 AQGs	2021 AQGs
$PM_{2.5}$, µg/m^3	annual	10	5
	24 h^a	25	15
PM_{10}, µg/m^3	annual	20	15
	24 h^a	50	45
O_3 , µg/m^3	Peak season^b	-	60
	8 h^a	100	100
NO_2, µg/m^3	annual	40	10
	24 h^a	-	25
SO_2 , µg/m^3	24 h^a	20	40
CO, mg/m^3	24 h^a	-	4

Annual and peak time: long-term exposure; 24 h/8 h: short-term exposure. µg = microgram.
[an] increase to the 99th percentile (i.e. 3 to 4 exceedance days per year).
[b] average of the maximum daily average O_3 concentration over 8 hours/6 months consecutive.

Investigations conducted by Rodrigues et al. [3] provided scientific evidence about the risks of micro and nanoplastics to human health and their exposure routes through the environment. Their results confirm that fine particles (PM2.5 and PM1.0) and even of submicrometer size, including plastic nanoparticles (MNPL) suspended in the air, can penetrate through the lungs and reach the body through the bloodstream, affecting all major organs, causing diseases in both the cardiovascular and respiratory systems. Further research has also shown an association between prenatal exposure to high levels of air pollution and developmental delay at three years of age, as well as psychological and behavioral problems.

Applied research has been developed, allowing the classification of urban centers as carbonic islands exhibiting fine anthropogenic particles based on electronic injection of engines whose combustion is more efficient and less polluting, generating much finer particles and, therefore, harmful to breathing. [1,4-5].

The depletion of the atmosphere by pollutants such as PM10, PM2.5, PM1.0, ozone, nitrous, and carbon dioxide is due to several anthropogenic phenomena, with the burning of fossil fuels being the most impactful. The historical neglect came to light thanks to the COVID-19 pandemic, which showed how vital the invisible atmospheric air is. Historically, we control what we see, and in this sense, coal soot filtration systems were developed in the 18th century. Over the last 60 years, mechanical filtration technologies have evolved to retain PM10, PM2.5, and PM1.0 efficiently. The publication by Lance [6] presents a historical overview of air purifier testing, as Offermann et al. [7], at the Lawrence Berkeley National Laboratory, with tests of flat, pleated, HEPA, electrostatic, and ionizing filters, using the same metrics for all variables, established the so-called Clean Air Delivery Rate (CADR), which is the effective rate of clean air supplied by filtration systems. Several research centers promoted exclusive tests with dry routes for solid particulate material filtration. These tests yielded efficiency rates categorized by particle diameter range, such as MERV (Minimum Efficiency Classification Value) from MERV1 to MERV16, and the ASHRAE Method. 52.2, which introduced a new standard for particulate dust with known weights. Figure 2 shows test results featuring "U" shaped efficiency curves exhibiting typical characteristics of dry electromechanical filtration technologies.

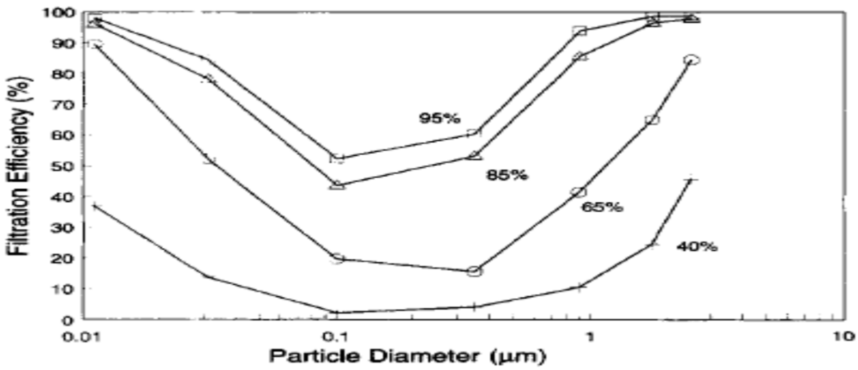

Figure 2. Typical electro-mechanical filtering curves. "Source: Hanley et al., 1994".

The COVID-19 pandemic shook the world, showing the vulnerability of buildings' ventilation systems, which cannot contain biological assets and gaseous pollutants. The ASHRAE-Position Document on Filtration and Air Cleaning [8] and other more recent publications on combating biological actives cite active technologies such as ozonolysis, UVc emission, and electrostatic filters. On the other hand, wet route technologies, such as air scrubbers, are not even listed in any compendium that deals with IAQ.

In the revision of the Brazilian standard NBR16401, there is a provision for using wet route technologies for air filtration by liquid washing, including in arrangements without mechanical filters. The recommendation that air quality parameters be communicated to users of public buildings was also included.

Gaseous pollutants are essential in the greenhouse effect, causing global warming. Methane (CH_4) is the most harmful nitrous oxide (NOx) and is a critical atmospheric pollutant in the formation of acid precipitation. However, carbon dioxide (CO_2) is responsible for the most significant anthropogenic emission of gases into the atmosphere.

As a counterpoint, the evolution of air quality measurement devices monitored using laser scattering reading chambers proved capable of continuously monitoring air quality in real-time and indoor environments. it also allows management of operational adjustment parameters, aiming to maintain the air quality within limits, recognizing the standards established by the project for a given building, and the rational use of energy that will be applied sparingly when necessary. air quality in indoor environments can be managed dynamically and automatically through a higher renewal rate or physical-chemical-biological air purifiers.

Pollutants have changed their criticality, with gases and aerosols, including biological active ingredients (bioaerosols), assuming a predominant role that makes filters unsuitable for controlling contaminants. thus, complementary or alternative treatment technologies are necessary. they face the challenge of controlling the concentration of substances in the same physical state as atmospheric air, that is, air as a gaseous mixture. the palliative measures applied to increase the rate of indoor air renewal could be more effective due to the worsening of outdoor air quality, as shown above in Figure 1, for several cities worldwide. in addition to increasing energy consumption to overcome the load loss, more efficient filters are needed in an inglorious race to adapt to the comfort conditions required by conscious users.

The concept of net zero, or zero energy balance in buildings, should be the primary focus in the world, increasingly concerned with reducing energy costs. furthermore, as it is a relatively new concept, this new picture brings new challenges and instigates renewable and sustainable energy research in achieving zero net operating energy consumption.

Research shows that approximately 40% of global primary energy consumption and greenhouse gas emissions in Europe are due to buildings. Combining air decarbonization with energy efficiency is possible and can be achieved simultaneously.

The so-called OAS outdoor air systems are widely used in air conditioning projects. however, carbon dioxide levels in the current atmosphere are rising and requiring more significant external air flows, impacting energy consumption, and thus, we are in a critical paradox. in this case, air treatment through chemical conversion can remove pollutants that are not mechanically retained, enabling the efficient removal of small molecules such as carbon dioxide. our approach differs because we promote the chemical transformation of carbon dioxide or carbonic acid; it is a CCT (carbon capture transform) technology through carbonation [4] with the chemical solubilization and neutralization route, with alkaline liquid cooled in a venturi process centrifuge. carbon dioxide is subjected to a chemical neutralization reaction, transforming it into a soluble solid salt that will become a treatable liquid effluent and no longer be part of the air composition.

Therefore, reducing the concentration of carbon dioxide through external air and circulating return air treatment systems makes it possible to increase the air conditioning usage cycle, reducing the external airflow with a reduction in thermal load. this guarantees indoor air quality and reduces energy consumption, contributing to achieving a NET zero energy balance in buildings. I have observed that the energy efficiency x air quality paradigm must start from the assumption that the priority variables and parameters are air quality since it is remunerated and users increasingly know their rights to clean air.

3 Technological innovation

Technologies from the industrial field recognized in the literature, such as air washing by liquid spraying, turbulent flow, or centrifugation, are not even mentioned in any HVAC publication, whether American or European, despite everyone's consensus that the air is clean after rainfall.

Authors are convinced that air treatment using refrigerated humid means will ensure air quality and allow for a reduction in external air ventilation rates, given the drastic reduction in the content of carbonic acid, our well-known CO_2, primarily responsible for the need for high rates of external air in buildings' air conditioning systems. EN13779 [9] establishes outdoor air quality classes (ODA) to correlate with the indoor air quality objective (IDA) and thus establishes minimum filtration classes as follows: ODA 1- applies where the WHO guidelines[2] and any national air quality standards or regulations for outdoor air are met; ODA 2 - applies where pollutant concentrations exceed WHO guidelines or any national air quality standards or regulations for outdoor air by a factor of up to 1.5; ODA 3 - applies where pollutant concentrations exceed WHO guidelines or any national air quality standards or regulations for outdoor air by a factor greater than 1.5, and the typical gaseous pollutants to be considered are cited in the evaluation of external ambient air for the design of ventilation and air conditioning systems, such as carbon, sulfur and nitrogen oxides, ozone, lead and volatile organic compounds; in this sense, ASHRAE standard 62.1[10] in appendix E-tableE-1 lists "ips literi" the six pollutants classified by EPA-NAAQS- National Ambient Air Quality Standards (40 CFR part 50), in other editions it was a mixture of standards from several international and American entities, bringing significant ambiguity and difficulty in application. Most European buildings operate with EU7/EU8[6].

However, currently, the decarbonization of our planet's atmosphere is a challenge for humanity, as the repercussions are global, as demonstrated in printed climate Figure 1, in locations where the air is terrible, that is, the atmosphere is dynamic and submicron pollutants are not subject to gravitational action and remain wandering around the world's atmosphere, occurring in remote locations. Now, if we consider the gaseous impact, the issue is more democratic, as carbon dioxide is a gas and, as such, expands continuously, as measured in isolated locations such as Manua Loa in Hawaii, which show the change in tangent, alerted in 2000, configured as depicted in Figure 3, exhibiting the mountain range evolution of CO_2 rates in the global atmosphere with values reaching 421 ppm of CO_2 in April 2023.

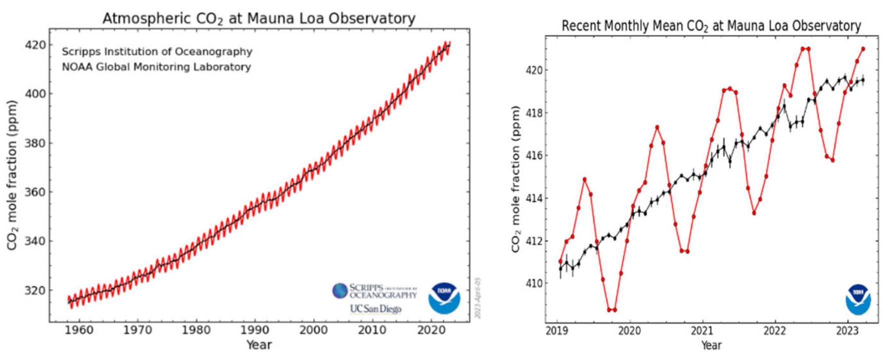

Figure 3. Evolution of the concentration of carbonic acid in the atmosphere.

Source: https://gml.noaa.gov/ccgg/trends/mlo.html.

4 Liquid air filtration

Since 2009, authors have been involved with the development and monitoring of implementations of external air intakes for air conditioning in places with contaminants, such as carbon black and urban dust, as well as odors and the saline atmosphere typical of coastal areas. Satisfactory and pioneering results from empirical applications encourage them to evolve with the application of exclusively wet route technologies associated with refrigerated cycles to reduce the temperature of the air washing fluid below the region's wet bulb temperature, as well as pH control peripherals (hydrogen ionic potential) aiming to ensure an alkaline environment that guarantees the neutralization of acids, including carbonic acid (CO_2) and inactivation to biological species. The operation of air washers with cooled liquid minimizes the thermo-hygrometric impact and eliminates the need for a fan coil dedicated to external air.

This work analyses the test results of an installation implemented in 2017 in a shopping mall in Rio de Janeiro/Brazil. The aim was to extract salt mist from the air that caused corrosion of all electrical measuring instruments in the project, culminating in a blackout during business hours. In addition to qualifying inherent physical-chemical aspects, the installation is instrumented with thermo-hygrometric control, as there is no thermal dissipation in the room, with a resistance bank and a secondary evaporator being applied to the line to guarantee throughout the year and under any condition, the design set-up: 24°C@55% R.H. From operational start-up, the system protects the internal environment and removes a high level of soot material removed by multi venturi liquid centrifugation of the hydrodynamic precipitator. Figure 4 shows the achievement of high levels of hydraulic extraction of particulate matter and absorption of carbon dioxide.

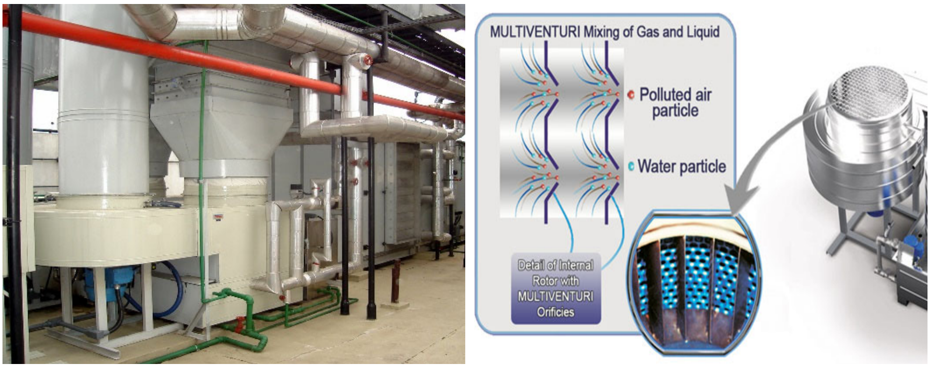

Figure 4. Hydrodynamic precipitator and multi-venturi internal detail of the simultaneous centrifugation of liquid and air in a limit load rotor. Source: Flavors laboratory, São Paulo, SP/Brazil.

The parameters under analysis will be particulate matter in the fractions of PM10, PM2.5, and PM1.0, while the gaseous one will be carbon dioxide (CO_2). The research in spectra is equivalent to those applied in air handling units (AHU). It is worth noting that in the hydraulic reduction of particulate matter, liquid filtration has an exclusive characteristic of constant performance in contrast to mechanical filtration, which throughout its helpful life fluctuates from 60% of the nominal value at the beginning of the life cycle, even at values above the nominal when approaching saturation.

To carry out the field tests, measuring sensors using three dedicated sensor modules were developed: one for measuring the concentration of particulates (PM1.0, PM2.5, PM4.0, and PM10), another for measuring CO_2 concentration, and one for measuring temperature, humidity, and atmospheric pressure.

Particulate matter measurement is carried out through optical particle counting based on laser scattering with self-cleaning capacity. The PM4.0 and PM10 quantities were estimated and the PM1.0 and PM2.5 quantities were effectively measured. The measurement of carbon dioxide concentration is based on the highly accurate, non-dispersive infrared spectroscopy method, which automatically compensates for slow variations in heat and humidity. The CO_2 sensor operates from 0 to 40,000 ppm with an expanded measurement uncertainty of ±50 ppm, and finally, the integrated sensor for measuring temperature, humidity, and atmospheric pressure is a microelectromechanical sensor (MEMS) with digital filter Integrated IIR. This sensor has its best estimated measuring capacity of ±0.12 hPa for absolute atmospheric pressure, ±3% for relative humidity, and ±1°C for temperature.

Figure 5. (a) Intake external air scenario. (b) Refrigerated hydrodynamic precipitator. (c) internal monitored environment. Source: authors in the field. Rio de Janeiro/BR, 2023).

The self-aspiration of the hydrodynamic precipitator generates the flow. The test applied two sensors: one being installed in the air intake flow path (MCQA2), shown in Fig.6a; and another (MCQA3) in Fig. 6b, downstream of the supply air duct network, near the floor, we have the purified and air-conditioned, with temperature and humidity control.

Figure 6. (a) In and (b) Out Sensors and portable CO_2 meter; (c) authors in the field, 2023.

The installation consists of a hydrodynamic precipitator operating at 3,000 m³/h of external airflow, consuming a total of 6.3 kW, including refrigeration per compact unit and a bank of reheating resistors. The tests were conducted following a continuous monitoring protocol spanning six days (21-27/04/2023) during stable weather conditions, with reduced traffic due to holidays. The location chosen is a prime spot in a strictly residential city, situated approximately 200 meters from a lagoon-sea connection channel with salt water; this is the ambiance of the installation. Liquid samples were collected from the equipment at the test's initiation and conclusion to analyze electrical conductivity. This conductivity is attributed to the saline nature of the coastal atmosphere and the formation of carbonates resulting from the neutralization reaction of carbon dioxide by sodium hydroxide present in the used detergent, as described in the classic acid-base reaction equation.:

$$CO_2 + 2NaOH > Na_2CO_3 + H_2O. \quad (1)$$

Following a period of data stability indicating reduced pollutant levels in the region, we opted to simulate extreme scenarios during the final hour of measurement. This was done with the intention of assessing the reduction of particulate matter and carbon dioxide under adverse conditions. For this purpose, a 10 kg cylinder of carbon dioxide was used. It was discharged in the engine room; an environment that does not receive regular cleaning and contains high amounts of urban particulate matter that is resuspended. The air intake grilles were not exposed to any mechanical filter. Figures 7, 8, 9, and 10 illustrate the stability period and the disturbance caused by CO_2 cylinder discharge in a way that values of 6852 ppm of CO_2 were reached in the input sensor and simultaneously 1204 ppm in the internal environment, experiencing a reduction of 82.4%, confirmed by the 166% increase in carbonate content in the scrubbing liquid. Notably, carbon dioxide is more soluble in the cold liquid used in the equipment. After the system was operated for six years, the continuous digital temperature and humidity sensors show the stability achieved by controlling the heating resistance bank and the cooling coil.

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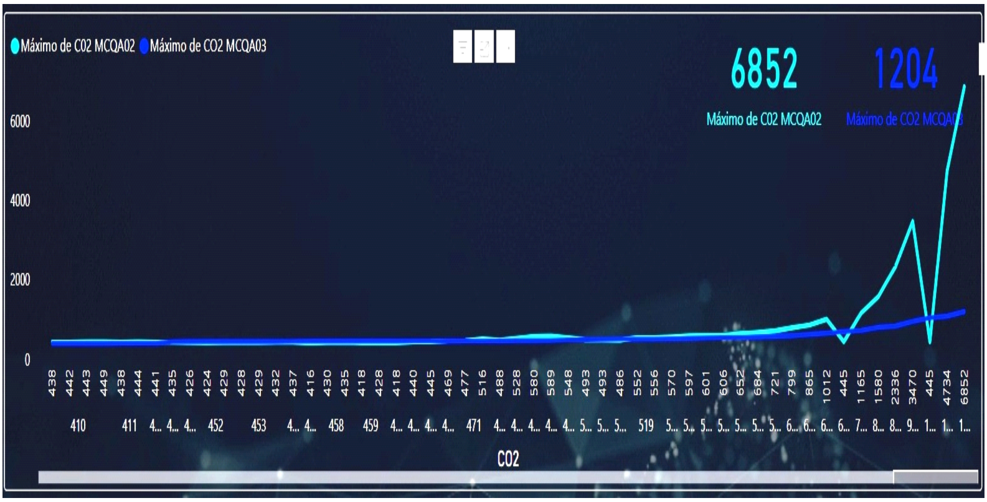

Figure 7. Solubilization, chemical absorption of CO2, and stable humidity, including in the simulated CO_2 discharge scenario. Source: Measurements performed by 3R Brasil Tecnologia Ambiental.

The behavior of hydraulically extracted particulate matter presents remarkable results: 98.41% reduction for PM10; peak result for PM2.5 reached 97.7% and 94.8% for PM1.0. Indeed, significant effects confirm the importance of air treatment technology via the liquid route to the minimum equivalent level of mechanical filtration, such as F9 (85-95% PM2.5). The analysis of the initial and final liquids of the hydrodynamic precipitator demonstrates an increase in the initial carbonate content of 14.9 mg/l, which reached 39.7 mg/l as $CaCO_3$. In contrast, the pH increased from 7 to 7.99, and the electrical conductivity from 132.5 to 153 µS/cm, demonstrating an increase in saline ions. The operation with alkaline liquid (pH = 7.5) ensures the dissolution of the LPS (lipopolysaccharides) layer of the microorganisms, which neutralizes the biologically active ingredients, converts and fixes the solubilized CO_2 transformed into sodium bicarbonate when washing the air with alkaline liquid, as certified in the liquid analysis reports.

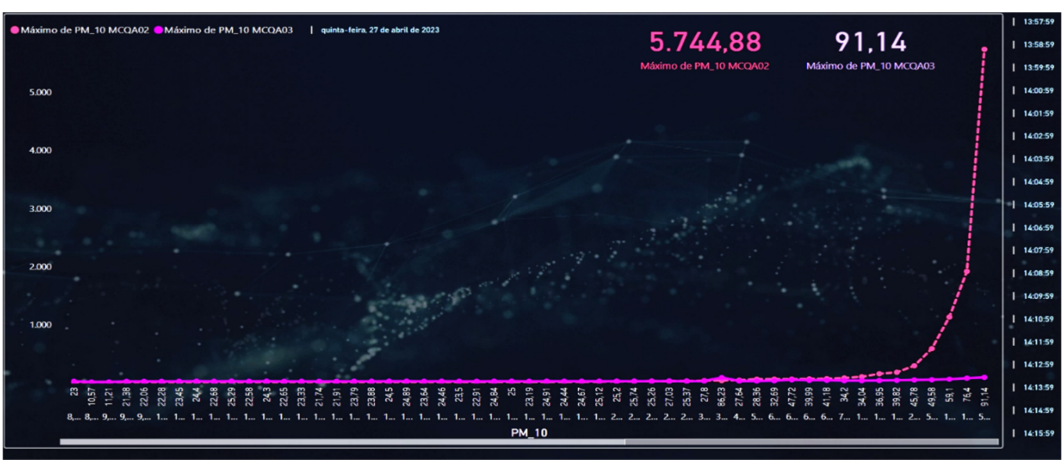

Figure 8. Liquid Filtration for PM10 in a continuous and simulated scenario in the air intake and the internal environment simultaneously. Source: 3R Brasil Tecnologia Ambiental.

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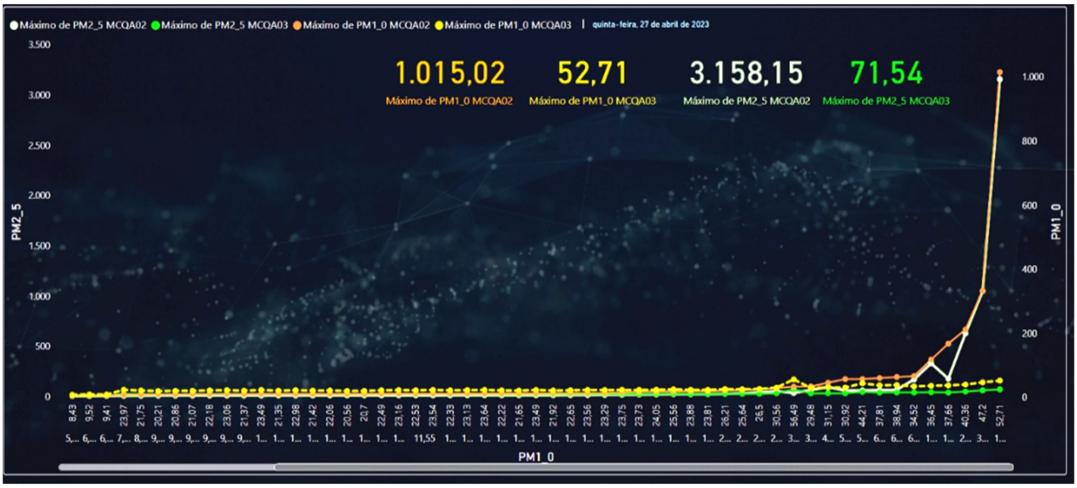

Figure 9. Liquid Filtration for $PM_{1.0}$ $PM_{2,5}$ in a continuous and simulated scenario in the air intake and the internal environment at simultaneous times.Source: 3R Brasil Tecnologia Ambiental.

New technologies, such as liquid air filtration, require empirical installations that accumulate experiences and results to support knowledge. We have installations in air intakes of air conditioning systems in cinemas, catering, and electrical rooms; In September 2023, we participated in an exhibition in a modern Event Center, large in 50,000 m² of area, 17 meters high (850,000 m³) and 25,000 visitors in four days, where a hydrodynamic precipitator operated in the open, i.e. air intake and discharge in the same air-conditioned environment.

Figure 10. Hydrodynamic precipitator in operation with pH = 7,5; fresh and pure air to visitors and dashboard online IAQ. Source: Febrava expo - São Paulo, SP/Brazil, 2023.

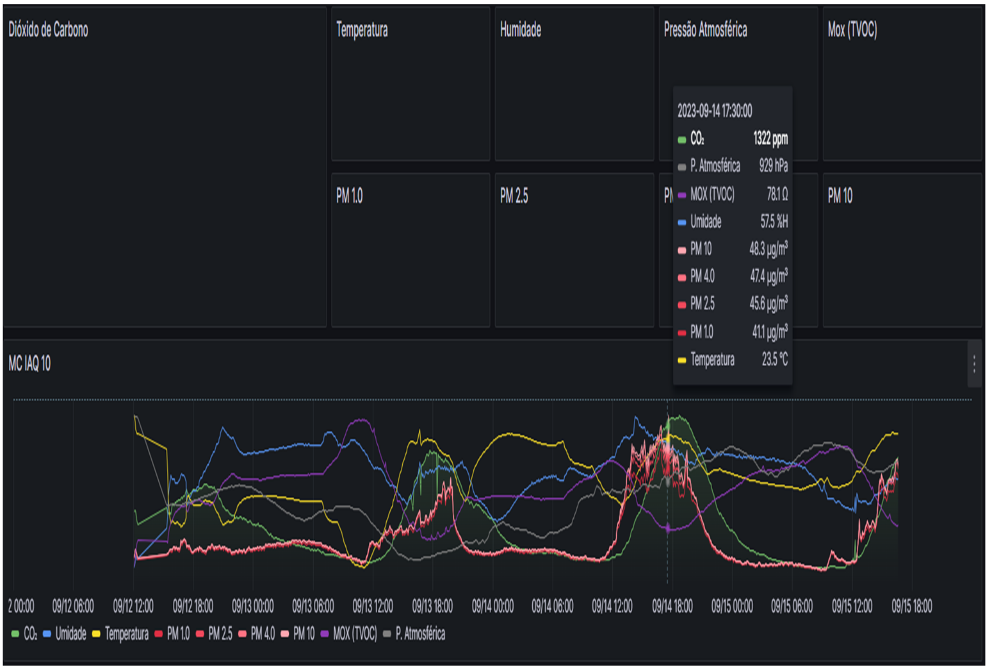

Figure 11. Liquid Filtration for PM1.0 PM2,5 in a continuous and simulated scenario in the air intake and the internal environment at simultaneous times. Source: Measurements performed by 3R Brasil Tecnologia Ambiental.

The air quality was continuously monitored during the four-day event. Figure 11 depicts the sinusoidal nature of the measured variable, whose amplitude refers to the occupancy of the environment at different times. As shown, a drop in the CO_2 particulate matter increases with temperature with the shutdown of the air conditioning system at night. At the opening of the visitation, at 1 pm, the new cycle begins, and the indoor air quality reaches an incredible 1322 ppm of CO_2 at 6:30 pm, while the processes appear to be cumulative in terms of PM2.5 particles = 45.6 µg/ m³ and PM1.0 = 41.1 µg/m³, i.e., 200% above the 2021 WHO legislation for short-term exposure. The comfort temperature was considered satisfactory at 23.3°C, for a level of 57.5% H. At this point, it became evident that mechanical filtration did not meet the indoor air quality criteria. Samples of the circulating liquid in the hydrodynamic precipitator were analyzed during the four-day event, and the transformation of carbon dioxide CO_2 was confirmed through the formation of carbonates with a concentration of 2,424 mg/l; biological inactivity was also certified with bacterial indices at 450 CFU/ml and fungi in the range of 390 CFU/ml, at the acceptable levels for drinkable water.

5 Conclusions

Atmospheric contamination leads to air-cleaning technologies migrating from industrial processes to applications in urban air conditioning systems. This affirmative indeed leads to breaking a taboo due to the increased thermal load of latent heat due to humidity. However, it is partially controlled by the reduction of sensible heat and the lower vaporization rate, thanks to the operation of the circulating liquid at temperatures below the dew point. The benefits achieved in air quality with constant performance and without disposable elements, associated with the control of physical, chemical, and biological pollutants at levels above who standards, transform liquid filtration into a selection option for air treatment in air conditioning systems of indoor environments, with the guarantee of lower energy consumption and operational costs. Liquid filtration, when used in hospital environments with resistant colonized bacteria, will probably be responsible for reducing hospital infection rates; this is the next stage of ongoing studies aimed at reducing mortality, comorbidities, and hospitalization costs.

Acronyms

AQG: Air Quality Guidelines

CADR: Clean Air Delivery Rate

CFU: Colony Forming Unit, a unit that estimates the number of microbial cells (bacteria, fungi, viruses, etc.) in a viable sample.

HVAC-R: Heating, Ventilation, Air Conditioned- Refrigeration

IAQ: Indoor Air Quality class.

MCQA: Meter Control Quality Air

ODA: Outdoor Air Quality class.

IDA: Indoor Air Quality class.

Authors acknowledge their profound respect for the memory of the scientist Giuseppe Capulli, particularly for his legacy, sense of perseverance, obstinacy, and creativity to battle for technological innovation for the well-being of humanity through the preservation of the environment and improvements in the quality of life.

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