

Evaluating new photocatalytic air cleaner

A new photocatalytic air cleaner applied to the management of microbiological indoor air quality is examined in this article. Studied in research was the effectiveness of devices used in the microbiological purification of the air. This specifically involves the inactivation of biological aerosols in an air handling unit. Focused on was the first device working on the principle of photocatalysis. This system, called NEO and developed by CIAT, (patent WO 2004/081458), involves the combination of filtration in adsorbent and heterogeneous photocatalysis.

The air cleaning device in question was settled in a test box located in a wind tunnel called ONE-PASS. This test facility is composed of an intake air fan and an exhaust air fan, in order to regulate the test box to maintain a slightly negative pressure, which prevents any exterior leakage. A HEPA filtration unit is settled upstream to remove any particles from the supplied air and another one is present downstream to avoid any pollution in the exhaust air.

The ONE-PASS is characterised in terms of the homogeneity of velocity profiles and particulate profiles. The aerosolisation of the bacteria *Staphylococcus epidermidis* used for the tests was controlled. The flow of bacteria was stable and its concentration known. Three main criteria of the purification rate were studied to determine the level of effectiveness: concentrations of total flora, cultivable bacteria and particle count. A purification rate superior to 98% has been found for the NEO system in the ONE-PASS platform for the cultivable bacteria.

Increased awareness

An influenza pandemic, Legionnaire's disease, intoxications by mould and mildew, nosocomial infections, and bio-terrorism are

topics that have largely contributed to increase public awareness regarding airborne microbiological risks.

Present everywhere in our varied environments, biological pollutants, inhaled or ingested, can have a considerably negative consequence on human health. Enclosed spaces sometimes constitute "ecological niches" which facilitate the reproduction of biocontaminants and further increase the occupants' exposure to them.

The microbiological composition of the air is complex. We can observe "live" microorganisms (moulds, bacteria, and viruses), antigenic or toxic microbial fragments, as well as volatile organic substances of microbiological origin (COV_m). This pollution, depending on the level of exposure and the occupants' sensitivity, can be the origin of diverse pathologies.

In this context and in complementing the main prophylactic measures implemented to limit the propagation of such biological entities, the control of the microbiological indoor air quality in buildings through the use of adapted systems for air cleaning seems to be important.

This article describes a method to test air cleaners and the results obtained for a particular technology.

Materials and methods

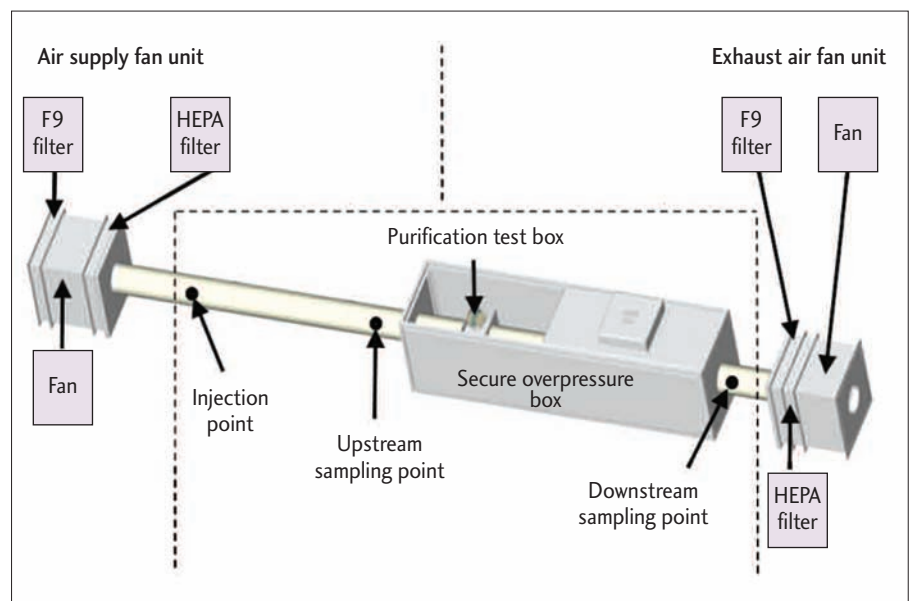
Test platform

The test platform ONE-PASS, developed by CIAT, is located at CSTB, which is the French Scientific and Technical Building Centre. This platform is specifically designed to determine the efficiency of new technologies used in air cleaners for one pass through. It is composed of two fan handling units at the end of each side of a long stainless steel 304L duct with a diameter of 200 mm (Fig. 1). These units are composed of two filtration stages, one F9 (EN 779) and the other HEPA (H14 according to EN 1822) and an incorporated fan. One of these units is used to supply air and the other to extract air.

A small purification box, which is located in the stainless steel duct, allows the testing of a variety of techniques used in air cleaning.

There is an injection point at the beginning of the duct which introduces aerobiocontamination into the platform and two sampling points on each side (upstream

Figure 1: Platform test schema.



* CIAT Research & Innovation Centre, France

† CSTB Microbiology of Indoor Environment Laboratory, France

‡ CERTES, Paris XII University, France

and downstream) of the purification box to evaluate its efficiency.

Injected microbiological aerosol introduced into this platform has been predetermined by CSTB research standards.

Flow and physical measurements

The profile of air velocity in the platform test is measured by a hot-wire anemometer (KIMO VT 100) according to the standard NFX 10-112. The pressure upstream of the purification test box and the pressure drop of the tested air cleaner is measured by a manometer (KIMO MP 100).

The relative humidity and the temperature in the platform test are checked during all the tests with a thermo-hygrometer.

Particle sampling and measurements

An optical particle counter (Grimm Technology 1.108) is used to verify the particulate density and to measure particulate efficiency of the air cleaner test. To sample airborne particles with the optical counter, we use an isokinetic probe, which reduces any loss during the sampling. The data acquisition is made every 6 seconds on 16 granulometric channels from 0.3 to 20 µm with an air flow of 1.2 L.min⁻¹. The analysis of the optical counter data transferred reveals the concentration and size distribution of the aerosol.

Bacteria sampling and measurements

The difficulty in the microbiological sample is the fact that there is a notion of viability. As a consequence, we must not destroy the bacteria, for example, before their analysis. To reduce this obstacle, the sampling probes have been tested and some liquid impingers (SKC) have been used. The culture on dishes is conducted on a liquid section of the sampling, and the filtration and analysis by microscopy on another section. Sampling flow of the impinger is 12.5 L.min⁻¹.

The culture of bacteria is done on Petri dishes and is analysed by Unit Forming Colonia (UFC) counting, according to the standard EN 13098.

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The technique of analysis in microscopy is fluorescence coloration and UFC counting, giving total flora data.

Patented NEO technology by CIAT

The NEO concept is based on the combination of filtration using an adsorbent material such as activated carbon and heterogeneous photocatalysis. In addition to the advantages of these two technologies, the combination of them creates a synergy. In the case of activated carbon, contaminants are mainly adsorbed on its specific surface area. The major drawback of this type of filter is activated carbon saturation. Its usage limit is known as the breakthrough point and is very difficult to anticipate in the case of variations of concentration and flow rates. Once this point has been reached, the device no longer provides the desired output concentration. Photocatalysis using titanium dioxide (TiO₂) consists of heterogeneous catalysis in which the solid catalyst is only active under ultraviolet range irradiation. Under certain conditions, the heterogeneous photocatalytic process is capable of mineralising the pollutants completely. It is broken down into five phases. First is the transfer of reagents to the photocatalytic surface, the second is the adsorption of reagents on the photocatalytic surface, the third one is the photochemical reaction between the reagents adsorbed on the photocatalytic surface; mineralisation of organic compounds, the fourth is the desorption of photocatalytic reaction products and the last is the diffusion of products from the photocatalytic surface.

The major drawback of photocatalysis used on its own is the low adsorption capacity of the catalyst (titanium dioxide) which does not enable it to handle pollution peaks. In this case, in the event of high concentrations and/or increase in passage rate, pollutant mineralisation will not be complete. Combining an activated carbon filter with a photocatalysis system makes it possible to eliminate the respective major drawbacks of both processes when used

independently and substantially reduces maintenance operations.

Platform test qualification

Air and particle tightness

The air tightness of ONE-PASS has been tested according to the standard NF EN 1886. The results of this test confirm the good tightness of the platform.

The particle tightness is checked using a particulate counter upstream and downstream of the small box tested. To preserve the tightness, when we test a technology on an air cleaner with a high pressure drop, we have enclosed the small box within an over pressurised box. The measurements of particle levels reveal that there are no particles of 0.3 to 20 µm in the platform. So we obtain a perfect clean slate in test results.

Velocity profiles

The velocity profiles have been determined for the upstream and downstream sampling points, for three different air flows and for three pressure drops in the air cleaner unit (minimal, medium and maximal) according to the standard NFX 10-112. The different measurement points of air velocity are shown in Figure 2.

The duct diameter is 200 mm so the different distances are d₁ = 6.4 mm, d₂ = 27.5 mm and d₃ = 62.5 mm.

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Figure 2: Points position.

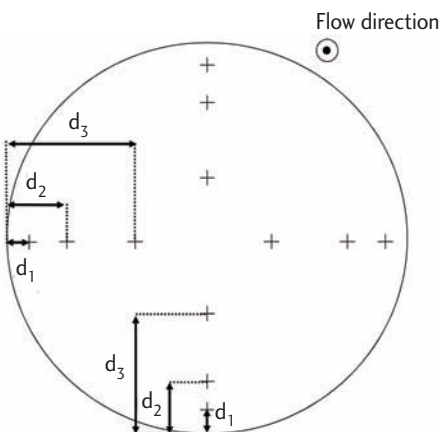


Table 1: Physical parameters/conditions.

Tests	Conditions	Medium (n=10)	SD
Particulate	RH (%)	31.9	10.4
	T (°C)	20.7	3.8
Microbiological	RH (%)	43.0	11.6
	T (°C)	21.5	3.8

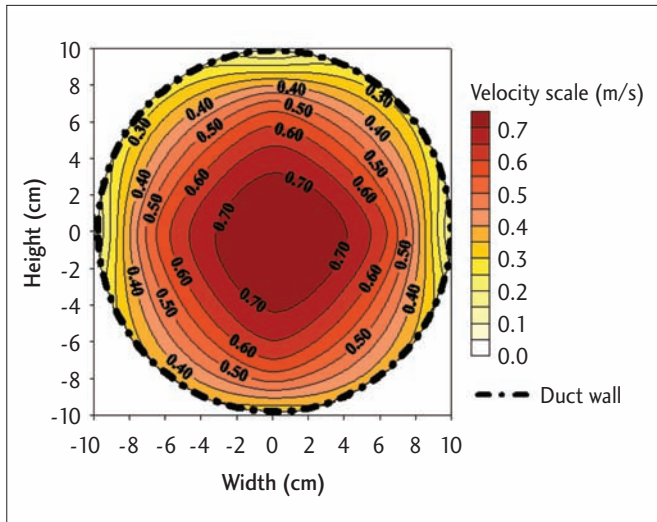


Figure 3: Upstream velocity profile.

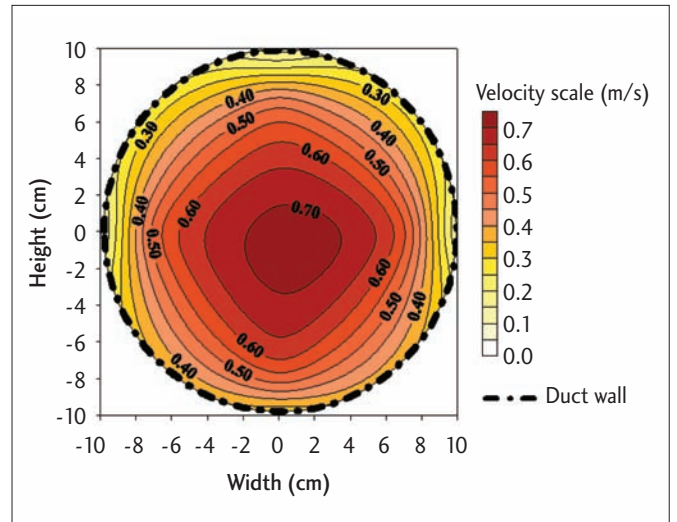


Figure 4: Downstream velocity profile.

The results demonstrate that the homogeneity of the profiles is maintained in every case. For example, for an air flow velocity regulated at $0.66 \text{ m.s}^{-1} \pm 0.05 \text{ m.s}^{-1}$, two velocity profiles are presented in Figure 3 and Figure 4. We see that the two profiles are homogeneous, whereas one is the upstream profile and the other the downstream one.

For all the tests carried out with the profiles, homogeneity is conserved.

The regulation point of the velocity has been also defined by these profiles after more than six tests. The velocity measurement at this point represents the medium velocity in

the duct. For the subsequent testing the velocity of air flow will be set at this point.

Particulate profiles

The homogeneity of particulate profiles is verified by injection of a calibrated aerosol of *Staphylococcus epidermidis*. After obtaining non-homogenised profiles with the injection probe orientated in the direction of the air flow, we take the measurements with the injection probe orientated in the opposite direction. By changing the probe orientation, we have been able to obtain homogenised particulate profiles for all granulometric

ranges, with negligible sedimentation of particles superior to $1 \mu\text{m}$. To see if this effect could have an impact on results, we determine the losses of aerosol without the air cleaner system settled in the duct.

Particulate and microbiological loss

Three kinds of measurements have been conducted to quantify all particulate loss. For every test, an aerosol of *Staphylococcus epidermidis* is used in the injection. The use of this microbiological aerosol makes it possible to evaluate the impact of the loss of particulate, total flora and cultivable microorganism concentrations. The first measurements concern particulate loss. A comparison between upstream and downstream sampling points has been performed. To prevent the differential which can exist between two optical counters, only one is used. Therefore measurements are taken in cycles of sampling. The cycles are defined after several tests of defining stabilisation time. The measurement cycle is described in Figure 5.

Some measurements have also been taken after an injection of saline solution to cover the entire granulometric range. The second and third measurements target microbiological losses. The sampling was conducted by liquid impingers at the same time for upstream and downstream points every 15 minutes. The analysis of particles, cultivability and total flora loss reveal that the loss is negligible because their magnitude is in the measuring error range, which is $\pm 10\%$.

Results

Test conditions

The tests on NEO technology are conducted on a reduced scale prototype. It consists of two flat square filters with a flow area of 100 mm by 100 mm aside and a UV lamp positioned between the two filters (Fig. 6).

The measurements, the results of which will be presented later in the article, are taken with a frontal air velocity of 0.7 m.s^{-1}

Figure 5: Particulate measurement cycle.

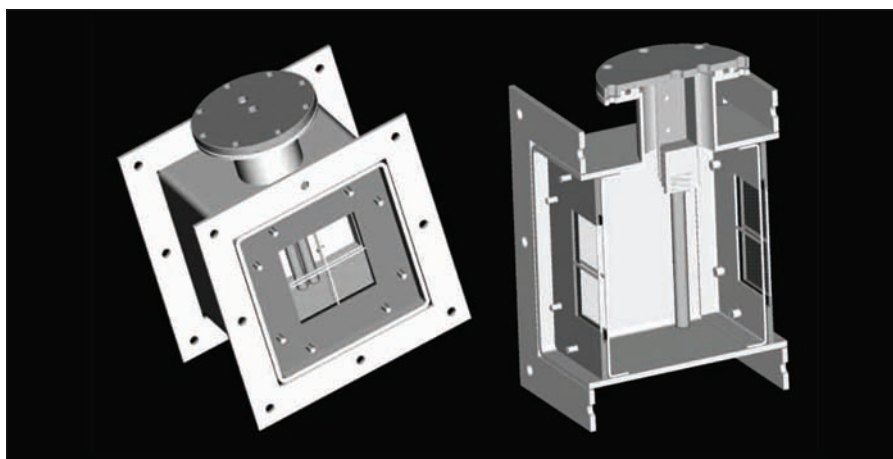
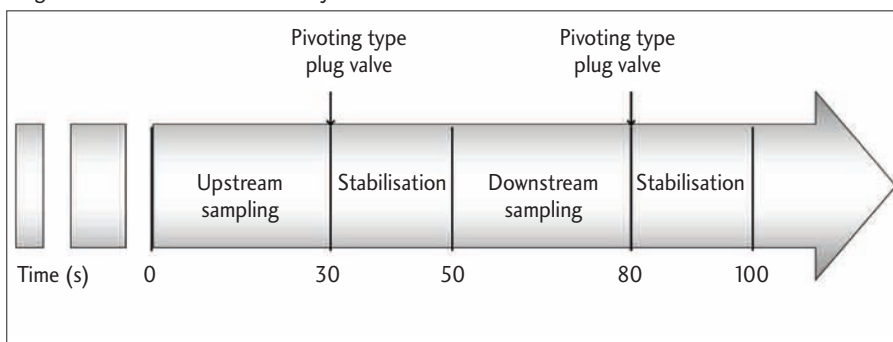


Figure 6: Schemas of NEO prototype.

and the UV lamp switched on. The air velocity flow has been chosen in order to replicate the velocity of air recommended for ventilation systems. During the tests on the NEO system, physical parameters have been checked. Table 1 gives the average values and the standard deviations (SD) for the relative humidity (RH) and the temperature obtained for the five tests (n=5).

Particulate effectiveness

According to CSTB, the *Staphylococcus epidermidis* has a size included in the range of 0.5µm to 1.5 µm. So the granulometric channel, the size of which is from 0.3 µm to 0.4 µm presumably coming from particulate debris, and the channel superior to 2 µm, are not integrated in the calculation of the efficiency rate, because size does not correspond to the size range of the bacteria and therefore its counting is not significant. The particulate removal efficiency rate with *Staphylococcus epidermidis* of the NEO system in one pass is 56% with a standard deviation equal to 4%.

Microbiological effectiveness

The counting of bacteria after a culture is only valid if the number of UFC ranges from 30 to 300 according to the standard EN 13098. According to the annexe D of this standard, the concentration of UFC obtained in an impinger is calculated using respectively equations 1 and 2 (see panel containing equations) to determine the cultivability and the total flora.

The cultivability efficiency rate on *Staphylococcus epidermidis* with the NEO system in one pass is 99.2% with a standard deviation equal to 0.9%. This result is illustrated in Figure 7.

The total flora efficiency rate on *Staphylococcus epidermidis* with the NEO system in one pass is 62% with a standard deviation equal to 14%. This standard deviation is elevated due to the measurement method in which we count only 0.03% of the filter area.

Discussion

The tests conducted on efficiency rates of air cleaners with microbiological contaminants have been done in real life conditions so the

Equations.	
$C = \frac{\Sigma C x V_0}{V_1 x (n_1 + 0.1 x n_2) x d x V_a} \quad (1)$	
$C = \frac{\Sigma N x S x V_0}{n x s x V_1 x d x V_a} \quad (2)$	
C: Concentration in UFC.m ⁻³ .	
V ₀ : Total volume of suspension in mL.	
d: For (1), dilution factor from which the first countable dilution was obtained. For (2), dilution factor of filtered solution.	
n: Number of counted microscopic fields (which is fixed at n=30 for our tests).	
n ₁ : Number of identical Petri dishes in the first countable dilution in UFC.	
n ₂ : Number of identical Petri dishes in the second countable dilution in UFC.	
V ₁ : For (1), volume applied on each gelose in mL. For (2), filtered volume in mL.	
N: Number of microorganisms on microscopic field.	
S: Filter area in m ² .	
s: Microscopic field area.	
V _a : Total volume of sampling air in m ³ . with $V_a = Q x t$ Q: sampling flow t: sampling time	(2)

parameters of the tests are not under control. This configuration does not permit the determination of the true purification efficiency of air cleaners because some of the contaminants are lost (remain on the side walls of the duct, on walls and ceiling in the case of measurements taken in a room). In our configuration of the ONE-PASS, all the risks of losses are eliminated by all the controls which have been performed during the qualification phase. This advantage allows us to say that the efficiency rate calculated is the real efficiency of the air cleaner tested.

Beyond the primary results obtained with the reduced scale prototype of NEO, these

tests show the inherent difficulties with the qualification of systems intended for the destruction of microorganisms in the form of aerosols, especially due to the absence of a normative environment. The qualification of the test facility requires a multitude of tests in order to guarantee the reliability of the results, and especially their reproducibility. The results obtained on this first prototype of the air cleaner are encouraging even if certain mechanisms occurring in the reactions remain to be specified.

The next stage is the introduction of an optimised purifier in a real scale in a test facility reproducing as accurately as possible the indoor environment. The above described experiment could be transferred to the ASTERIA platform for an even more realistic experiment. This platform of tests was conceived and built within the framework of the public-private partnership between the CSTB and CIAT. It is composed of a reproduction of two office rooms, which are ventilated by a HVAC system. This reproduction is enclosed in an overpressure box. The test platform ASTERIA would make the subject of qualification tests identical to those which were carried out with the platform test that we have just described.

The first results of the work completed within the framework of the thesis of M. Stephane Delaby were the subject of a publication presented at the 22nd French Congress on Aerosols (Paris in November 2006). In parallel to the performance testing of purification systems, the analysis of risks to human health from by-products (nanometric particles, COV, toxins...) resulting from the destruction of microorganisms, continues.

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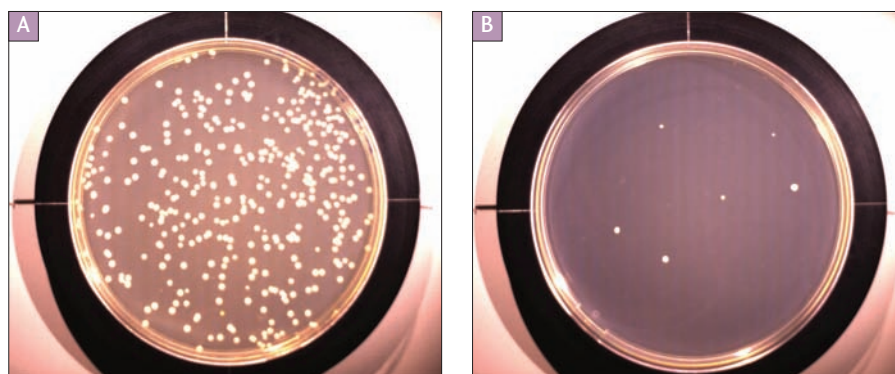


Figure 7: Photographs of upstream (A) and downstream (B) culture boxes.