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To the kind attention of Vice-president
Eng. Prof. Giuseppe Madonia

Milan, 3 December 2024

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI CHIMICA

HYLA-EST DEFENDER system: Testing of the efficacy as an air purification system and for cleaning hard and soft surfaces

1. HYLA-EST DEFENDER system: efficiency as air purifier

1.1 Set-up used to perform measurements

To validate the efficiency of the HYLA-EST device (air and room cleaning system, called HYLA in this report) several measurements were performed inside a room with a volume of about 40 m^3 that simulates a typical indoor domestic environment. A series of measurements were carried out evaluating the concentration of both Particulate Matter (PM) and Volatile Organic Compounds (VOC) artificially introduced in the room. PM concentrations were measured in three fractions using a portable fine dust monitoring unit (PM10 - PM2.5 - PM1), *i.e.* P-DustMonit (Contec), while TVOC (Total Volatile Organic Compounds) concentrations were determined using the NetPID (Lab Service Analytics) tool.

1.2 Analytical instrumentation employed

The P-DustMonit monitoring unit was used to measure atmospheric particulate matter. This instrument continuously measures and records airborne particles and in particular the PM10, PM2.5 and PM1 fractions. This instrumentation has been recently used for the evaluation of the efficiency of air purification systems [Fermo, P., Comite, V., Falciola, L., Guglielmi, V., Miani, A. Efficiency of an air cleaner device in reducing aerosol particulate matter (PM) in indoor environments (2020) International Journal of Environmental Research and Public Health, 17 (1), art. no. 18)].
The VOC sensor used is based on the photoionization principle and capable of detecting a wide range of VOCs with a higher molecular weight than methane (which is therefore not detected). In order to validate the effectiveness of the instrument and its reproducibility, a series of preliminary tests were

carried out dispersing VOCs in the room. A commercial nail solvent was used for this purpose. The instrument was found to be reproducible. In addition, the detection limit is much lower than the minimum concentrations typically detectable in an indoor environment (between 0.1 and 0.2 ppm on average), while the maximum detectable concentration declared by the manufacturer is 3 ppm.

1.3 TVOC concentration reduction

To evaluate the ability of HYLA to reduce the concentration of TVOC in the air, a series of experiments has been carried introducing known concentrations of a specific VOC to simulate a possible real situation. For this purpose, a solvent container was opened for shorter or longer periods of time as described below in the experimental section. The container was placed at a distance of about 30 cm from the detector. Fig. 1 shows the entire trend of TVOC acquired during the entire measurement period. The NetPID instrument was initially switched on and stabilized.

The average value of TVOC concentration in the room, when the HYLA device was not working, was about 0.2 ppm. In Table 1 the peaks showing up in Fig. 1 and zoomed-in region in Fig. 2 are listed. For each peak, the exposure time, the peak intensity and the operation mode of the HYLA device are indicated. The first peak is caused by an exposure time of 15 s with the device off. The test was then repeated, obtaining a peak of equal intensity (peak 2). Afterwards, the test was repeated with the same exposure time, but with the HYLA system on (peak 3): this has led to an evident reduction of the intensity of the peak, i.e. about a half of its concentration. Afterwards the HYLA system was again switched off. Subsequently, a prolonged exposure time of 30 min (peak 4) was used to obtain a very intense broad peak. At 12:55 a.m. the HYLA system was turned on and a continuous reduction of the peak was observed. At 1:25 p.m., after the signal had stabilized, always keeping the device on, a new exposure was made for a period of 30 min (peak 5).

Fig. 1 – Trend of the TVOC concentration (ppm)

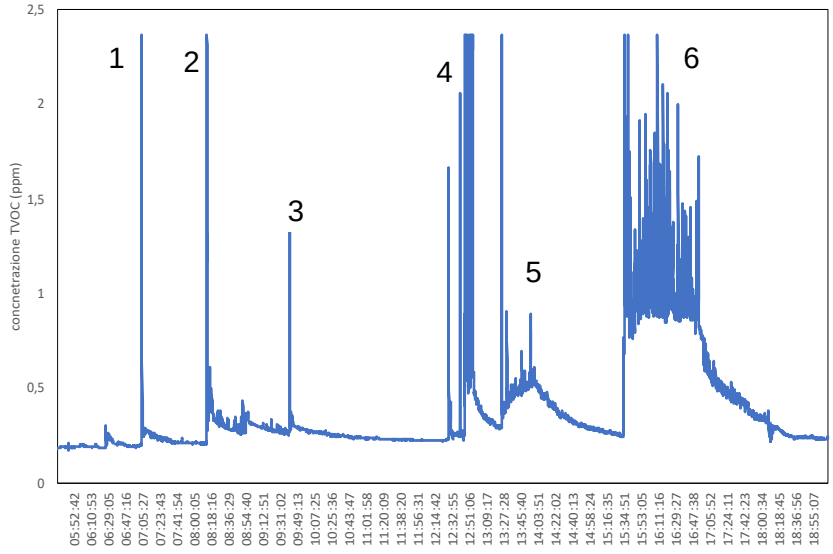
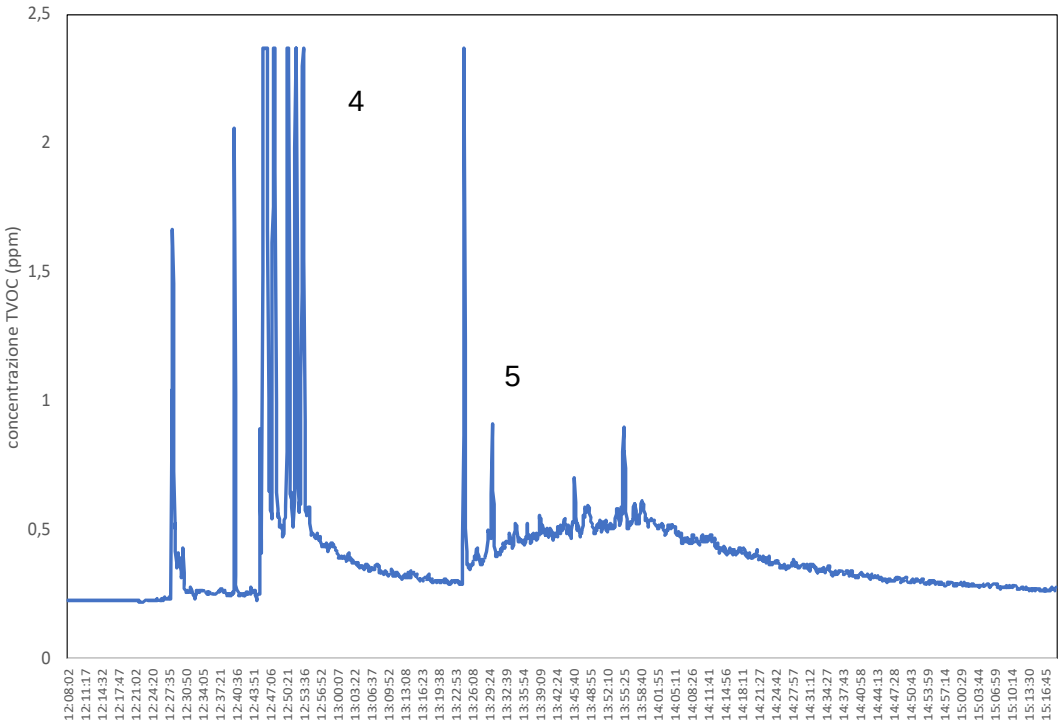


Fig. 2 – Trend of the TVOC concentration (ppm): detail of Fig. 1



Contrary to peak 4, in this case we observed a much less intense signal with only one short peak as high as with the device switched off, demonstrating that HYLA has a considerable effect on reducing TVOCs. After again switching off the HYLA system, an exposure time of 1 h was used to strongly increase the concentration of TVOCs in the room (peak 6). It is interesting to note that at 4:30 p.m., although no more VOCs were introduced into the room, the concentration remained high, indication a low natural reduction rate. At 4:48 p.m. the device is then turned on to obtain an exponential reduction of the signal that in about 2 hours reaches the initial value.

Table 1 - Peak intensity recorded by the NetPID instrument for different exposure times.

Peak	Exposure time	Peak intensity	Operation HYLA device
1	15 s	2,37 ppm	OFF
2	15 s	2,37 ppm	OFF
3	15 s	1,36 ppm	ON
4	30 min (12.25 – 12.55)	broad peak; high	OFF
5	30 min (13.25 – 13.55)	broad peak; high	ON
6	1 h (15.30 – 16.30)	broad peak; high	OFF

1.4 PM concentration reduction

To evaluate the ability of the device to reduce the naturally present PM concentrations, the background concentrations present in the room were initially acquired. Subsequently, some dust was dispersed in the room to obtain an increase in PM concentration (see Fig. 3). In particular dust that is commonly present on surfaces in a home was dispersed by a fan. The concentration of the various particle size fractions then immediately increased. In correspondence to the first peak (3:04 p.m.) an initial PM10 concentration of about 200 $\mu g/m^3$ was reached (the HYLA device was switched off in this case). Then the test was repeated (3:34 p.m.), this time suspending up to a PM10 concentration of of 963 $\mu g/m^3$. This second test was performed with the HYLA device switched on and waited until the initial conditions were restored. The third test was performed trying to suspend a quantity of powder similar to the previous one, in this case 943 $\mu g/m^3$, but this time the device was switched off. The powder decreasing curve confirmed what was observed with the first experiment (same slope of the curve). The slopes of the curves observed during the phase of the recovery of the initial conditions have been evaluated comparing the one obtained with the device switched on and the one obtained with the device switched off. This evaluation was made by calculating the parameter S (slope), i.e. the average reduction rate, expressed as: $S= \Delta C/ \Delta t$

where:

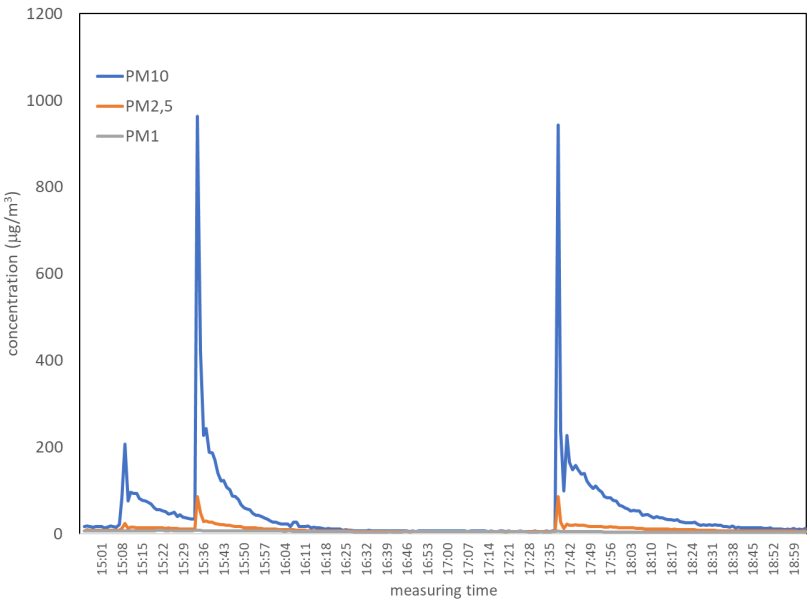
ΔC = variation of PM concentration in $\mu g/m^3$ in the time interval

Δt = interval time

Table 2 – parameters related to the calculation of S for PM10 fraction

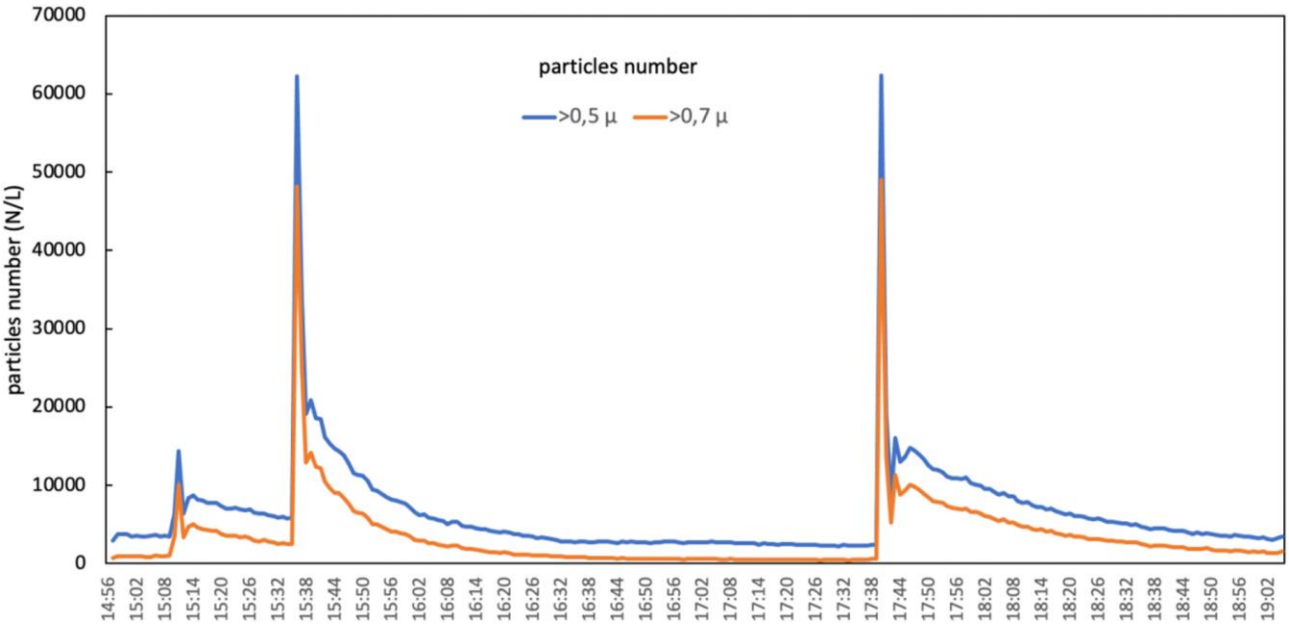
t (10 min)	C [µg/m³]	S [µg/m³/min]
HYLA ON		
15:37	421	31,9
15:47	102	
HYLA OFF		
15:11	75	1,9
15:21	56	

Fig. 3 – PM concentration trend



As it can be seen from the values shown in Table 2, the S parameter when the instrument is in operation is considerably higher than when the device is turned off. In particular, the reduction rate with the HYLA system was about 17 times higher than for only natural deposition. Moreover, within 20 min the HYLA device, starting from high PM10 concentration, allowed to significantly reduce it. In the absence of the device for the same identical conditions, it would have taken a time of more than 1 hour to come back to the initial situation.
Fig. 4 shows the trend of the particles number concentration for two different fractions with particle diameters less than 0.5 µm and 0.7 µm, respectively. It can be observed that the reduction rate is gain higher with the HYLA device switched on.

Fig. 4 – Particle number concentration trend



1.5 Conclusions

Accordingly, based on the tests carried out, it can be concluded that the HYLA device is effective both in the reduction of VOC levels and of airborne particle concentrations. There is an improvement in the average reduction rate by a factor of 16.8 for the chosen setup; moreover, in about 20 min the HYLA device, starting from high PM10 concentrations, allows to almost restore the dust values initially present in the environment. When generating VOC concentrations of the order of ppm, with the HYLA device switched on, the maximum measured concentration of the peak is at least 50% lower than without the HYLA device. It can therefore be stated that the tests to verify the functionality of the HYLA-EST DEFENDER device, both with regards to airborne particles and volatile organic compounds, are deemed to have been passed. This device can therefore be used as a mitigation system to improve the air quality

inside a domestic environment by reducing dust and volatile organic substances that may be emitted by various domestic activities such as, for example, cleaning or cooking of food.

2. HYLA-EST DEFENDERsystem: efficiency as air purifier for the cleaning of hard surfaces

In this second round of investigations, we focused our attention on the chemical substances aspirated and then retained by the aqueous component of the system.

2.1 Set-up and use of the equipment for vacuuming in an indoor domestic environment

The HYLA system (new) was assembled and prepared for vacuuming by connecting the flexible tube, the two rigid tubes and then the convertible multipurpose floor brush to the motor block. The water tank was filled up to the level indicated by the manufacturer ("water to this level") with approximately 4 litres of water.
The system was turned on and used continuously for 25 minutes in a domestic environment with 90 m^2 floor area, consisting of two bedrooms (parquet floor), a living room (ceramic floor + one carpet), two bathrooms (ceramic floor) and a kitchen (ceramic floor). The flat is inhabited by a family of two adults and a child, to simulate a typical indoor domestic environment.
After the aspiration phase, the contents of the tank were poured into a clean container for subsequent analysis. Before pouring, bulkier solid residues were collected and discarded (Fig. 5).



Fig. 5 – Bulkier solid residues collected and discarded after filtration

2.2 Filtration of the tank water

The tank water was left to settle for a few hours, so that the coarser residues end up on the bottom of the container. The supernatant was then filtered on quartz filters (47 mm, QMA), using the filtering equipment shown in Fig. 6.

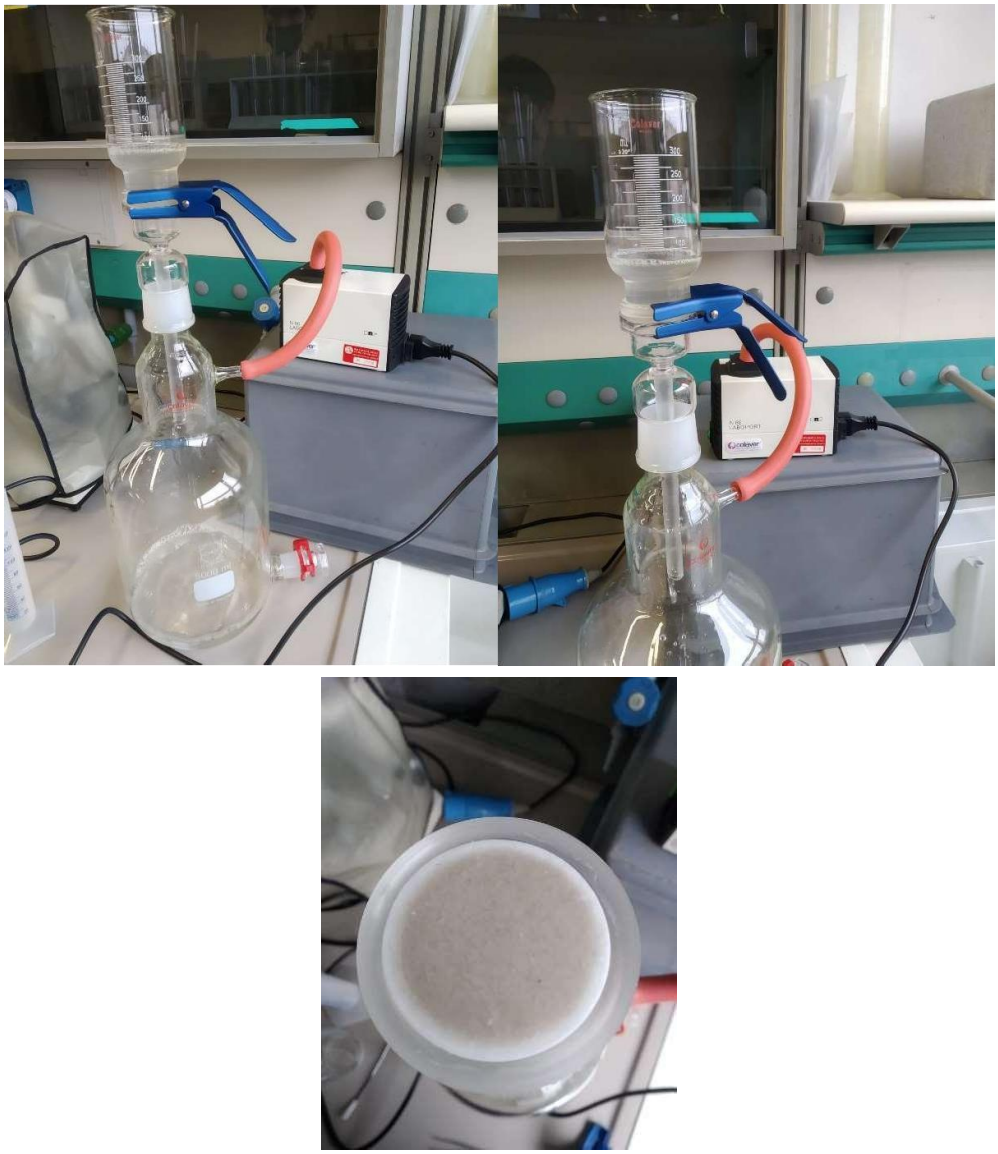


Fig. 6 – Filtering equipment

To allow efficient filtration, a vacuum was created inside the collection container with the aid of a mechanical pump.
The filtration procedure was performed according to the following time schedule and filtration volumes:

		Filter Weight / mg		
Filter Number	**Filtered water Volume / mL**	**PRE-filtration**	**POST-filtration**	**Filtered material / mg**
1	250	157.64	171.34	13.70
2	50	162.22	< pre	n.d.
3	100	156.69	160.62	3.93
4	100	154.55	159.40	4.85
5	100	155.53	160.05	4.51
6	50	156.24	156.65	0.42

Table 3 – Filtration parameters

Note that in the case of the 250 mL filter, it was not possible to completely finish the filtration because the coarse residues still present in the water completely clogged the filter. In the case of filter 2, a decrease in the mass of the filter was observed after filtration. Probably, in this case there was a loss of filter material during the filtration process. Except for this case, the weight of the filtrate increases as expected with the amount of filtered water.
The filters with the sampled residues are shown in Fig. 7.
Both the residual filtrate on the quartz filters and the filtered water were analyzed to evaluate their content.

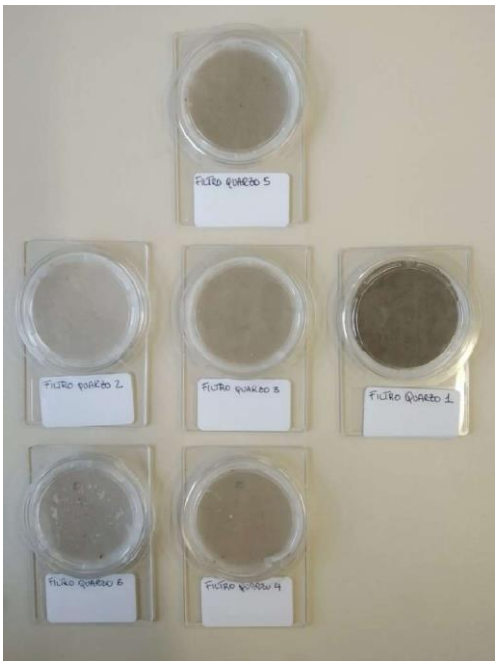


Fig. 7 – Collected filters

2.3 Chemical-physical analysis of the post-filtration tank water

The chemical-physical analysis of the water was conducted both on an unused sample of water of the same type used for the vacuuming phase (point 2.1) as well as on the filtered post-vacuuming tank water. The results of the analyses are summarized in tables 4 and 5. The limit values indicated in the last column are listed as reference for a typical order of magnitude.

Table 4 – General parameters for the analyzed water (n.d. = not detectable)

Parameters	Clean water	Dirty water	U.M.	Limits according to Italian law (D.lgs 31/2001) for drinking waters
pH	6.9	6.8	pH unit	6.5 -9.5 unità di pH
Turbidity	1	35	NTU	1 NTU
Colour	4.45	>50	Pt Co Unit - Hazen	No limit
Conductivity	29.6	**267**	µS/cm	2500 µS/cm
Calcium carbonates	n.d.	n.d.	mg/L	No limit
Hydroxides	n.d.	n.d.	mg/L	No limit
Partial alcalinity	n.d.	n.d.	mg/L	No limit
Total alcalinity	14.3	45.5	mg/L	No limit
Bicarbonates	14.3	45.5	mg/L	No limit
Fixed residue	21.2	**191.1**	mg/L	No limit
Hardness	n.d.	9	°F	No limit

Table 5 – Specific parameters for the analysed water

Parameters		Clean water	Dirty water	Difference	U.M.	Limits according to Italian law (D.lgs 31/2001) for drinking waters
	B	0.05	0.08	0.03	mg/L	1 mg/L
	Na	7.19	51.13	**43.94**	mg/L	200 mg/L
	Mg	0.48	4.85	4.37	mg/L	No limit
	Ag	0.27	0.14	*-0.13*	µg/L	10 µg/L
	Al	1.98	58.83	**56.85**	µg/L	200 µg/L
	K	0.45	17.10	**16.65**	mg/L	No limit

METALS	**Ca**	1.09	26.98	**25.89**	mg/L	No limit
	V	0.01	0.76	0.75	µg/L	50 µg/L
	Cr	0.20	18.22	**18.02**	µg/L	50 µg/L
	Mn	0.65	23.05	**22.4**	µg/L	50 µg/L
	Fe	8.42	42.16	**33.74**	µg/L	200 µg/L
	Ni	1.01	13.09	**12.08**	µg/L	20 µg/L
	Cu	0.00	0.06	0.06	mg/L	1 mg/L
	Zn	6.56	153.45	**146.89**	µg/L	No limit
	As	0.02	1.14	1.12	µg/L	10 µg/L
	Se	0.03	0.24	0.21	µg/L	10 µg/L
	Sr	3.14	50.44	**47.3**	µg/L	No limit
	Cd	0.06	0.08	0.02	µg/L	5 µg/L
	Sb	0.12	2.19	2.07	µg/L	5 µg/L
	Hg	0.00	0.06	0.06	µg/L	1 µg/L
	Ba	0.67	14.34	**13.67**	µg/L	No limit
	Ti	0.39	0.49	0.1	µg/L	No limit
	Mo	0.02	1.17	1.15	µg/L	No limit
	Tl	0.00	0.02	0.02	µg/L	No limit
	Te	0.00	0.01	0.01	µg/L	No limit
	Gd	0.00	0.01	0.01	µg/L	No limit
	Li	0.20	1.30	1.1	µg/L	No limit
	Ga	0.00	0.02	0.02	µg/L	No limit
	Rb	0.27	11.86	**11.59**	µg/L	No limit
	Co	0.01	0.38	0.37	µg/L	No limit
	Zr	0.03	0.14	0.11	µg/L	No limit
	W	0.10	35.74	**35.64**	µg/L	No limit
	Bi	0.00	0.03	0.03	µg/L	No limit
	Pb	0.57	5.24	**4.67**	µg/L	10 ug/L
	Be	0.00	0.01	0.01	µg/L	No limit
	U	0.01	0.02	0.01	µg/L	No limit
Anions and ammoniu	ammonium	0.058	1.698	1.64	mg/L	0.5 mg/L
	chlorites	0.017	0.000	*-0.017*	mg/L	0.7 mg/L
	chlorides	3.097	40.684	**37.587**	mg/L	250 mg/L
	nitrates	0.99	5.727	**4.737**	mg/L	50 mg/L

m	nitrites	0.000	0.291	0.291	mg/L	0.5 mg/L
	sulphates	1.27	10.169	**8.899**	mg/L	250 mg/L
	phosphates	0.000	0.127	0.127	mg/L	No limit
	fluorides	0.255	0.133	*-0.122*	mg/L	1.5 mg/L

It was not possible to perform analyses on pesticides because the sample, despite filtration, was too cloudy and led to a clogging of the pre-column of the analysis instrument. Neither was it possible to conduct analyses on VOCs because the sample was too concentrated in surfactants, which caused the formation of foams and bubbles that did not allow analysis.

2.4 Analytical instrumentation employed to investigate the residues collected from water filtration

On the quartz filters obtained by water filtration, the concentration of the carbonaceous fraction was determined using the TOT (Thermal Optical Transmittance) technique. This method makes it possible to determine the concentration of organic carbon (OC) and elemental carbon (EC). The measurements of OC and EC were conducted in accordance with the reference standard EN 16909:2017 - Ambient air - Measurement of elemental carbon (EC) and organic carbon (OC) collected.
Furthermore, to investigate the particles dimensions and their chemical composition, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) analyses were performed with a Hitachi TM-4000 scanning electron microscope equipped with a 4-quadrant BSE (back-scattered elections) detector, a low-vacuum SE (secondary electrons) detector, and an Oxford AztecOne EDX. By utilizing low vacuum conditions, images could be obtained without metallization of the sample. Observations were made at different magnifications (30x, 100x, 250x, and 300x) and acquired in BSE mode. For each sample, EDX spectral element maps were acquired in false colours. The Oxford AZtecOne EDX system offers the standard windows integral mapping mode, where the area of each peak in the spectrum is summed to identify the elements present and their concentration. Additionally, the system features a second mapping mode called TruMap, which is suitable for specimens with overlapping peaks. This approach uses deconvolution to fit the element peak shapes across the entire spectrum for each pixel in the EDX map. It provides the benefit of resolving overlapping peaks and automatically eliminating data artefacts and false background variations. Map Acquisition Settings provided a resolution of 512 pixels to acquire maps in more detail, an acquisition time of 50 frames (passes over the map area), and the processing time set to 'Sensitive' mode to process the X-ray signal from the EDX detector and removing noise. The pixel dwell time was set to 100 µs. Map acquisitions were performed at an acceleration voltage of 15 kV.

2.5 Analytical results on quartz filters obtained after filtration

Due to the inhomogeneity of the filters, it was not possible to quantify separately the two fractions, OC and EC, since the analytical determination is based on the measurement of filter transmittance, and it was not homogeneous for the filters under investigation. It was therefore only possible to obtain an estimation of the concentration of TC (Total Carbon), which represents 30 % to 40 % of the mass of the particulate material collected on the filter. As far as the other components, the particulate material is composed mainly of particles containing silicates, as also highlighted by SEM-EDX analyses (Figs. 8 - 11). In fact from the point of view of the chemical composition of the particles, the presence of numerous metals such as Ca, Mg, Al, K and Na, which are commonly associated with the presence of silicates and which were highlighted on the single particles together with an increasing of Si signal, can be observed (however, it must be pointed out that silicon cannot be quantified because the filter on which the particles were collected is made of quartz). A high concentration of C is associated with the presence of carbonaceous materials. In addition to these elements, spot analyses on the particles showed in one case the presence of S, Cl and Fe, while in another case Ni (possibly present as an oxide or carbonate because it was not associated with other elements) was detected. From the distribution of the individual elements, it can be seen that Ca is present over the entire surface of the filter (silicon and oxygen are due to the matrix, *i.e.* the quartz filter).

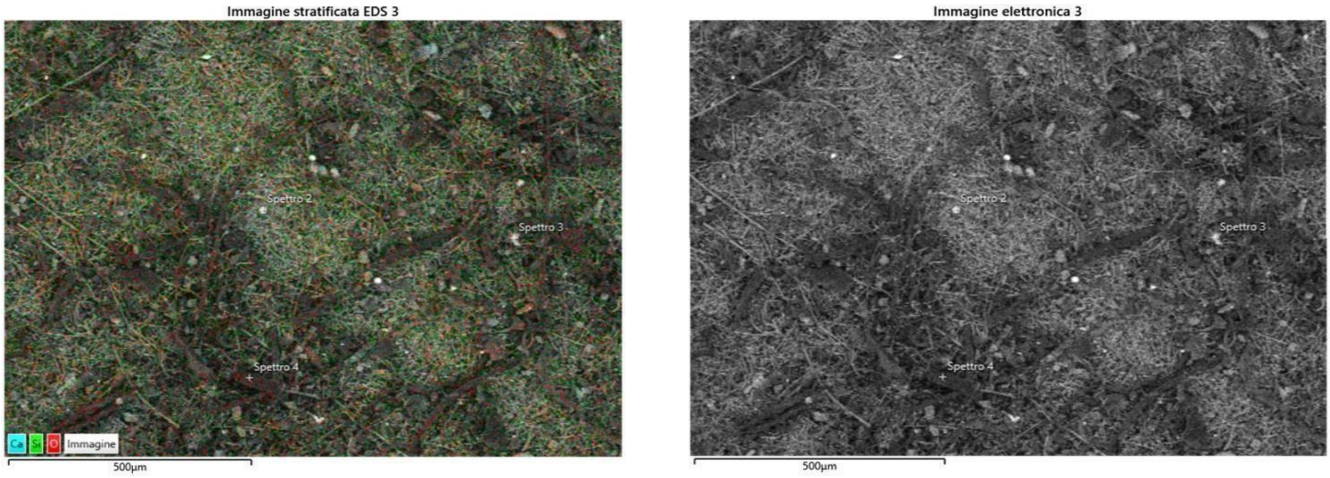


Fig. 8 – EDX analysis with additional indication of elements distribution (elements overlapping)

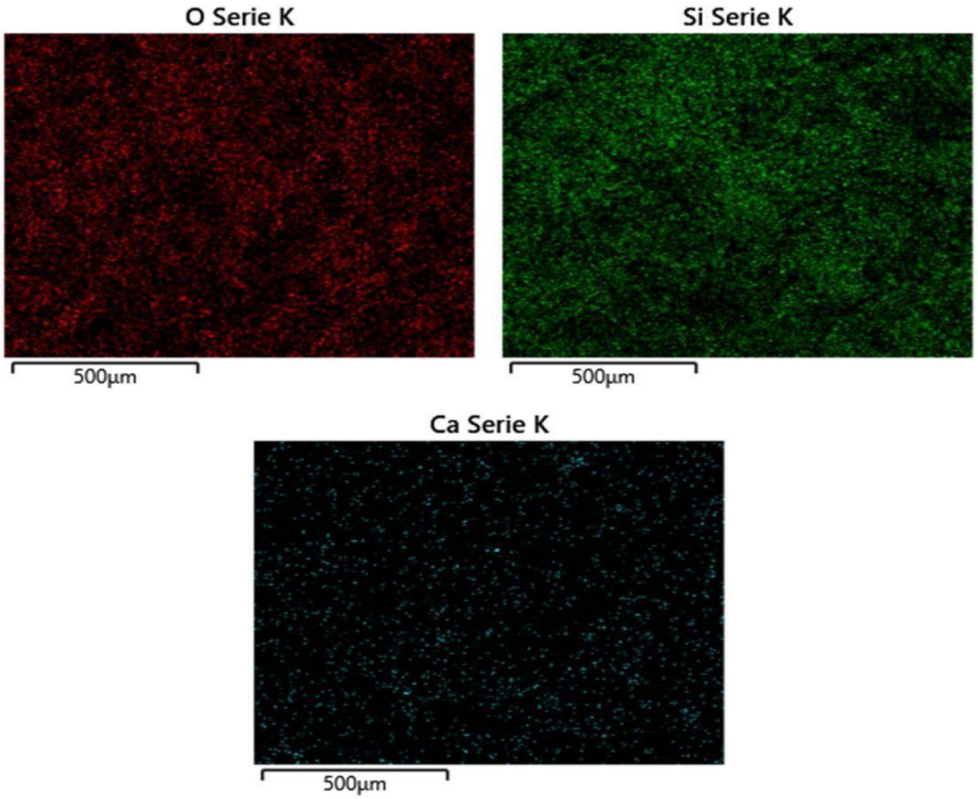
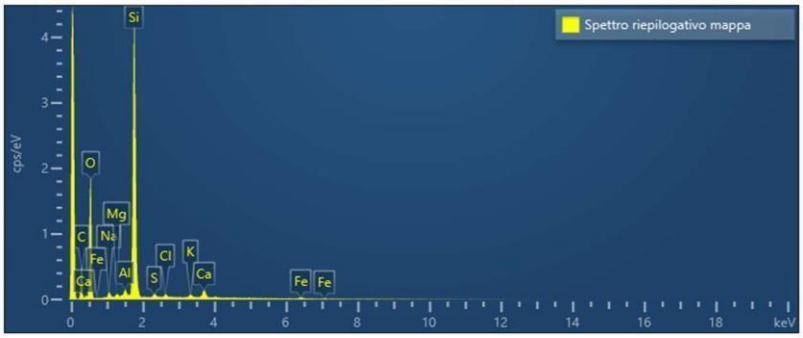


Fig. 9 – EDX analysis for indication of the elemental distribution

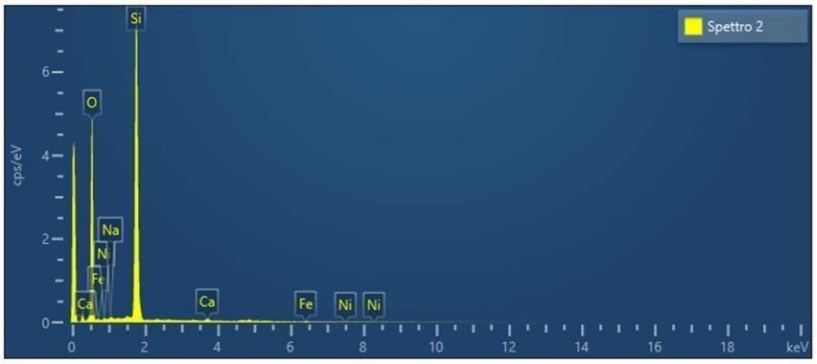


element	signal	Weight %	SD %	Atomic %
C	K line	34.92	0.85	46.58
O	K line	39.06	0.57	39.11
Na	K line	0.55	0.05	0.38

Mg	K line	0.23	0.03	0.15
Al	K line	0.41	0.04	0.24
Si	K line	21.44	0.31	12.23
S	K line	0.35	0.04	0.18
Cl	K line	0.34	0.04	0.15
K	K line	0.39	0.05	0.16
Ca	K line	1.40	0.06	0.56
Fe	K line	0.92	0.11	0.26
Total		100.00		100.00

Note that in this case signal is also due to the background.

Fig. 10 – EDX punctual analysis of the chemical composition of the investigated particle (one of the particles that appear lighter in Figure 8).



element	signal	Weight %	SD %	Atomic %
O	K line	59.08	0.31	71.98
Na	K line	0.28	0.08	0.24
Si	K line	39.19	0.28	27.20
Ca	K line	0.65	0.08	0.32
Fe	K line	0.73	0.16	0.26
Ni	K line	0.07	0.19	0.02
Total		100.00		100.00

Fig. 11 – EDX punctual analysis of the chemical composition of the investigated particle

2.6 Conclusions

With regard to the system's ability to remove carbonaceous substances, it has been demonstrated that particles of this nature are present in the particulate fraction filtered on quartz filters. A fraction of about 35 % compared to the total mass of particulate material collected on the filter lies in the typical range for atmospheric particulate matter. y means of SEM-EDX analysis, it was observed that the particles on these filters are often coarse in size and contain, in addition to carbon, a high concentration of silicates as well as a small concentration of iron, which is a typical element of both natural and anthropogenic origin.

3. HYLA-EST DEFENDER system: efficiency as air purifier for the cleaning of soft surfaces

For soft surfaces, the same methodology as previously described was followed. No substantial differences were observed except for some differences in the analysis of individual particles observed by means of the SEM-EDX technique. While Si and O are always observed due to the presence of the quartz matrix, a diffuse presence of calcium in this case was not observed. The particles are smaller (no more clusters of particles are present as in the case of hard surface cleaning) and clearly distinguishable above the quartz matrix. By carrying out punctual analyses on the individual particles, it was also possible to put in evidence that they consist of carbonaceous substances. Very fine particles were also clearly visible in Figure 12 on the surface of the quartz fibres. Punctual analysis on these particles showed that they consist mainly of carbonaceous substances (as reported in the table corresponding to this analysis, the carbon content is higher than 50%).

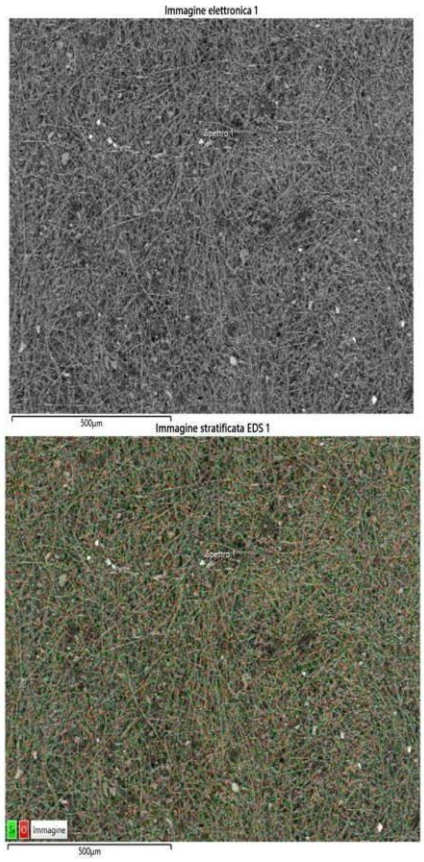
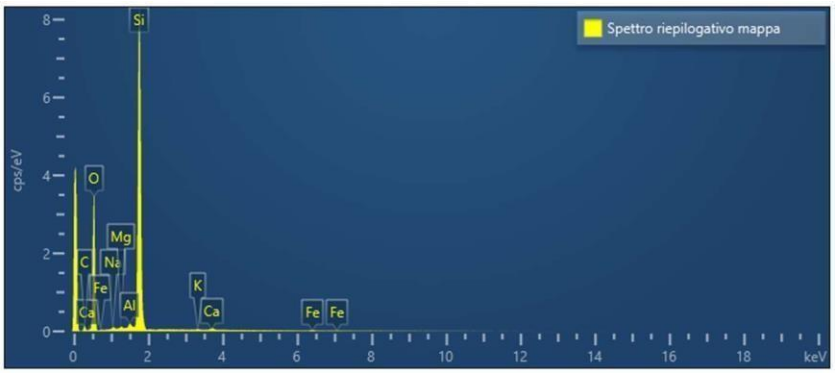


Fig. 12 – EDX analysis for indication of the elemental distribution



Element	signal	Weight %	SD %	Atomic %
C	K line	11.48	0.79	17.70
O	K line	48.44	0.48	56.10
Na	K line	0.32	0.04	0.25
Mg	K line	0.23	0.04	0.17
Al	K line	0.39	0.04	0.27
Si	K line	37.91	0.38	25.01
K	K line	0.15	0.04	0.07
Ca	K line	0.47	0.05	0.22
Fe	K line	0.63	0.10	0.21
Total		100.00		100.00

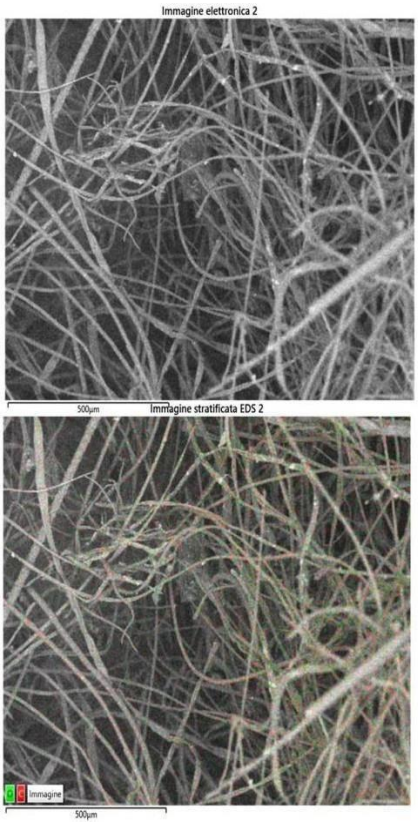
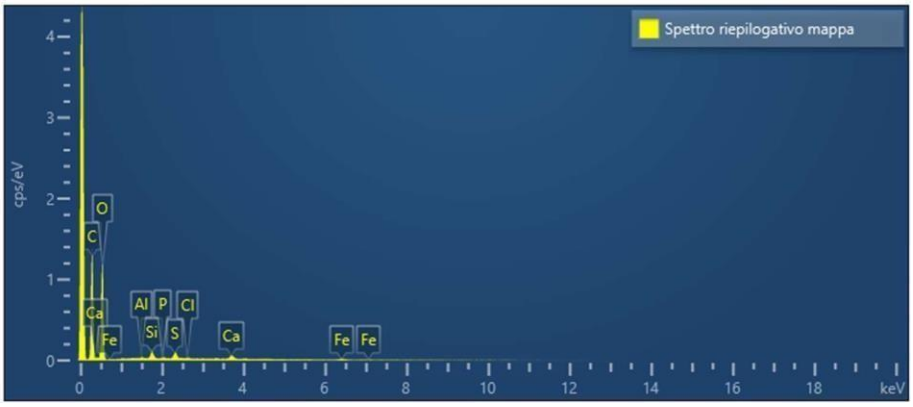


Fig. 13 – EDX analysis with the indication of elements distribution



Element	signal	Weight %	SD %	Atomic %
C	K line	53.32	0.50	61.32
O	K line	43.29	0.49	37.38
Al	K line	0.11	0.04	0.06
Si	K line	0.69	0.05	0.34
P	K line	0.15	0.04	0.07
S	K line	0.77	0.05	0.33
Cl	K line	0.15	0.04	0.06
Ca	K line	0.81	0.07	0.28
Fe	K line	0.71	0.15	0.17
Totale		100.00		100.00

Fig. 14 – EDX punctual analysis for the chemical composition of the investigated particle

3.1. Conclusions

It can be concluded that the system is able to act in a similar way on both hard and soft surfaces. However, in this second case, numerous fine particles consisting of carbonaceous substances have been identified It is important to remember that the finest particles are the most dangerous for human health, as they are capable of penetrating deeply into the respiratory system. It is also known from scientific literature that many carbon substances that are carcinogenic to humans are found in the fine fraction of atmospheric particulate matter.

General conclusions

The HYLA-EST DEFENDER Device is highly effective both for air purification and for cleaning hard (e.g. floor) and soft (e.g. carpets, sofas and curtains) surfaces. In particular, the device stands out for its ability to reduce levels of VOCs (volatile organic compounds), i.e. substances in a gaseous state that can be harmful to health as well as the concentrations of particles suspended in the air (atmospheric particulate matter, PM) and in particular those of the smallest size (fine fraction, including PM1 which is composed by particles with diameter less than 1 micron) that are able to penetrate deep into the respiratory system and that have been linked to the onset of a number of serious pathologies (including cancer). These characteristics make the HYLA device a valuable tool for improving indoor air quality in domestic environments. With regards the cleaning of hard surfaces the system is able to remove carbonaceous substances, silicates and certain metals harmful for the human health, as was highlighted by analysing the filters collected during cleaning operations. This was possible thanks to the acquisition of analyses conducted at very high magnifications using electron microscopy and chemical micro analysis. The performances of the HYLA device is similar for both hard and soft surfaces. On the latter ones (including carpets, mattresses, sofas, curtains, etc.) the system stands out for its effectiveness in removing fine particles of carbonaceous nature, which tend to accumulate in large quantities on this type of surface where they can be adsorbed and consequently accumulate. As has already been pointed out, the finest particles pose a significant health risk. Therefore, the constant use of a device such as HYLA on soft surfaces within the home would yield significant benefits by reducing exposure to these contaminants.

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The scientific validation tests of the HYLA-EST DEFENDER Device were conducted by Professors Paola Fermo and Luigi Falciola at the Chemistry Laboratory of the Department of Chemistry, University of Milan, Italy.



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The scientific validation of the tests conducted on the HYLA-EST DEFENDER Device was reviewed by Professors Jorge Barrio, Jing Shang, Elia Marin, Enrico Greco, and Dr. Stefan Schumacher who approved it.



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