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An applied aerobiological study to test the efficacy of pollen filters in limiting indoor pollen contamination

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Abstract

A simultaneous indoor and outdoor aerobiological monitoring was conducted to test the efficacy of a special pollen filter in impeding the entrance of aerobiological particles into living spaces and other structures marked by specific health needs. The efficacy levels of these membranes were tested through aerobiological monitoring carried out outdoors and indoors, in a special simulator located in the nearness and realised as a small-scale building model for simulating real indoor environments. The pollen monitoring carried out during approximately four months indicated a reduction in pollen concentration registered inside the special building simulator in comparison with the outdoor concentrations. The pollen reductions were different on the base of the different plant taxa. In particular, the highest percentages of reduction were recorded for the pollen of Poaceae and Cupro/Taxaceae (about 80%), while the lowest were those related to Urticaceae pollen (about 50%). These results can well be justified in consideration of the pollen size even if the artificial membranes were able to partially restrain the entering pollens utilising a special tissue with a uniform and consistent mesh width of about 70 μm , which is larger than the largest pollen deposited on the indoor monitoring apparatus.

Keywords: *Pollen, indoor–outdoor monitoring, pollen filters*

Many particles of varying origin can be detected in the atmosphere when monitored both indoors and outdoors. Particularly, aerosol is constituted of biological particles of different sizes. Some may be of anthropogenic origin, while others such as pollen and spores are of natural origin. The latter can affect the health of many, especially allergic people, acting as pathogens, antigens, or allergens.

Interest in the relationships between environmental factors and allergies has increased during the recent years, particularly in consideration of the rising number of people affected by these problems. Especially in certain environments such as urban areas marked by high atmospheric pollution or in consideration of the quality of the indoor building environment equipped with window air-conditioner systems, interest has been strongly raised (Solomon et al., 1980; D'Amato et al., 2002). The study of aerobiological components distributed in the atmosphere and the applicative investigations have

received a strong boost in the last few decades with the development of special methodologies that allow the precise concentrations of pollen and spores moving in the air in terms of pollen per volume per day to be determined (Yankova, 1991; García-Mozo et al., 2006). These methods have permitted the determination of the flowering periods and pollen emission entity of anemophilous allergenic species (first of all grass pollen), allowing for the establishment of effective health risk thresholds (Florido et al., 1999; Puc & Puc, 2004; Feo Brito et al., 2010). The pollen of several anemophilous species represents one of the principal allergy-inducing factors among the aerobiological particles in persons who are particularly sensitive (D'Amato & Spieksma, 1990; Gioulekas et al., 2004; D'Amato et al., 2007).

According to the assumptions of Thommen (1930), pollens are required to have certain characteristics to be considered allergenic: they must have an allergenic protein content, and should

be produced and emitted in great quantity from widespread sources; moreover, they must be highly transportable into large areas by wind.

Fabric pollen filters are rarely tested quantitatively. Sacchi and Price (1988) found no difference in the amount of pollen deposited on glass slides coated with silicone grease and placed in mesh bags (0.9×0.9 mm mesh) in comparison with slides left uncovered. Anderson (1976) used *Fraxinus americana* L. to test the permeability of nylon monofilament filters (pore size 1.21 mm) to wind-borne pollen (diameter $33.2 \mu\text{m}$). He found fruit set in inflorescences covered by screen bags to be 70% of uncovered inflorescences, while in inflorescences covered by glassine envelopes fruit set was entirely eliminated. Goodwillie (1999) compared counts of wind-borne pollen deposited on petroleum jelly-coated microscope slides enclosed in bags with slides that were not enclosed. The author found that slides in bags had fewer pollen grains than the open ones; however, the difference was not significant.

The principal aim of the present study was to test the actual efficacy of a special pollen filter in impeding the entrance of aerobiological particles into living spaces (i.e. homes) where allergic individuals are present, into public facilities such as hospitals, and other structures marked by specific health needs. The efficacy levels of these membranes were tested through aerobiological monitoring simultaneously carried out outdoors (on the roof of Perugia University's Agricultural Faculty) and indoors, in a special small-scale building simulator especially constructed to simulate the normal conditions of a habitation exposed to pollen flows circulating in the atmosphere.

Materials and methods

In order to perform a correct evaluation of aerobiological concentration outdoors (in the atmosphere) and indoors [inside the 'confinement simulator' (CS)], a preliminary study was conducted considering both the general and specific characteristics of the trends from 1 June to 30 September 2009. The sampling season range was determined in consideration of the flowering periods of the principal anemophilous taxa in the study region. Moreover, the study period considered was characterised by low rain levels and low relative humidity (RH) percentages, which could negatively interfere with the pollen circulation.

Some initial tests were conducted to verify the pollen monitoring efficiency inside the CS to the point of defining a specific protocol of procedures to optimise the study in terms of monitoring position, duration, and daily periods during which the investigation is performed best. The pollen and spore

monitoring methodology typically used nowadays in qualitative and quantitative investigations is the volumetric type, which permits identifying the daily concentrations of the material dispersed in the atmosphere (Orlandi et al., 2003, 2005; Galán et al., 2008; Bonofiglio et al., 2009).

Air flow was sampled by a special vacuum pump, which aspirates a constant volume of air (10 l/min) in which the biological particles were distributed. A Hirst model (Hirst, 1952) was used as the typical base instrument with a mounted Burkard Spore Trap and a Lanzoni VPPS 1000 or VPPS 2000 volumetric sampler. In the present study, two different volumetric samplers were utilised for both the indoor and outdoor monitoring activity, although they aspirate the same volumes of atmospheric air (10 l/min) and are constructed by the same company with the same technical components. They differ in size considering if devoted to indoor monitoring (VPPS 1000) or outdoor monitoring (VPPS 2000) (Figure 1).



Figure 1. Pollen trap VPPS 1000 (A) [$20 \text{ cm} \times 30 \text{ cm} \times 25 \text{ cm}$, width (W) $\times$ length (L) $\times$ height (H)] located inside the 'confinement simulator' (B) ($100 \text{ cm} \times 150 \text{ cm} \times 60 \text{ cm}$, $W \times L \times H$) on the roof of the Agriculture Faculty of Perugia University, Italy.

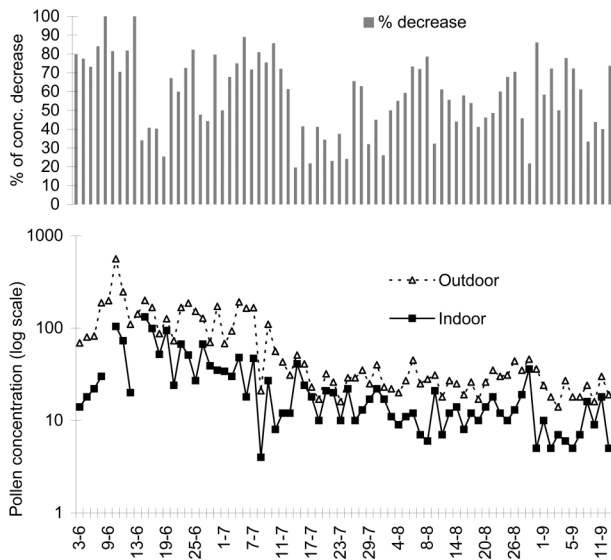


Figure 2. Total indoor and outdoor pollen concentration trends and percentage decrease.

Installation of the monitoring station

The monitoring station represented by the CS was positioned in a way to avoid the presence of nearby obstacles potentially creating atmospheric whirlwinds, which may cause a possible distortion of the results.

The CS was constructed entirely from wood to simulate a building with typical window openings. The CS size was approximately 150 cm × 100 cm and 60 cm in height. The windows were equipped with special pollen filters, fitted with a wooden frame to impede the entrance of the various pollens present in the atmosphere. The CS was positioned on a terrace 20 m above ground on the roof of the Agriculture Faculty of Perugia University (Italy), away from public parks, industrial areas, sources of smog emission. The locality was also to ensure an ease of control and management of the sampling station.

Pollen filters gauze

The pollen filters were composed of a special inductile, monofilament tissue, with a uniform and consistent mesh structure, having a pore diameter of about 70 μm , allowing the necessary ventilation but acting as a barrier against particles, pollen and pollen fragments through the generation of a static field (di-electric characteristic). The pollen filters gauze was produced by Texstop International, Vaduz, Principality of Liechtenstein, a leading company in the production of pollen protection systems for people suffering from allergies.

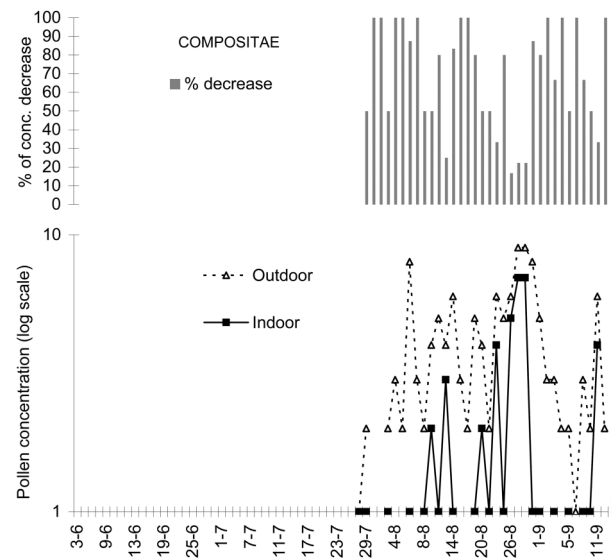


Figure 3. Indoor and outdoor pollen concentration trends and percentage decrease (Compositae).

Moreover, it can be considered that a filter barrier with small mesh fabric comparable to that used in the present study reduces internal turbulence in the chamber as shown in a study (Neal & Anderson, 2004) that reported some results about aerodynamic characteristics within filter bags used in reproductive biology studies. These investigations conducted inside the bags with vertical and horizontal pollen monitoring slides demonstrated that wind velocity is presumably reduced and pollen settles more quickly and thus does not have sufficient velocity to reach or adhere to the vertical slides determining a major deposition on the horizontal plane.

Monitoring samplers used

The outdoor monitoring was carried out with a VPPS 2000 Lanzoni sampler (developed by Lanzoni spa, Bologna, Italy) located at about 5 m distance from the CS, capable of monitoring specific quantities of atmosphere (10 l/min) during an entire week. The laboratory techniques, in line with well-known protocols (Fornaciari et al., 1996), permitted obtaining the average daily outdoor concentrations for the principal anemophilous species of the various families emitting pollen during the study period. Instead, the indoor monitoring (inside the CS) was realised with a VPPS 1000 Lanzoni sampler (Figure 1), also considering that this particular trap is able to capture the aerobiological material for seven days (24 hours a day) continuously (limiting the apertures in the CS and hence its contamination), and that its small size permitted positioning it inside the CS. This instrument also permits capturing the same volume of air as the VPPS 2000 (10 l/min).

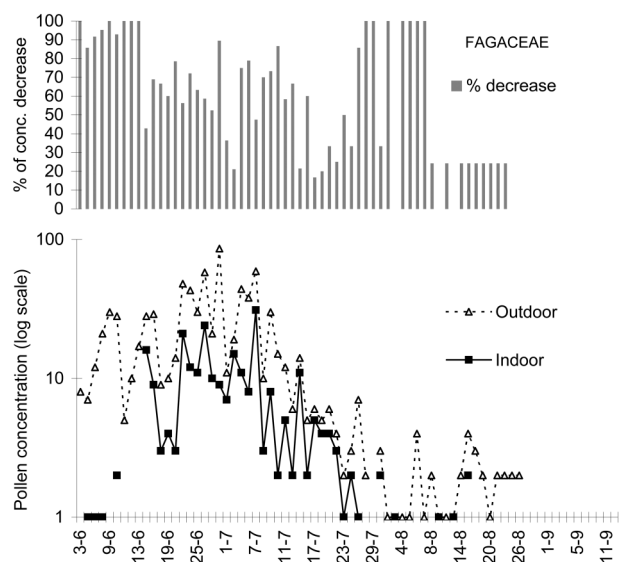


Figure 4. Indoor and outdoor pollen concentration trends and percentage decrease (Fagaceae).

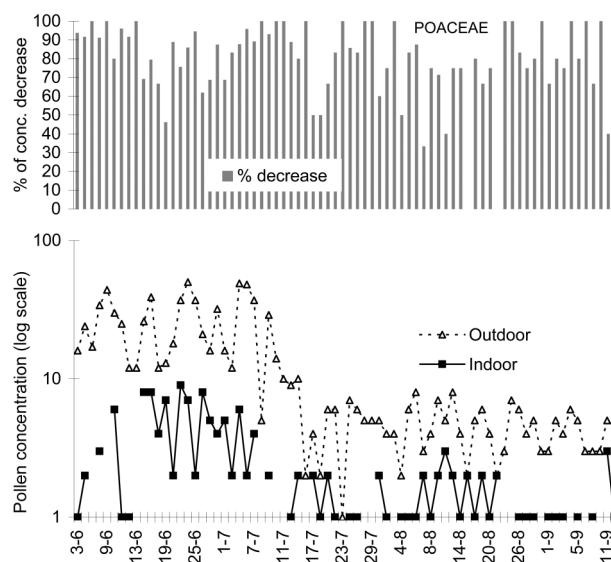


Figure 5. Indoor and outdoor pollen concentration trends and percentage decrease (Poaceae).

Pollen data elaboration

First, a graphic analysis was realised to highlight the principal trends in pollen monitoring in the atmosphere in comparison with those obtained inside the CS protected with pollen filters. Moreover, to study the quantitative differences between the two environments (outdoors and indoors) from a statistical point of view, an analysis of variance (ANOVA) was carried out considering the total pollen concentrations and the specific pollen emissions related to the principal anemophilous species.

A drop in pollen concentration expressed as a percentage was calculated to confirm the efficiency of the artificial filters in diminishing pollen entrance into the CS. This index was also calculated for the total pollen concentrations and individually for the principal families of anemophilous plants (Figures 2–9). Finally, a relationship between pollen size and the pollen concentration decrease percentages was evaluated to ascertain the importance of this biological characteristic (Figure 10).

Results

The tests performed indicated as the monitoring furnished different pollen concentrations during the 24 hours with highest intensity of biological flows during the first hours of the day, generally influenced by wind velocity, inducing us to consider the monitoring period during the 24 hour a day.

The two pollen concentration series in Figure 2 show a clear difference in monitored particles from a quantitative point of view (the differences ranged from 11% to a maximum of 84% during the high

concentration periods – first days of July), but very similar patterns in terms of the pollen emission trends. The two series effectively present a high correlation value, $r = 0.75$ ($p < 0.01$), testifying that the indoor pollen concentrations are directly dependent on those recorded outdoors. Despite this close relationship, the non-parametric Wilcoxon and Sign test realised for each plant family demonstrated as the significant quantitative differences between the two concentration series were unlikely to occur by chance (Table I). This result is particularly useful, demonstrating how the artificial ‘membranes’ utilised in the CS as pollen filters are able to determine a significant decrease in indoor pollen concentrations. A non-parametric test was considered due to the normality check results (Skewness, Kurtosis, Omnibus normality) for which the normality assumption should not be accepted as in several cases for the environmental bio-aerosols.

All pollen of the principal plant families (Compositae, Fagaceae, Poaceae, Oleaceae, Urticaceae, Cupressaceae/Taxaceae and Chenopodiaceae/Amaranthaceae) presented significant differences between indoor and outdoor concentrations demonstrated by the clear rejection of the null hypothesis (Table I).

The results of total pollen concentration decrease (see Figure 10) evidence the mean decrease percentage calculated during the entire monitoring season (55%) and its trend, showing how the pollen filter membranes used in the investigation reduced the indoor pollen concentrations on average by 55%, with only a brief period (about 10% of the total monitoring period) of scarce filter reduction (Figure 2).

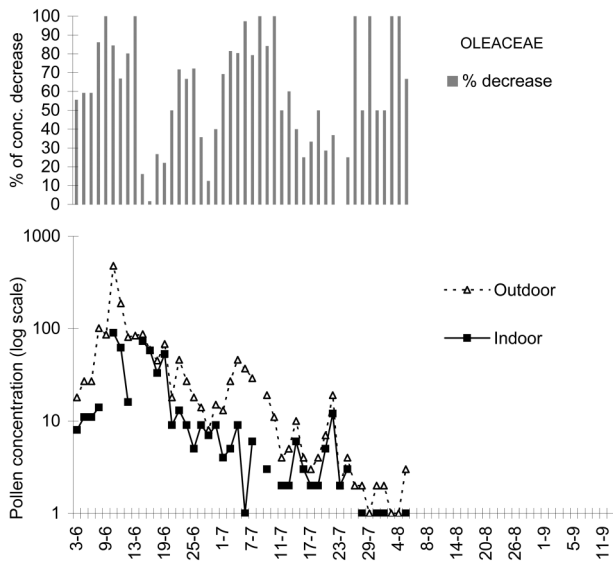


Figure 6. Indoor and outdoor pollen concentration trends and percentage decrease (Oleaceae).

The highest pollen reduction percentages in outdoor–indoor pollen emission for the principal types of plants that flower during the study period were recorded for the pollen of Poaceae and Cupro/Taxaceae (about 80%), while the lowest were those related to the Urticaceae pollen (about 50%).

Pollen concentrations of Compositae

The plants belonging to this very widespread type in the study area are *Ambrosia artemisiifolia* L., *Artemisia* sp. and *Taraxacum officinale* F. H. Wigg. with longest flowering period from spring until autumn. The pollen grains produced and emitted by these plants are medium to small in size (20–30 μm). During the study period, low indoor and outdoor concentrations were recorded. The average concentration decrease for this type of pollen proved to be about 68%, highlighting how the pollen filter membranes performed their role properly (Figures 3, 10).

Pollen concentrations of Fagaceae

The primary allergological species of this plant family are *Castanea sativa* Miller and *Quercus* sp. These species have a flowering period of about three months, between May and July, with the pollen grains ranging in size from 11 to 30 μm . During the monitoring period, a particularly high emission was recorded during the first days of July, with more than 80 pollen grains/ m^3 air. In this case, the drop in pollen concentration was 55% on average, presenting results not as high as for other species (Figures 4, 10).

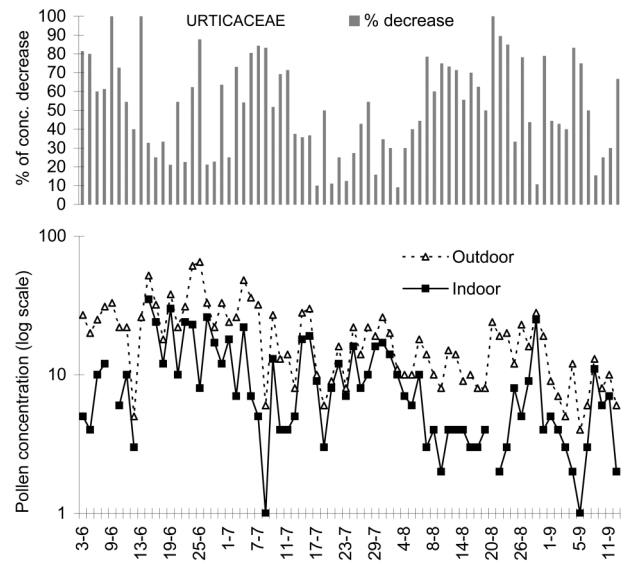


Figure 7. Indoor and outdoor pollen concentration trends and percentage decrease (Urticaceae).

Pollen concentrations of Poaceae

Avena, *Dactylis*, *Lolium*, *Poa*, *Festuca*, etc., are the typical present genera of the family. In particular, the main period of pollen emission for *Dactylis glomerata* L., *Festuca arundinacea* Schreb., and *Avena fatua* L. can be considered to run from the end of spring through summer. Pollen grain size ranged from 25 to 40 μm . The peak of Poaceae pollen was recorded in June and July, in this case the percentage of concentration decrease proved to be around 80% on average, probably due to the size of the same Poaceae pollen grains (Figures 5, 10).

Pollen concentrations of Oleaceae

Fraxinus excelsior L., *Fraxinus ornus* L., *Ligustrum vulgare* L., and *Olea europaea* L. are the representative species of the Oleaceae family during the pollen monitoring period. In this case, the highest pollen concentrations were recorded during the first weeks of June, when the olive groves around the monitoring site were still emitting a massive quantity of their pollen (pollen size ranged from 20 to 25 μm). The percentage of concentration decrease reached values of about 60% (Figures 6, 10).

Pollen concentrations of Urticaceae

Parietaria diffusa Merl. and W. D. J. Koch and *Urtica dioica* L. are the species that emit pollen in the study area during June for Urticaceae. The pollen grains are quite small, ranging in size from 14 to 19 μm . The concentration decrease in percentage between indoor and outdoor pollen traps reflected

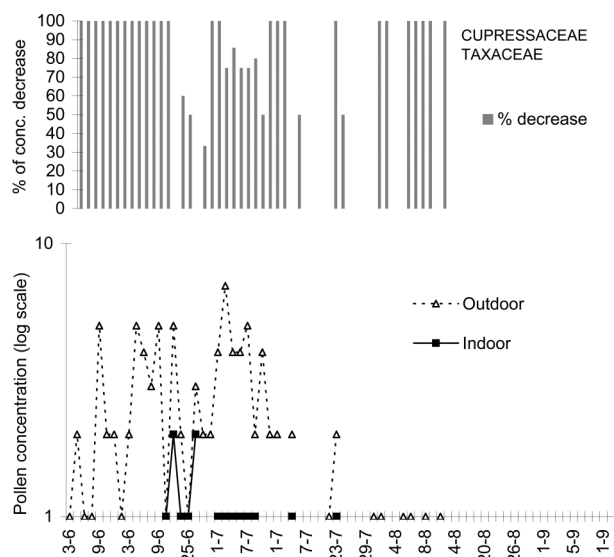


Figure 8. Indoor and outdoor pollen concentration trends and percentage decrease (Cupressaceae/Taxaceae).

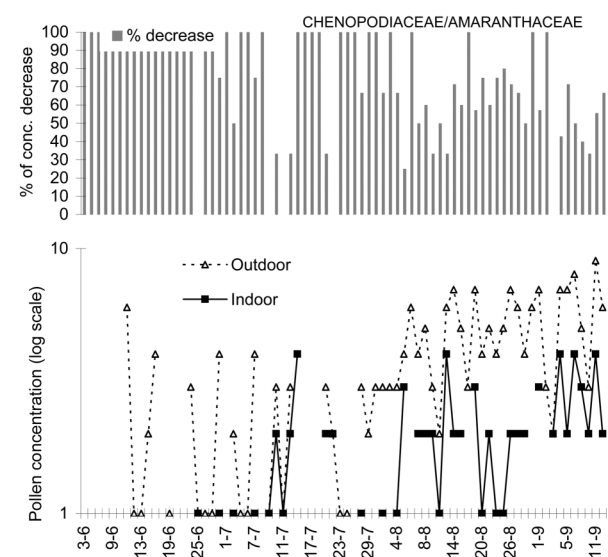


Figure 9. Indoor and outdoor pollen concentration trends and percentage decrease (Chenopodiaceae/Amaranthaceae).

this particular size, with the lowest levels at about 45–50% (Figures 7, 10).

Pollen concentrations of Taxaceae and Cupressaceae

Different species (*Thuja occidentalis* L., *Juniperus communis* L., *Taxus baccata* L.) are the principal representatives of this group during monitoring because their flowering period runs from April to June. The pollen of these species ranged between 20 and 30 μm in size, and the outdoor pollen monitoring revealed low values (not higher than 7 pollen grains/ m^3 air),

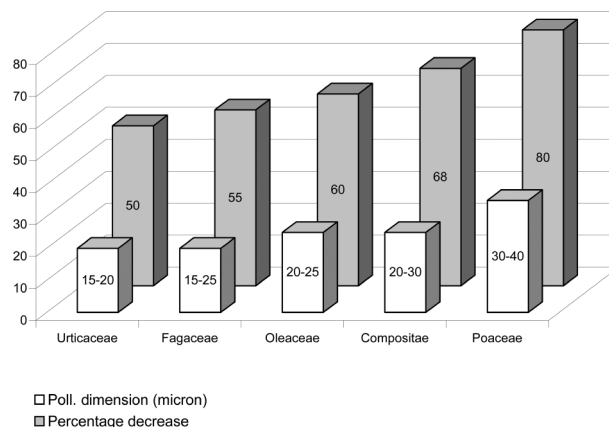


Figure 10. Relationships between pollen size (in micrometres) and the percentages of pollen decrease (indoor-outdoor).

while the decrease in concentration during the study reached about 80% (Figure 8).

Pollen concentrations of Chenopodiaceae and Amaranthaceae

Chenopodium album L. and *Amaranthus cruentus* L. are the two species most present with their pollen emissions during the summer period (from June to October). The pollen grains produced range 20–30 μm and our monitoring activity recorded the higher concentrations during the first days of September. Low pollen volumes were recorded for this group of plants also and the decrease in concentration reached an average 75% (Figure 9).

Discussion

The monitoring of the particles distributed in the atmosphere showed different results in comparison with those monitored inside the CS. The internal and external pollen series showing that the indoor pollen concentration was linked to those recorded outdoors demonstrated how the artificial 'membranes' used in the CS as pollen filters are able to determine a significant decrease in indoor pollen concentrations. Moreover, the selection of pollen released by the filter was probably linked to their aerodynamic characteristics, in fact although of small-medium size, the pollen of Cupressaceae/Taxaceae and Chenopodiaceae/Amaranthaceae-types encountered problems in penetrating the filters with high percentages of pollen decrease inside the CS. This evidence should stimulate new experimental investigations on structural characteristics of pollen (exine and intine, endo-reticulations) such as on their geometries (spheres, spheroids) in order to assess the importance of their shape considering aerodynamic properties by wind dispersal.

Table I. Results of the non-parametric Wilcoxon and Sign test realised for each plant family.

Alternative hypothesis	Probability level	Reject H0 at 0.050	Z-Value	Probability level	Reject H0 at 0.050	Z-Value	Probability level	Reject H0 at 0.050
Compositae								
X1-X2<>0			4.659	0.000	Yes	1.000	0.000	Yes
X1-X2<0			4.659	1.000	No	4.663	1.000	No
X1-X2>0			4.659	0.000	Yes	4.655	0.000	Yes
Fagaceae								
X1-X2<>0			6.586	0.000	Yes	1.000	0.000	Yes
X1-X2<0			6.586	1.000	No	6.589	1.000	No
X1-X2>0			6.586	0.000	Yes	6.582	0.000	Yes
Poaceae								
X1-X2<>0			6.905	0.000	Yes	1.000	0.000	Yes
X1-X2<0			6.905	1.000	No	6.908	1.000	No
X1-X2>0			6.905	0.000	Yes	6.901	0.000	Yes
Oleaceae								
X1-X2<>0			6.070	0.000	Yes	1.000	0.000	Yes
X1-X2<0			6.070	1.000	No	6.073	1.000	No
X1-X2>0			6.070	0.000	Yes	6.066	0.000	Yes
Urticaceae								
X1-X2<>0			6.556	0.000	Yes	1.000	0.000	Yes
X1-X2<0			6.556	1.000	No	6.560	1.000	No
X1-X2>0			6.556	0.000	Yes	6.553	0.000	Yes
Cupressaceae/Taxaceae								
X1-X2<>0			4.832	0.000	Yes	1.000	0.000	Yes
X1-X2<0			4.832	1.000	No	4.836	1.000	No
X1-X2>0			4.832	0.000	Yes	4.828	0.000	Yes
Chenopodiaceae/Amaranthaceae								
X1-X2<>0			5.731	0.000	Yes	1.000	0.000	Yes
X1-X2<0			-5.731	0.000	Yes	-5.727	0.000	Yes
X1-X2>0			-5.731	1.000	No	-5.734	1.000	No

Conclusion

The pollen monitoring carried out during approximately four months indicated a reduction in pollen concentration registered inside the special building simulator in comparison with the outdoor concentrations. These results can be well justified in consideration of the pollen size; in fact, utilising a special tissue with a uniform and consistent mesh structure of about 70 μm (much larger than the largest pollen deposited on the indoor monitoring apparatus), the artificial membranes were able to partially select the entering pollens based on their size. Therefore, the efficacy of the used pollen filter was demonstrated above all for the plants with the largest pollen grains (Poaceae, Cupro/Taxaceae, and Oleaceae) while for the other monitored pollen typologies (Urticaceae) it was lowest.

Another consideration that can be derived from the present investigation is that the pollen blocked with the highest percentages were those of the plant families having the highest allergenic activity in the study area (Poaceae, Urticaceae, Oleaceae), demonstrating the efficiency of the pollen filters and their potential

utilisation as window screens into living spaces, hospitals and other structures with specific health needs. In particular, the use of 70 μm mesh window screens produce a small brightness reduction inside the chamber not affecting normal visibility.

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