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# Methods for Evaluating Dust Accumulation in Ventilation Ducts

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## ABSTRACT

*Methods for evaluating the composition and accumulation of dust in ventilation ducts have been developed. Samples of settled dust were collected in one apartment house, one school, and four office buildings. The total mass of dust was determined gravimetrically, the counts of fungal spores and bacteria were determined by culture methods, and the pollen was counted by microscopy. The total protein concentration of the dust was determined by the Coomassie Brilliant Blue method, applied specifically to this purpose.*

*Total dust mass varied from 3.6 to 140.8 g/m³ and the normalized accumulation of dust from 0.51 to 12.8 g/m² per year. Counts of viable fungal spores ranged from 200 to 22,500 cfu/m² and of bacteria, from 490 to 35,900 cfu/m². The amounts of pollen and protein ranged from 43 to 27,900 and 9 to 930 mg/m², respectively. The average proportion of protein was 0.7% of the total mass.*


## INTRODUCTION

The accumulation of settled dust in ventilation ducts is a potential source of indoor air pollutants. Such accumulation has not been characterized so far and, therefore, its importance to indoor air hygiene is not known. Additionally, there is little information regarding the emission of contaminants deposited in HVAC systems into the building air. Considering the sources of potential odor and allergen, the organic fraction of accumulated dust may be of importance. Common to all organic material are biological macromolecules, such as proteins. At present, there are no methods available to separate and characterize this fraction from total dust. The purpose of our work was to develop methods for the quantification, characterization, and evaluation of the dirtiness and hygiene of ventilation ducts. In this study, special emphasis was put on developing a method for determining the total protein content of the dust.

## MATERIALS AND METHODS

### Study Objects

The study was conducted in Kuopio, a middle-sized city in eastern Finland. Study objects were situated in six buildings; one of them was an apartment house, one a school, and the rest of them were office buildings. The ages of the ventilation systems varied from five to eleven years, and none had been cleaned. The height of the air inlet indicates how high the inlet of the ventilation duct is above the ground level. The distance between the sampling area and the filter in the duct was measured. The air velocities were calculated from designed values.

The filters used in these buildings were classified according to the EU-standard. Some properties of the ventilation systems are presented in Table 1.

Buildings A and G were situated in the downtown area beside main streets with heavy traffic. Building B was an apartment house in a residential area. Offices C and D and school F were located in another residential area. The offices C and D were situated in the same building. In office C the supply air was taken from outside, whereas office D used partly recirculated air. Building E was situated near a highway.

### Sampling

The dust samples from the bottom of the horizontal ducts was loosened from an area 96 × 424 cm² with a nozzle and collected in the filter (pore size 0.8 μm). The T-shaped nozzle was a 2-cm scale model of the nozzle of a vacuum cleaner. Next to these sampling areas, we took a contact sample to determine viable bacteria and fungi.

The first samples were taken in April, May, and June 1990. The sampling was repeated at the same sites in September 1990 to determine the accumulation rate of dust.

In building A the samples were taken from different floors, in April from the ground floor, in May from the first floor, and in June from the second floor. In building B only one sample was taken in April. The rest of the ducts were large enough to take several samples. In the next few months, the samples were taken at areas next to the previous sample area. In September 1990 the last samples were collected from exactly the same areas where the first samples were taken.

### Analysis of the Dust

Surface density (g/m²) and accumulation (g/m²·year) of dust deposited on duct surfaces were determined. The proportion of inorganic residue was determined as annealing lost by annealing the dried sample at 550°C. The results indicate how much inorganic material the dust contains, and they were calculated as percentages (%) of the total dust.

The total protein concentration was measured by the Coomassie Brilliant Blue method (Spector 1978). For the analyses,

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TABLE 1
Some Parameters of the Ventilation Systems

| Sample | Year when duct was built | Filter classification | Height of inlet [m] | Distance from filter [m] | Air velocity in duct [m/s] | Building |
|---|---|---|---|---|---|---|
| 1 | 1983 | EU2 + EU5 | 8 | 9.5 | 0.9 | office A |
| 2 | " | " | 8 | 5.5 | 1.0 | " |
| 3 | " | " | 8 | 5 | 1.2 | " |
| 4 | " | " | 8 | 9.5 | 0.9 | " |
| 5 | " | " | 8 | 5 | 1.2 | " |
| 6 | 1985 | EU3 | 5 | 1 | 3.5 | apart. B |
| 7 | 1982 | EU3 | 5 | 1 | 2.0 | office C |
| 8 | " | " | 5 | 1 | 2.0 | " |
| 9 | " | " | 5 | 1 | 2.0 | " |
| 10 | " | " | 5 | 1 | 2.0 | " |
| 11 | " | " | 5 | 1 | 2.0 | " |
| 12 | " | " | 5 | 1 | 2.0 | " |
| 13 | 1982 | EU3 | 5 | 3 | 1.5 | office D |
| 14 | " | " | 5 | 3 | 1.5 | " |
| 15 | " | " | 5 | 3 | 1.5 | " |
| 16 | 1981 | EU7 | 12 | 3 | 5.6 | office E |
| 17 | " | " | 12 | 3 | 5.6 | " |
| 18 | " | " | 12 | 2 | 7.9 | " |
| 19 | " | " | 12 | 3 | 5.6 | " |
| 20 | " | " | 12 | 3 | 5.6 | " |
| 21 | " | " | 12 | 2 | 7.9 | " |
| 22 | 1984 | EU3 | 2 | 3 | 2.0 | school F |
| 23 | " | " | 2 | 3 | 2.0 | " |
| 24 | " | " | 2 | 3 | 2.0 | " |
| 25 | 1979 | EU2 | 10 | 6.5 | 2.8 | office G |
| 26 | " | " | 10 | 9 | 2.8 | " |
| 27 | " | " | 10 | 13 | 2.8 | " |

00 mg dust was weighed to a 50 mL plastic test tube, and 1.5 mL 0% trichloroacetic acid (TCA) was added. The mixture was reated by an ultrasonicator for two minutes and centrifuged at 000 x G for 15 minutes. The acid extract was carefully removed y Pasteur-pipette. The precipitate was suspended to 1.5 mL cold % TCA, centrifuged, and the acid extract was removed. The pre- pitate was suspended once more in 1.5 mL 5% TCA and extract- d for 20 minutes at 80°C temperature in a waterbath. The extract as mixed occasionally by glass rod. The suspension was cooled an icebath, centrifuged, and the acid extract was carefully moved. The same treatment with another 1.5 mL 5% TCA was peated and the acid extract was removed as mentioned before. ie precipitate was dissolved in 2 mL 1-M NaOH for some hours room temperature. The precipitate was centrifuged again and extract was carefully removed to a smaller glass test tube. The otein concentration of the extract was determined by the omassie Brilliant Blue method, with spectrophotometric mea- ements at the wavelength of 595 nm. Bovine serum albumin SA) was used as a standard protein. The results were given as protein/m$^2$.

The amounts of pollen in the dust were counted by micro- py using Bürker's method (Baker et al. 1955). Duplicate por- is of 20 mg from each sample were mixed with 1 mL 20% vatol mounting liquid (Kapyla 1989). The counts of the pollen e determined by using three classes according to wight and neter: Picea-type 110.8 x $10^{-9}$ g (68-91 µm), Pinus-type 37.0 × $^{9}$ g (44-52 µm), Betula + Poa -type 1.4 × $10^{-9}$ g (22-70 µm) nley and Linskens 1974).

### robial Cultures

The contact samples to determine viable bacteria and fungi incubated at room temperature (20°C) for five days in the dark. The colonies were counted, and the results are given as colony-forming units per square metre (cfu/m$^2$) of the ventilation duct surface. The culture medium for bacteria was a plate count agar with added cycloheximide and for fungi it was malt extract agar-based yeast and mold medium with added streptomycin.

### Statistical Analysis

The results were analyzed by regression statistical analysis. The results show significant correlation (R) at the 0.05 probability level. The correlation is slightly significant when $p<0.05$, significant when $p<0.01$ and very significant when $p<0.001$. The differences between groups in a variable were analyzed by one-way variance of analysis at a significance level of $p<0.05$.

## RESULTS AND DISCUSSION

In the samples collected during April, May, and June, the surface densities ranged from 3.6 to 140.8 g/m$^2$ and during September from 0.09 to 0.79 g/m$^2$. The average surface density of all samples was 18.2 g/m$^2$. The accumulation rate of the dust ranged from 0.51 to 12.8 g/m$^2$ per year and in September from 0.26 to 1.73 g/m$^2$ per year. The average was 2.3 g/m$^2$ per year. The average density and accumulation of the dust were three times higher than in a Danish study (Nielsen et al. 1990). The results of our investigation are higher probably because of one study object, which had much dirtier ducts than other objects due to the high concentration of pollen.

Inorganic residues ranged from 58% to 91% of the total dust and the average was 80% of the dust. The same trend can be observed in another study (Mamane 1990). The results of our investigation had no correlations ($p<0.05$) to protein concentrations.

The average protein concentration was 195 mg/m$^2$ and the average proportion of the protein was 0.7% of total dust. The

TABLE 2

The Concentrations of Picea-, Pinus-, and Betula+Poa-Type of Pollen, the Total Pollen, and the Protein Collected from the Dust of Supply Air Ducts

| Variable | N | Mean ($mg/m^2$) | Range ($mg/m^2$) | Percentage of dust (%) |
|---|---|---|---|---|
| Protein | 17 | 195 | 9 - 924 | 0.69 |
| *Picea* | 12 | 2200 | 45 - 13800 | 3.84 |
| *Pinus* | 16 | 2710 | 39 - 21300 | 5.86 |
| *Betula* + *Poa* | 16 | 59 | 4 - 245 | 0.23 |
| Total pollen | 16 | 4420 | 43 - 27900 | 8.97 |

average amount of total pollen of the dust was 9.0% (see Table 2). Protein values between 5.9% and 28.3% of different pollen residue have been reported (Stanley and Linskens 1974). Therefore, most of the protein found in our dust samples originates from pollen. The correlation between protein concentration and total pollen counts was 0.968 ($p<0.001$).

The average count of fungal spores was 6,100 cfu/$m^2$ (200-22,500) and the count of bacteria was 7,020 cfu/$m^2$ (490-35,000). The appearance of fungal spores and bacteria had a correlation of 0.875 ($p<0.001$). They had no correlations ($p<0.05$) to the protein concentrations.

The statistical analysis showed that the filter classification had effect on Picea- and Betula + Poa types of pollen (see Table 3). The height of the inlet from the ground level had negative correlations to the microbes ($p<0.05$); the higher the inlet was, the lower the microbial counts. The air velocity had no correlations to any variables measured ($p<0.05$).

The nozzle designed for our study was a suitable tool for collecting the dust from the ducts: it was sharp enough to loosen the dust but soft enough not to scrape off the surface material of the duct.

## CONCLUSION

In our study, methods have been developed to characterize the dust accumulation in supply air ducts. We have developed the method to separate and analyze the total protein content of the dust. The correlation of protein to biological material was studied. According to our preliminary results, pollen protein is the major component of the total protein, while the protein contributions of spores, bacteria, and other sources are negligible. In this study, fibers and heavy metals were not analyzed from dust samples. These impurities should be considered in further studies.

TABLE 3

The Correlation (R) of Different Variables to the Filter Classification and the Probability of the Correlation (P)

| Variable | Filter classification | | |
|---|---|---|---|
| | N | R | P |
| Dust accumulation ($mg/m^2$/year) | 27 | -0.490 | ** |
| Protein ($mg/m^2$) | 17 | -0.483 | * |
| *Picea* ($mg/m^2$) | 12 | -0.757 | ** |
| *Pinus* ($mg/m^2$) | 16 | - | N.S. |
| *Betula* + *Poa* ($mg/m^2$) | 16 | -0.626 | ** |
| Total pollen ($mg/m^2$) | 16 | - | N.S. |
| Fungal spores (cfu/$m^2$) | 19 | -0.466 | * |
| Bacteria (cfu/$m^2$) | 19 | - | N.S. |

At the table probabilities was marked as following figures: N.S.= non significant, * = slightly significant, ** = significant, *** = very significant.

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