REDUCTION OF MICRO-ORGANISMS BY HVAC SYSTEM FILTERS AND ANALYSIS OF THE MICRO-ORGANISMS PASSING THROUGH THE FILTERS

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ABSTRACT

In order to determine the amount of micro-organisms present before and after the filters of HVAC systems, 6 systems in 5 buildings were monitored every 2 weeks for one year. Measurements were taken in triplicate and simultaneously before and after the filters using a six stage Andersen sampler. The reduction of total of micro-organisms through the air filters ranged from 20% up to 93% and was associated with filtration efficiency rating. In most of the HVAC systems the total cfu levels were low or very low after the pre filters and the main filters. The micro-organisms were also analysed by particles mass (the six stages of the Andersen sampler) to determine which micro-organisms were small enough to have the potential to penetrate deep into human lungs and cause adverse health effects (stages 4, 5 and 6 of the sampler). These smaller sized micro-organisms were significantly reduced by the filtration media. The results also revealed advantages and disadvantages between HVAC type and design including filter type, maintenance, and moisture damage. During the study, sources of micro-organisms contamination were also identified and mitigation could be performed.

INTRODUCTION

The search for causes of the recent increase in complaints and building related symptoms from office workers (and the association to energy saving building maintenance practices) has increasingly labelled HVAC systems and there components such as air filters as strong source of indoor air pollution in buildings. This is partly based on the fact that air filters were designed to collect organic material which is a potential nutrient source for the large amount of micro-organisms the filters also collect in there normal service life.

However, still little is known about how micro-organisms behave on air filters even though it has been the topic in many different investigations which have mostly examined used and unused filters under laboratory conditions. Some of the results from these investigations were vastly different with some of the inferences from the results being misleading and/or not comparable with others. Conclusions from these investigation range from all micro-organisms dying on the air filters to micro-organisms proliferating and actually grow through filters (1,2). However, upon closer inspection, many of these conclusions were a miss-use of words brought about by a lack of basic knowledge of micro-organisms biology and/or poor study design.

The question of how efficiently do the air filters reduce micro-organisms has only been investigated by few people and than mostly under lab conditions (3,4,5,6).This investigation included field studies and was designed to determine the efficiently of air filters to quantitatively and qualitatively reduce the micro-organism loading as the air passed through the filter banks of large HVAC systems servicing public buildings.

METHODS

The reduction of micro-organisms in the air before and after filter banks was monitored for 1 year in 6 large HVAC systems servicing 5 public buildings. Samples were taken every two weeks. The HVAC systems were of different constructions and different ages. The systems typically had 1 to 3 filter-stages with the air sampling taken at the first two stages. Six 1st stage and four 2nd stage filters were measured. Samples where taken simultaneously before and after the filters while the HVAC was running. Before every measurement the air temperature, the atmospheric humidity and the air velocity were obtained in front of the filters.
The filter banks of the HVAC systems were fitted with filters of class G4, F6 and F7. The G4 filter was used as a second filter. The filter materials where either cellulose, synthetic or fibre-glass. The age of the filters was between new and 2 years service life.

The six stage Andersen sampler was used to sample micro-organisms and was placed 60 cm above ground level. Measurements were performed in triplicate using 3 different nutrient media which were malt-extract agar (MEA), blood-agar and Czapek-Dox-agar. These were used to differentiate between non mycelia building micro-organisms such as bacteria and yeasts (b), moulds (m), and yeast like fungi (y).

Out of the triplicate data for every single stage of the Andersen the mean value was taken. The values from the stages 3-6 where mathematical corrected (after Andersen, the principle of used holes)(7). The sum of all stages where calculated by volume (m^3) of sampled air. The calculation of the reduction of micro-organisms on air filters required the following reduction factor:

$$rf = \log(mc^{bef}) - \log(mc^{after})$$

where:
rf = reduction factor,
mc^{bef} = micro-organism concentration before filter,
mc^{after} = micro-organism concentration after the filter.

Following mathematical transformation, the results where calculated in percentage reduction for easier comparison. The reduced data are shown as a arithmetic mean value as a boxplot as the mean value of the reduction factors and not transformed into percentages.

Using the Andersen sampler made it possible to separate the particles into fractions between: (A) those who can and (B) those who can not penetrate deep in the human lung. Micro-organisms with an aerodynamic size bigger than 3,3 µm where considered as non penetrating and micro-organisms less than 3,3 µm were considered as lung penetration size (8).

RESULTS

The different filter-stages revealed different efficiencies of micro-organism reduction. The first filter-stage showed reductions of between 62,1% and 93,0 % with an average of 82,5 % reduction. However, the second filter-stage showed much lower reductions of between 20,2 % and 64,7 % with an average of 38,5 % reduction (see fig. 1).

The average micro-organism concentration of 179 cfu/m³ between the first and second filter-stage was much less than the air before the first filter-stage which was 752 cfu/m³.

By statistical comparison of the reductions, the results of filters from the same filter efficiency but from different location (i.e. the 1st or 2nd filter-stages) within the same HVAC showed no significant differences (ANOVA; p = 0.000). The only exception was a filter class F 7 (ANOVA; p = 0,246).

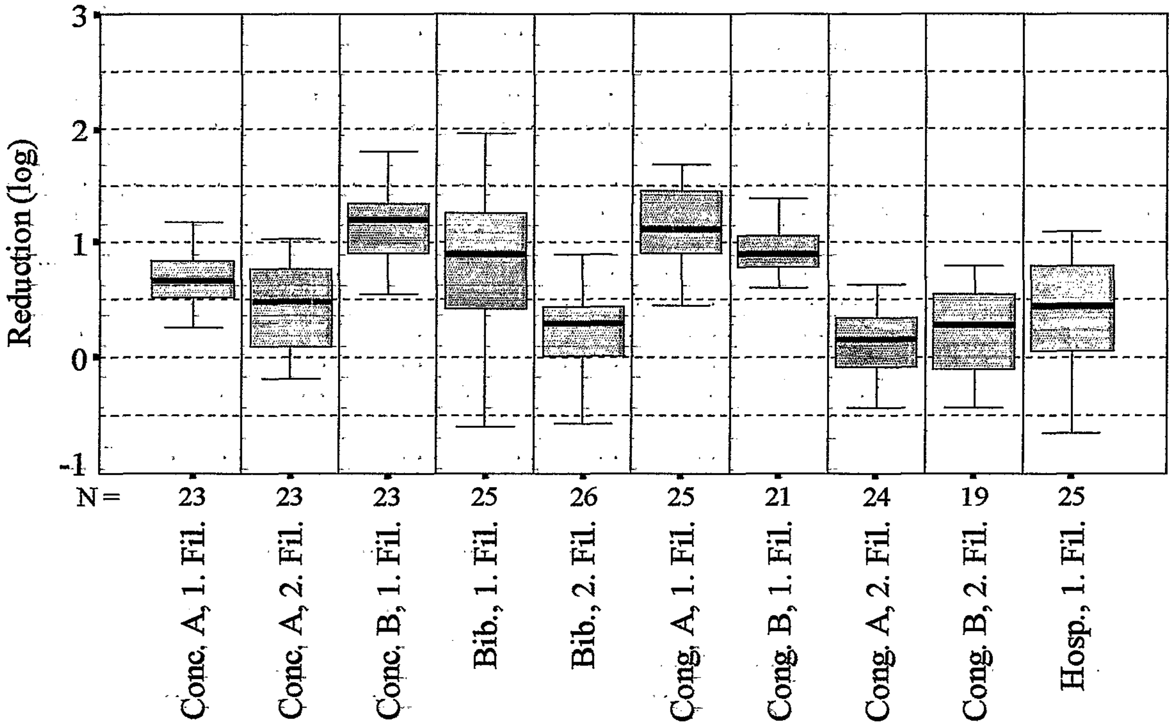

Fig. 1: Reduction of micro-organisms concentration of air filters on the different locations

The results showed that the air filters from the first filter-stage were reducing the micro-organisms concentration as good as the current European guidelines were demanding for atmospheric particles, and in some cases, the filters were performing even better. However none of the second filter-stage air filters reached the demands for filter efficiency to reduce micro-organisms concentration (9,10). The greatest reduction of total cfu from micro-organisms was found at the first filter-stage in the Concert Hall B. The lowest reduction occurred in the second filter-stage in a Congress Hall's HVAC system.

The greatest increase of micro-organisms concentration after an air filter of the first filter-stage occurred in a Hospital. An increase was also found in all of the second filter-stages and in the first filter-stage of a Library (see fig. 1). However, no increase could be calculated between the average value and the mean value.

In separating the total cfu of the micro-organisms in the 3 different fractions, the cfu from moulds showed the best reduction with an exception at the second filter-stage of the Concert Hall A (see table 1).

Table 1: Reduction of the different micro-organisms concentration fraction (cfu/m³) in percentage (%)

Building	Filter Bank	Before the Filters cfu/m³	After the Filters cfu/m³	Bacteria	Moulds	Yeasts
Concert Hall A	1st	933	277	70,3	87,5	83,4
Concert Hall A	2nd	177	88	61,5	57,8	8,7
Concert Hall B	1st	559	38	84,6	97,2	81,4
Library	1st	571	345	58,6	96,6	70,8
Library	2nd	445	363	21,3	35,1	8,0
Congress Hall A	1st	1013	95	88,6	95,5	89,2
Congress Hall B	1st	1013	135	80,3	90,9	84,9
Congress Hall A	2nd	54	62	10,4	48,9	0,0
Congress Hall B	2nd	40	24	5,7	74,8	-0,8
Hospital	1st	420	405	51,5	81,5	59,6

It could be shown that the micro-organisms capable of lung penetration where more efficiently reduced than the larger sized micro-organisms, with the exception at the first filter stage of the Library (see table 2).

Table 2: Reduction of total micro-organisms cfu (%) depending on particle size

Building	Filter Bank	Particles > 3,3 mm (%)	Particles < 3,3 mm (%)	Total Particles
Concert Hall A	1st	72,1	84,9	79,4
Concert Hall A	2nd	10,1	75,6	64,7
Concert Hall B	1st	86,2	94,6	93,0
Library	1st	89,0	79,6	81,0
Library	2nd	17,0	27,5	27,3
Congress Hall A	1st	91,0	94,3	92,6
Congress Hall B	1st	87,0	87,5	86,6
Congress Hall A	2nd	-8,9	37,0	20,2
Congress Hall B	2nd	9,5	47,9	41,9
Hospital	1st	59,4	67,3	62,1

DISCUSSION

The results show a greater reduction of micro-organisms for the first filter-stage then for the second stages. This particular result is difficult to easily explain especially as the second filter-stages were normally fitted with air filters of a higher efficiency rating than were used in the first filter-stage. This may be due to some methodology error as the micro-organisms in the first filter-stage are reduced to the point that they were nearly below the detection limit of the sampling method. This is a general problem when measuring low cfu numbers as it makes the results inexact especially when they are all calculated up to cfu per cubic meter.

This can be also shown by statistically comparison of the reduction results. Only filters that had a high cfu concentration (> 360 cfu/m^3) before could provide an exact result of the reduction factor. Because of this, only the results of the first filter-stage are useful for discussion.

The air velocity in front of the filters varied from 1,0 m/s to 10,2 m/s by an average of 4,2 m/s for all filters. The Andersen sampler's best efficiency is known around its impact air velocity (1 m/s). Otherwise there will be an over- or underestimation of cfu (11). Till now there are no devices known to reduce this faults to a minimum. Therefore it was decided to use the Andersen sampler as demanded by the producer.

The best reduction of micro-organisms were found in a single stage HVAC-system. This was also the newest HVAC investigated. The outdoor air intake was over several levels above ground and transported the air through a more than 30 m long ductwork to the first filter-stage. The same design of construction occurred also at the location where the highest increase of micro-organisms behind the air filter appeared (first filter-stage Hospital). However, at the Hospital the outdoor air intake was only about 3,5 m above ground level and the last filter change was more then two years ago. On this particular filter, the micro-organisms concentration for bacteria and moulds behind the filter increased once dramatically.

The first-stage air filter of the Library was mounted close behind the outdoor air intake. This allow accidental moisture damage on the air filter during wet winter months. This in turn caused an excessive increase of bacteria in the air after the filters. After one period of moisture damage and low outdoor air temperature, the high micro-organisms concentrations after the air filter remained for a period of three month after the initial water damage.

After the first filter-stages of the Congress Hall, an more efficient reduction of cfu could be created by preheating the outdoor air before the first filter-stages. The average reduction factor with the preheaters was better than for air filters with the next higher filter efficiency. The average reduction factor for total cfu counts was within the guidelines for all first filters but not for all of the micro-organism fractions. The best reduction for micro-organism fractions was found for moulds. This result is opposite to the results from previous investigations (12).

This investigations could show an increasing micro-organisms concentration for bacteria in the air after an air filter from only 23 weeks service life and low outdoor temperatures (4). Such results were only possible to be detect in a field investigation. Laboratory investigations have the disadvantage of not using the stronger more vital wild strains of bacteria and the "naturally" occurring nutrition on the air filters was missing (13).

CONCLUSIONS

The reduction for micro-organisms that are able to penetrate the lungs was greater than for the larger particles (as would be expected). However, in the air behind the filters there were less micro-organisms of a size that could penetrate the lungs than the larger particles that can not penetrate deep into the lungs. A significant discovery of the study was to reveal that when there was a contamination of the HVAC-system, there was always a significant increase of the smaller lung penetrating micro-organisms. The efficiency of air filters was also shown to be related to the way the HVAC-system is constructed, the level of maintenance to the whole system, and how often the air filters were changed.

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