

INSTALLATION OF A ULTRAVIOLET IRRADIATION SYSTEM, TYPE C, PLANT AND ITS INFLUENCE ON INDOOR AIR QUALITY

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ABSTRACT

We have investigated the effect of UVC on IAQ in a ventilation plant in a typical office building. The UVC-system consisted of UVC-lights for irradiation on all central components in the Air Handling Unit. A similar ventilation plant, but without UVC, was chosen as a reference plant. Microorganisms on surfaces, living airborne mould spores and MVOC (Microbial Volatile Organic Compounds) were sampled throughout the ventilation plant and in corresponding rooms before and after UVC-irradiation. In addition, parallel measurements in the reference plant were conducted. The number of colony forming units on surfaces were reduced in the "UVC-plant" after irradiation. For living airborne mould spores and MVOCs, no significant difference was observed. Conclusive UVC-systems seems in general to have little effect on IAQ in buildings with normal comfort ventilation plants.

INTRODUCTION

Microbes like bacteria, fungi and virus are present everywhere in the air around us. We breathe microbes outdoors and indoors, often in a lower concentration indoors since the air filter in the ventilation plant of a building retains many of the microbes. Fungus is often the most significant contributor to microbiological pollution of indoor air. Some spores from fungus penetrate the filter but most of them are retained in the filter. Under right conditions, i.e. temperature above 5 °C and water requirements (water activity $a_w > 0.7$), the spores can start to grow, and if the right conditions prevail, the microorganisms may grow through the filter (Skarland press, 2000). This will cause a higher concentration of spores in the indoor air. A study showed an increase in the concentration of cfu/m³ in filtered air when the relative outdoor humidity was higher than 80 % for more than 3 days (Moritz, M., 2001). Many field studies have shown that increased concentrations of microorganisms may cause negative effects on indoor air quality (IAQ) (Pasanen, A.-L., 2001). Many of the airborne microorganisms are known to be pathogen to humans. Any microorganism that can cause disease is considered pathogen, but the term applies to any

microbial agent of respiratory irritation, including allergens or toxigenic fungi (Kowalski, W.J., 1998). Some of the microbes that are environmentally common may be pathogen to human when they occur in concentrations higher than normal, and some may only be pathogen to people whose health are compromised. Infections, allergies, toxic effects, irritations and general symptoms are health effects possibly caused by microbial problems in indoor air. (Pasanen, A.-L., 2001).

Thus it is of great importance to avoid indoor air concentration of microbes significantly higher than outdoor levels, and keep the normal flora throughout the ventilation plant.

UVC (ultraviolet irradiation, type C) (wavelength 220-290 nm)) has been used for years in food technology, pharmacy and medical applications killing microorganisms by destroying their DNA. UVC is proposed to minimize the concentration of unwanted microbes in indoor air and by this improve the IAQ in general (Klean ASA 2001 and Steril-air, 2001). UVC-installations in HVAC in office buildings are also claimed beneficial for the IAQ. However, we find little support for this in the per-reviewed literature UVC-installations are cost consuming in HVAC installations and their contribution to an improved IAQ should be justified before any general recommendations are put forward.

METHOD

The IAQ effect of UVC in a ventilation plant has been investigated in a typical office building in Norway, Oslo. The building had reported health complaints suspected being related to microbial growth in ventilation plant.

The layout and components of the Air Handling Unit (AHU) equipped with UVC-lights are shown in Figure 1. The filters are EU7 bag filters. UVC-lights are situated in the intake, upstream of the sound attenuator in the intake, upstream of the filter, in the fan, in the sound attenuator in the supply air, in addition to UVC-lights in all inspection parts of the AHU (see Figure 1). No UVC-lights were installed in the ducts. A similar ventilation plant, serving another part of the building was chosen as a reference (figure 2). The case and the reference plant were both equipped with rotating heat exchangers.

Living airborne mould spores, MVOC (Microbial Volatile Organic Compounds) and microorganisms on surfaces were sampled throughout the ventilation plant and in corresponding rooms pre- and post UVC-irradiation. In addition, parallel measurements in the reference plant were conducted. The pre and post measurements were conducted in September 2001 and October 2001.

Before UVC-irradiation, the ducts of the "UVC-plant" were ozonated (ozone concentration = 1000 ppb) to kill any possible microbial growth. Measurements post UVC-irradiation were conducted three weeks after ozonation. The reference plant was not ozonated.

Since UVC-irradiation only kills living microorganisms, only measurements for the living microbes were conducted. The total installation is on 3130 Watt distributed in the AHU. At the filter surface the power is 240 Watt.

Sampling sites in the AHUs are shown in figure 1 and 2. As shown, all three types of samples were carried out at the same places in both of the AHUs. This is also the case for the rest of the plants, i.e. ducts and rooms.

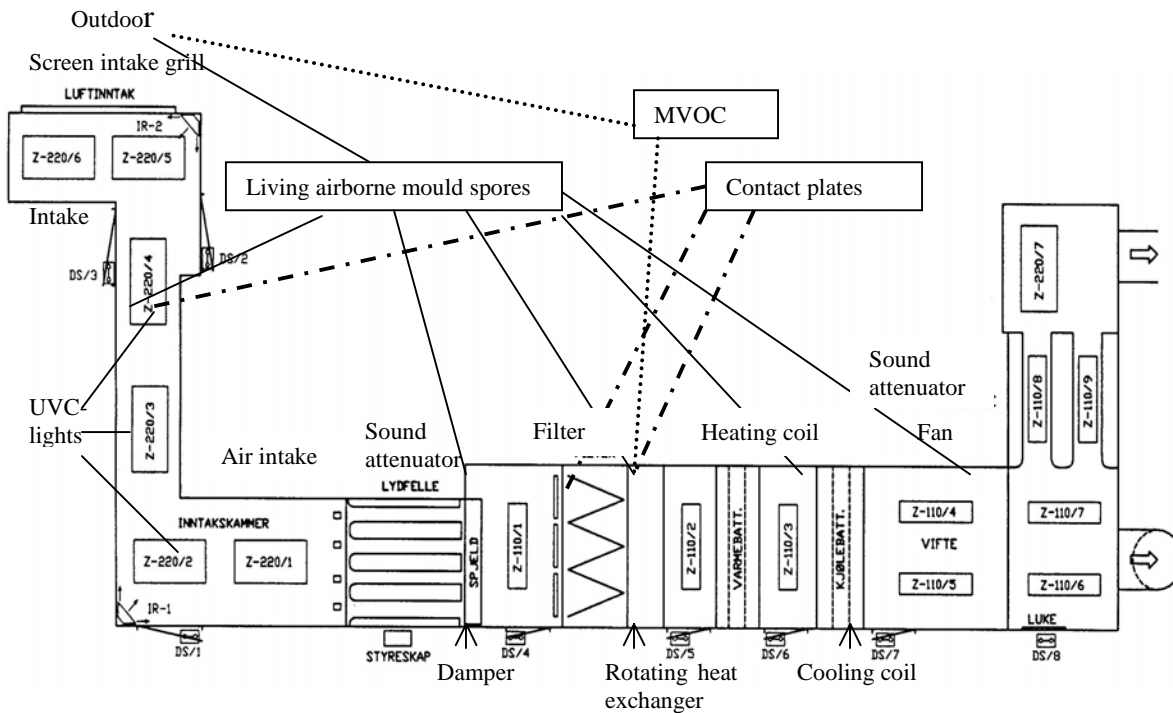


Figure 1. Samples in the "UVC-plant"

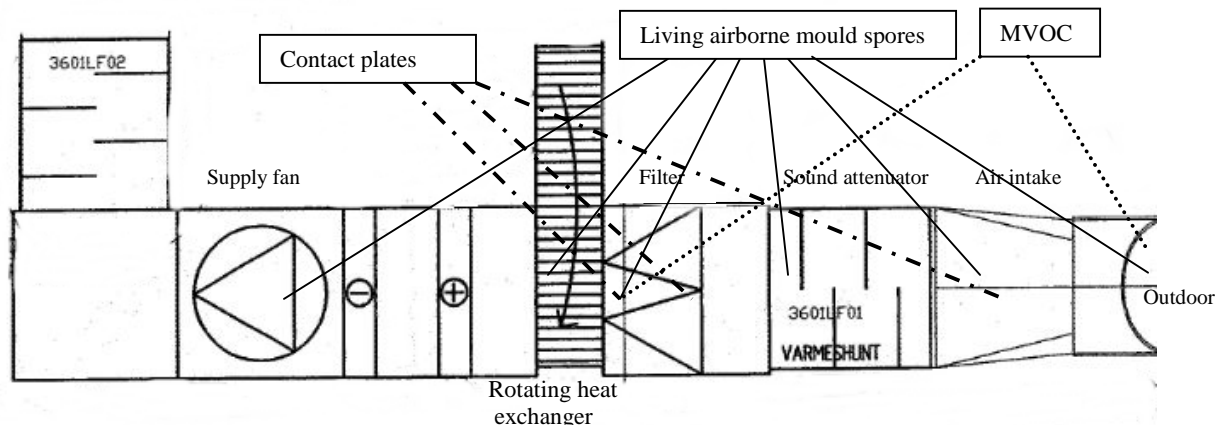


Figure 2. Samples in the reference plant

Living airborne mould spores

Measurements for living airborne mould spores were made by use of MicroBio Air Sampler (MB2); sampling volume 100 l of air are blown over two types of agar-containing medias; Malt Extract Agar (MEA) and Dichloran Glycerin Agar with chloramphenicol (DG18).

In addition to the outdoor samples, measurements were made throughout the AHUs in the air intakes, downstream sound attenuators, downstream filters, in the rotating heat exchangers and in the supply fans (ref figure 1 and 2) placing the air intake of the MicroBio upstream or towards the airstream. In the ducts the samples were taken close to the end of the string just before the rooms, with the nozzle pointing upstream. In the rooms the samples were taken ca 1.5 m above the floor holding the MicroBio with the nozzle pointing against the roof. The samples were taken at the same places pre and post UVC-

irradiation. The samples were conducted during a working day (8 am to 4 pm). Due to the change in concentration of living airborne mould spores during a day, a new outdoor sample was taken around 12 am. The samples were incubated 4-7 days, number of cfu's (colony forming units) and dominant species were found by use of microscopy.

MVOC

Emissions of Microbial Volatile Organic Compounds (MVOC) are suspected to contribute to health complaints alone or attached to particles. It is assumed that MVOCs can be produced in HVAC plants under operating (Schleibinger, H.W., 1997). Samples of MVOCs were taken; outdoors and upstream of the filters (ref figure 1 and 2) and in the supply ducts. Outdoor samples were taken as a reference. The samples were made by sucking approximately 120 l of air through an absorbent (carbon). Gaschromotography (GC) and masspectrometri (MS) were used for analyzing the absorbents for identification and quantification of MVOCs.

Settled spores

To investigate the amount of mould growth and living mould spores on surfaces, samples by contact plates with incubation media DG18 were performed. The samples were taken on surfaces in the air intake, and inside wall surfaces at the clean and the unclean sides of the filters (ref figure 1 and 2) and in ducts. A Petri plate with the medium was softly pressed to the area to be investigated. The samples are incubated in 4-7 days, and dominant species are found by use of microscopy.

RESULTS

Living airborne mould spores

Results from the samples pre- and post UVC-irradiation are given in figure 3 to 6. Figure 3 and 4 show the results from the "UVC-plant" and figure 5 and 6 show the results from the reference plant.

The outdoor concentration of mould spores vary from sample day 1 (before UVC-irradiation) to sample day 2 (after UVC-radiation). In order to compare the results from the two days of measuring, the results from the mould spore concentrations (cfu/m³) at sample day 2, are corrected for different outdoor levels at sample day 1.

$$\text{Correction factor} = \frac{\text{Outdoor cfu} / \text{m}^3 \text{ at sample day 1}}{\text{Outdoor cfu} / \text{m}^3 \text{ at sample day 2}} \quad (1)$$

The results from sample day 2 presented in the figures are all multiplied with the correction factor (1).

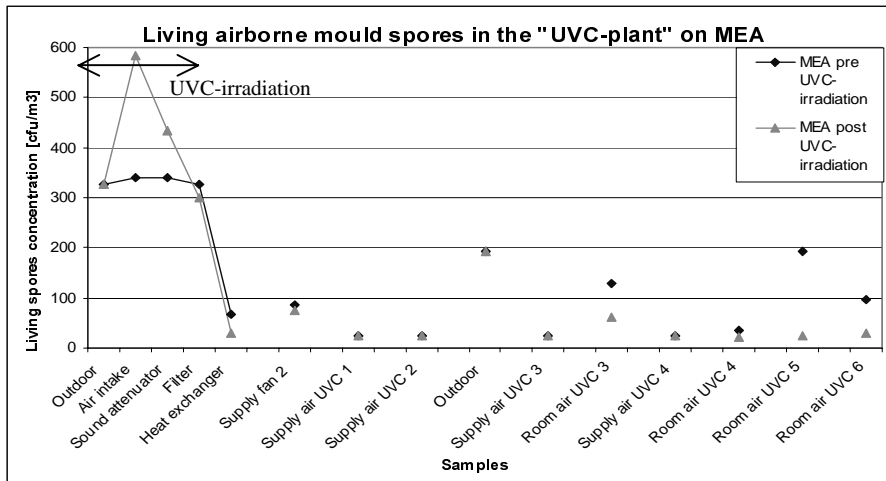


Figure 3. "UVC-plant" with medium MEA

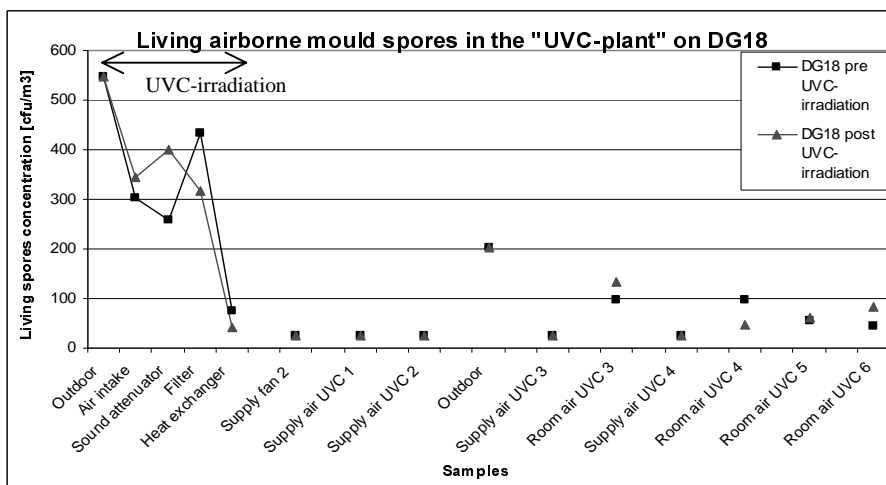


Figure 4. "UVC-plant" with medium DG18

The cfu levels are higher in the "UVC-plant" after irradiation for samples between the air intake and the filter. Downstream of the filter the cfu levels are lower or equal to the cfu levels before irradiation. This is not the case for measurements done by medium DG18 in room #1 and #2 where the cfu levels are somewhat higher after irradiation than before.

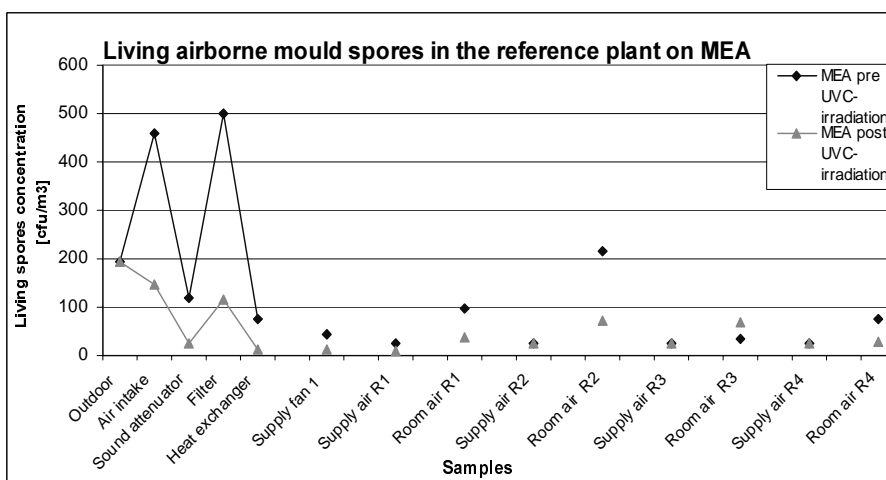


Figure 5. Reference plant with medium MEA

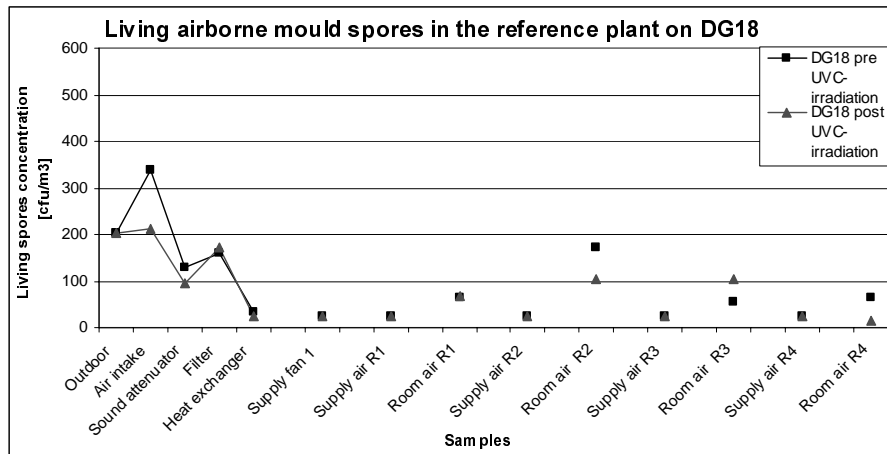


Figure 6. Reference plant with medium DG18

The cfu levels in the reference plant are lower in all samples after UVC-irradiation in the "UVC-plant" (sample day 2). This is not the case for measurements in room #3 where the level is higher after UVC-irradiation.

In most samples, species which are normal to find in indoor air like *Penicillium* and *Cladosporium* are dominant. Species which are somewhat rare to find in indoor air like *Stachybotrys chartrum* and *Aspergillus versicolor* are identified in some room air samples only.

Species identified in samples pre- and post UVC-irradiation do not differ significantly in the "UVC-plant" compared to the reference plant.

MVOC

Eight MVOCs (dimethyldisulphid, 2-pentanol, 3-methyl-1-butanol, 1-octen-3-ol, 2-hexanon, 2-heptanon, isobutanol and 1-butanol) and three other, often moist influenced VOCs (2-ethyl-1-hexanol, texanol and TXIB) were identified and quantified. For all samples VOC concentrations were lower than 0.1 ug/m^3 .

For measurements pre UVC-irradiation, the MVOC concentrations were in general found very low. The concentrations were not significant higher indoors than outdoors. The MVOC concentrations post UVC-irradiation were higher than normal in the outdoor air. The MVOC concentrations inside were not significant higher indoors than outdoors.

Settled spores

Results from the measurements of mould growth and living mould spores on surfaces are presented in table 1 and 2.

Table 1. Settled spores in the UVC-plant

Sample	Species pre UVC-irradiation (Measurement 1)	Comments	Species post UVC-irradiation (Measurement 2)	Comments
Air intake UVC-plant	<i>Botrytis cinerea</i> <i>Cladosporium</i> <i>Penicillium</i>	Heavy growth Mostly <i>Cladosporium</i>	No growth	
Pre filter UVC-plant	<i>Aspergillus versicolor</i> <i>Botrytis cinerea</i> <i>Cladosporium</i> <i>Penicillium</i>	Heavy growth Mostly <i>Cladosporium</i>	<i>Cladosporium</i>	Moderate growth Mostly <i>Cladosporium</i>
Post filter UVC-plant	No growth		No growth	
Air supply UVC 1	<i>Cladosporium</i> <i>Penicillium</i>	Moderate growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i> <i>Penicillium</i>	Minimal growth
Air supply UVC 2	<i>Botrytis cinerea</i> <i>Cladosporium</i>	Moderate growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i> Yeast <i>Penicillium</i>	Moderate growth. Mostly <i>Cladosporium</i>
Air supply UVC 3	<i>Cladosporium</i>	Heavy growth	<i>Cladosporium</i> <i>Penicillium</i>	Minimal growth
Air supply UVC 4	<i>Botrytis cinerea</i> <i>Chrysonilia sitophila</i> <i>Cladosporium</i> <i>Penicillium</i>	Heavy growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i> <i>Penicillium</i>	Moderate growth Mostly <i>Cladosporium</i>

The growth has decreased from heavy growth pre UVC-irradiation to minimal or no growth post UVC-irradiation on all the investigated surfaces. At end point ventilation terminal the growth has decreased less for 3 of the 4 places after UVC-irradiation, and at one sample point unchanged.

Table 2. Settled spores in the reference plant

Sample	Species pre UVC-irradiation (Measurement 1)	Comments	Species post UVC-irradiation (Measurement 2)	Comments
Air intake of the Ref	<i>Cladosporium</i>	Moderate growth	<i>Cladosporium</i> Yeast	Moderate growth Mostly <i>Cladosporium</i>
Pre filter Ref	<i>Cladosporium</i> <i>Penicillium</i>	Heavy growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i>	Heavy growth
Post filter Ref	No growth			Nearly no growth
Air supply Ref 1	<i>Botrytis cinerea</i> <i>Cladosporium</i>	Moderate growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i>	Minimal growth
Air supply Ref 2	<i>Botrytis cinerea</i> <i>Cladosporium</i> <i>Penicillium</i>	Moderate growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i> <i>Penicillium</i> Uidentifisert hvit	Moderate growth. Mostly <i>Cladosporium</i>
Air supply Ref 3	<i>Cladosporium</i>	Minimal growth	<i>Cladosporium</i> <i>Penicillium</i> Uidentifisert hvit	Minimal growth
Air supply Ref 4	<i>Botrytis cinerea</i> <i>Cladosporium</i> <i>Penicillium</i>	Moderate growth. Mostly <i>Cladosporium</i>	<i>Cladosporium</i> <i>Penicillium</i>	Minimal growth

The growth post filter has increased slightly from no growth at measurement 1 to some minimal growth at measurement 2. For some other sample spots the growth has decreased slightly from measurement 1 to 2. Beside this, the results are unchanged from measurement 1 to 2.

DISCUSSION

Living airborne mould spores

Due to the fact that UVC kills living mould spores on surfaces, it was investigated if this also gave an effect as a decreased concentration of living mould spore in the air in the "UVC-plant" after irradiation. For the reference plant, the concentrations were expected to be more or less unchanged pre- and post UVC-irradiation.

The results show that the concentrations of living airborne mould spores in the indoor air are low compared to the outdoor level in both of the ventilation plants - even before UVC-irradiation. After irradiation, the concentrations were at some places higher, at other lower or equal compared to the concentrations measured before UVC-irradiation. For the reference plant the levels of cfu/m³ are generally lower at all sampling sites, except downstream of the filter sampled with the medium MEA. However, this is not the case for medium DG18 at the same sample place. Because of this, it is suspected that this sample is biased.

Overall, no significant difference was discovered between the two ventilation plants, and the UVC-system seems to have had little effect on the concentration of living airborne mould spores.

Ideally, the velocity of any sampled air entering the nozzle should be equal to the local air velocity (so-called isokinetic sampling). In aggregates and ventilation ducts the isokinetic sampling is recommended (Pasanen, A.-L., 2001). Thus, other sample equipment like Air-O-Cell was considered. Air-O-Cell is claimed to be well suited for use in HVAC plants due to its capacity of isokinetic sampling. When sampling with Air-O-Cell, both dead and living fungal matter can be obtained. Dead microorganisms are suspected to have the same negative effect on IAQ as the living. Because of background fluctuations in the airborne spores, it was considered important to sample at as many parallel points as possible. Due to the changes in concentration of living airborne mould spores during a day, and from day to day, it is important to sample as simultaneously to get comparable results. Due to the required time sampling with Air-O-Cell, it was impossible to take as many samples as needed during a working day. Not measuring isokinetic, might bias the absolute results. The bias is considered most significant in the ducts due to the turbulence in the AHUs. However, this study analyze the relative change pre and post UVC-irradiation. The bias introduced by having none isokinetic measurements would be systematic and hence not bias any relative interpretation.

The cfu concentrations in ducts and room air were low even before UVC-irradiation. No significant changes were found after UVC-irradiation for ducts and rooms connected to the "UVC-plant" compared to ducts and rooms connected to the reference plant. The "UVC-plant" seems by this to have had no effect on the IAQ in regards to living airborne mould spores. However, due to the low concentrations before UVC-irradiation, a reduction in living airborne mould spores if heavily infested is not revealed.

The amount and species of living airborne mould spores in rooms will depend on the frequency window airing, the number of occupants and any other microbiological sources. The amount and species of living mould spores in room air can thus be significantly different from the supply ducts.

MVOC

The concentrations of MVOCs were low before UVC-irradiation in both of the ventilation plants. This was also the case after irradiation, which indicates that the "UVC-plant" didn't have any effect on

MVOCs, at least not at these low levels. Again, due to the low concentrations before UVC-irradiation, it is difficult to discover significant changes.

Settled spores

Due to the fact that the "UVC-plant" mainly kill microorganisms on surfaces, the great reduction in settled mould spores found on radiated surfaces in the "UVC-plant" was expected. Upstream of the UVC-irradiated filter the growth was found moderate but not zero as expected after irradiation. This can be explained by the "UVC-plant" not running all the time after UVC activation. The death-rate when killing mould spores by UVC depend on intensity of irradiation, spore concentration etc. and vary enormously for different species (Waipara, N.A., 1998). The reduction of the growth on the filter surface is however significant and hence the time in operation is assumed to be sufficient to investigate the effect of the irradiation. As expected, no significant change was seen in the reference plant. It was found a reduction in growth on surfaces in the ducts of the "UVC-plant" from pre to post UVC-irradiation. A similar small reduction was also observed on surfaces in the ducts in the reference plant, and hence the changes in the ducts might not be explained by UVC.

This study did not investigate health effects related to the UVC installation. However this is done in a Canadian study where they have investigated the feasibility of installing germicidal lights (GUV) in central ventilation plants. (Menzies, D., 1999). Our study is consistent with the Canadian in that no significantly difference in airborne bacteria and fungi pre and post UVC-irradiation was observed, but that microbiological pollution on surfaces had decreased. In regards to health effects no difference was discovered in the satisfaction ratings by the workers when the UVC-lights were on. The Canadian study concluded that it is feasible to install GUV lights in ventilation and air conditioning plants in offices without resulting in any adverse radiation effects on human.

In hospitals, UVC-systems have proven to be useful in decontamination of air and surfaces (Banrud, H., 1999). However it is important to use enclosed UVC sources because human exposure to UVC irradiation may cause damage to the skin and the eyes. (Banrud, H., 1999). Kill rates of microorganisms by using UVC-irradiation vary from organism to organism and is dependent on irradiation times (Sullivan, PK, 1999). In buildings at risk of terror attack by biological weapons, UVC-systems in the HVAC-installations is demonstrated to be a good preventive measure (Steril-air, 2001). However, the application of UVC in comfort ventilation systems is more questionable. UVC-systems is further proposed to be a suitable method for controlling energy and maintenance costs while achieving acceptable indoor air quality. (Young, D., 2000). Our study has shown that the UVC-system has limited effect on the IAQ. However, the results may be different in buildings where mould growth in the HVAC system is a problem. In buildings where the air intake leads to mould problems and where it can't be corrected by minor measures, UVC irradiation may be an alternative method to reduce the mould growth in the ventilation plant and thus prevent IAQ problems.

Mouldy supply filters may result in odor problems in a building (Ezeonu, I.M., 1994). In filter installations where mouldy conditions are difficult to avoid, UVC-irradiation of the filters may be an improvement by killing the microbes on the filter and by this prevent them in producing odoriferous volatiles.

CONCLUSION

Our investigation shows that the UVC-irradiation has no detectable effect on IAQ, in any case not to affect IAQ with respect to microbes in buildings where the concentrations of microbes are initially low. Hence, general recommendations to install UVC-systems in HVAC-plants are not justified. However

installation of UVC-lights in AHU upstream of filters may be useful in buildings having problems with mouldy filters, hence reducing mould growth and odoriferous volatiles.

ACKNOWLEDGEMENT

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