Indoor Air 1998; 8: 197–202
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INDOOR AIR
ISSN 0905-6947

Hygienic Aspects of Ground-coupled Air Systems

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Abstract Numerous ground-coupled air systems have been constructed in combination with heat recovery units in mechanically ventilated buildings in Switzerland. The objective of this study was to investigate the microbial content within these ventilation systems and to monitor the quality of the air supply. The concentrations and the types of microorganisms in the outdoor air, in the air of the pipes and in the supply air of twelve ground-coupled air systems were determined. In addition, three buildings were examined four times a year to cover seasonal changes. In general, the concentrations of fungal spores and bacteria in the air at the end of the underground pipes were lower than in the outdoor air, but great differences were observed between ventilation systems of large buildings and one-family houses. Occasionally, an increase in the concentration of *Penicillium*, *Aspergillus* or Actinomycetes was noted within a piping system. The concentrations in the supply air behind the filters were always low. Based on these investigations, the operation of ground-coupled air systems can be recommended as long as regular controls are undertaken and cleaning facilities are available.

Key words Indoor Air Quality; Microbial Contamination; Ground-coupled Air Systems; Ventilation.

Received 6 June 1997. Accepted for publication 23 February 1998.

Introduction

Many buildings with advanced energy concepts are equipped with mechanical ventilation. In Switzerland, ground-coupled air systems have been constructed in combination with heat recovery units in order to precondition the incoming air. In buildings of variable size and purpose (one-family houses, dwellings, commercial buildings) the incoming air is drawn through piping systems of plastic or concrete which are buried underneath the building or along the construction pit (Figure 1). The piping systems, with their collecting and distributing ducts, vary in size, design, pipe material and in the filter quality used in the heat recovery units (Table 1).

Since the relative humidity (RH) is very high and the temperatures are moderate within the pipes, concern has arisen regarding the hygienic aspects of ground-coupled air systems. Studies of conventional ventilation systems have demonstrated that microbial contamination has, in many cases, caused discomfort or adverse health effects (Ager and Tickner, 1983; Morey, 1988). The crucial factor for microbial proliferation within ventilation systems seems to be the water availability (Flannigan and Morey, 1996; Senkpiel et al., 1994). Provided that sufficient water is available on a surface, microorganisms are able to grow even at low temperatures and with low relative air humidity (Pasanen et al., 1991). Since condensation occurs and standing water was noticed in a number of pipe-systems microbial growth must be considered, especially since the dust accumulations inside the pipes present an adequate substrate.

In two one-family houses and one four-unit terrace house designed as low energy model buildings and equipped with ground-coupled air systems investigations of the content of microorganisms in the supply air and in the outside air have been carried out (Schneiders, 1994; Feist and Werner, 1994). However, ground-coupled air systems of large commercial buildings or piping systems older than three years have never been investigated before.

The aim of this study was to determine if microbial growth does occur in existing ground-coupled air systems of different ages and design and if the supply air might thus become contaminated with a

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Ground-coupled air systems consist of one or several buried pipes through which the supply air for a building is drawn. During the heating period, the solar energy stored in the ground preheats the outside air. In the summer, the lower ground temperature slightly cools the outside air.

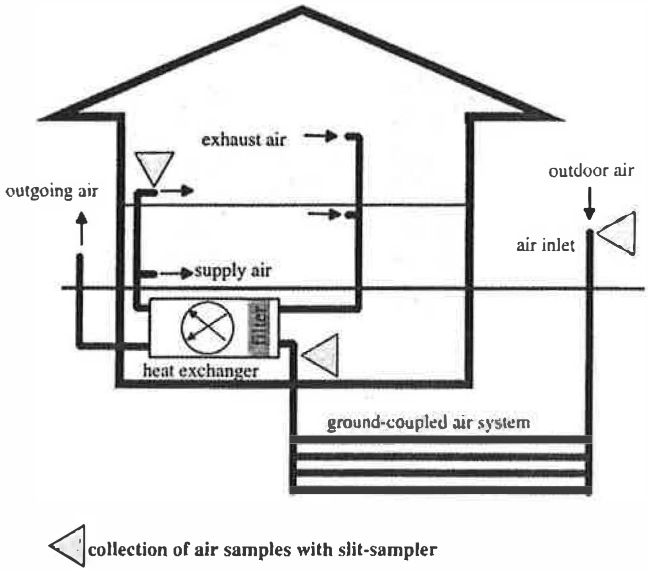

Fig. 1 Scheme of a ground-coupled air system with marked collection sites(◀)

concomitant risk for a health hazard. For this reason a cross-sectional investigation in different kinds of ground-coupled air systems as well as a one-year study in three selected buildings was carried out. Furthermore, these systems are between one and 13 years old and have different annual periods of operation.

Materials and Methods

Air sampling was conducted in twelve representative buildings with different ground-coupled air systems (Table 1) from January through October 1996. T twelve buildings were selected to represent whole spectrum in design, pipe material, size a age of all the ground-coupled air systems built Switzerland so far. Three of the buildings (D, E, were examined four times a year to monitor seaso differences. Air samples were collected in the o door air near the air inlet, in the air at the end of piping systems just in front of the filter units, and the supply air near the outlet employing slit sa plers. In some instances indoor air samples w taken in the centre of the unoccupied rooms. Samp were collected twice at each site in intervals of a f hours, starting with the first series early in the mo ing and continuing with the second at noon. C comitantly, relative humidity and air temperat were recorded.

Slit samplers (Casella, UK) with petri dishes w operated for 5 min at 30 l/min for the collection viable fungi and bacteria. Where required, access air ducts was established by connecting tub Fungal spores were sampled and cultivated on m extract agar and colonies were counted after incul tion for four days at room temperature and ide tified microscopically to genus level. Bacteria w sampled and grown at 30 °C for four days on tryp soy agar supplied with 10 mg/l Cycloheximid (F ka) to suppress fungal growth. Colonies w grouped according to morphology and transferred MacConkey agar to identify gram negative bacte Bacteria were microscopically grouped into ro cocci or Actinomycetes. Results were expressed

Table 1 Description of the investigated sites and systems (A–M). In building A the air is sucked through the draining facilities. Fil quality: coarse=EU3/4; fine=EU5/6

construction	A	B	C	D	E	F
building type	one-family	one-family	one-family	one-family	school	office
year of construction	1989	1995	1990	1994	1990	1993
air flow (m^3/h)	120	200	240	195	3500	8000–16000
air velocity (m/s)	1.9	0.2	0.9		3.5	1–2
number of pipes	1	12	15	9	5	20
length of pipes (m)	18	22	ca. 10	8	33	20
diameter (cm)	15	10	8	10	30	40
pipe material	cement	PVC	PVC	PE	cement	cement
filter quality	coarse	coarse	coarse	coarse	fine	fine
	G	**H**	**I**	**K**	**L**	**M**
building type	dwelling	dwelling	office	restaurant	food market	food market
year of construction	1994	1994	1989/90	1993	1983	1986
air flow (m^3/h)	855	2800	12000–17150	8500	26600	2500–15500
air velocity (m/s)	1.23	1.55		1.9	8	
number of pipes	4	1	43	30	7	14
length of pipes (m)	28	141	23		130	70
diameter (cm)	25	80	25	25	40	30
pipe material	PE	cement	HDPE	HDPE	HDPE	HDPE
filter quality	fine	coarse	fine	fine	fine	fine

colony forming units per cubic meter of air (CFU/m^3).

Results

Microorganisms in the outdoor air

The fungal and the bacterial concentrations in the outside air of the different buildings varied greatly (Figure 2). The local environment and the actual wind and weather conditions were important factors. The fungal spore concentrations varied also with the season (Figure 3). These results are in good agreement with a previous study conducted in the same region (Gubler, 1990). The average concentration was 130 CFU/m^3 during the winter months and reached a peak in summer with an average of 1400 CFU/m^3. Less fluctuation was noticed in the number of airborne bacteria. The lowest concentrations occurred in winter with an average of 103 CFU/m^3 and the highest during autumn and spring (mean concentrations: spring 160, summer 120, autumn 210 CFU/m^3).

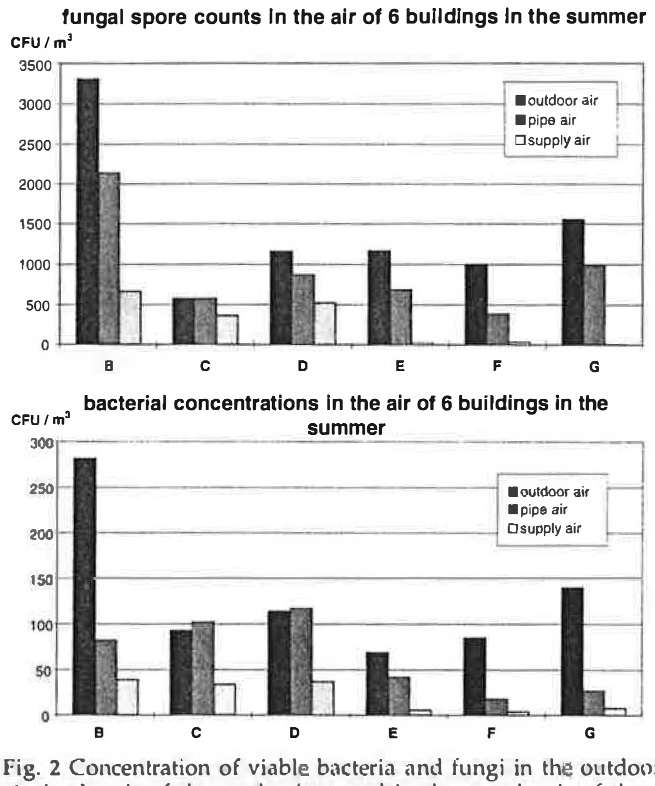

Fig. 2 Concentration of viable bacteria and fungi in the outdoor air, in the air of the earth pipes and in the supply air of three one-family houses (B, C, D) and three dwellings (E, F, G) with ground-coupled air systems in the summer (June, July). The reductions of the airborne concentrations from the beginning of the pipes to the end are clearly visible. The fine filters in building E, F, and G greatly reduce the germ concentrations, but also the coarse filters in buildings B, C, and D reduce the concentration of viable microorganisms

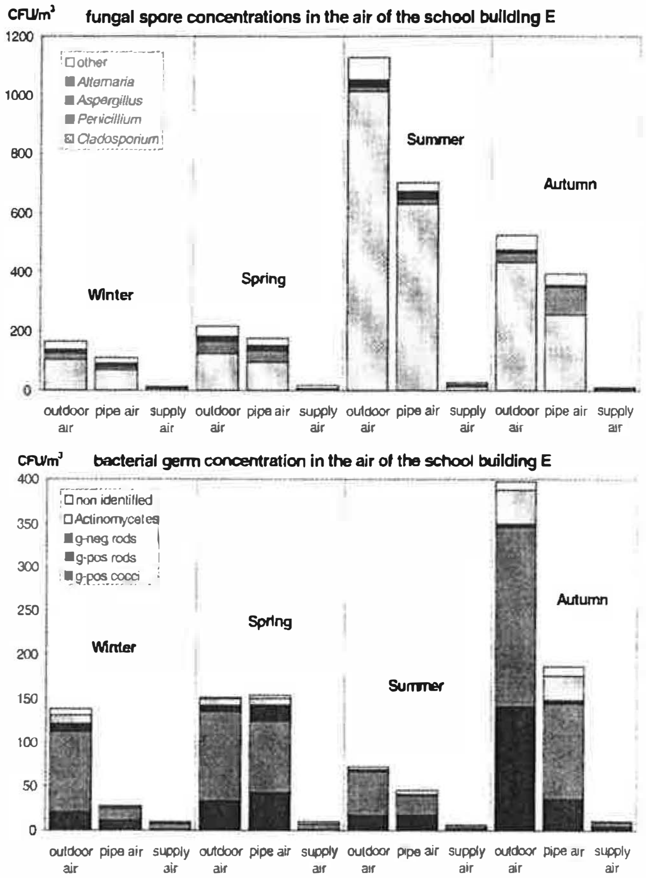

Fig. 3 Number of viable fungi of different genera and bacterial groups in the outdoor air, in the air of the earth pipes and in the supply air of building E at different seasons of the year 1996. *Cladosporium* is dominant in the outdoor air as well as in the supply air. Other fungal genera are in small concentrations *Penicillium*, *Aspergillus*, and *Alternaria*. Gram positive rods and cocci are the most important bacterial groups indoor and outdoors

Fluctuations within the pipes

In general, the concentrations of airborne fungal spores and bacteria after the passage through the underground pipes were lower than in the outdoor air. Table 2 shows the fungal and bacterial concentrations at the sampling points in a one-family house and a dwelling which have been investigated four times a year. The decrease in the number of viable airborne microorganisms differed greatly between systems of big buildings and one-family houses. In big ground-coupled air systems the reduction in microorganisms was much more pronounced and the concentration in the supply air was irrespective of the season and the outdoor concentrations. Moreover, the higher the volume of the air flow through the pipes the greater the reduction of the airborne microorganisms (Table 3). Occasionally, an increase in the concentration of a single fungal genus *(Penicillium, Aspergillus)* compared to the outdoor air was noted (Figure 3). In some one-family houses the bacterial concentration increased due to higher num-

Table 2 Bacteria and fungi in outdoor air, in the air of the pipes and in the supply air of the one-family house (D) and the dwel (G) which were investigated quarterly. The concentrations of microorganisms in the supply air are significantly lower than the outd air concentrations except for the bacterial concentrations in building D in winter

microbial concentrations		one-family house (D)				dwelling (G)			
	(CFU/m^3)	winter	spring	summer	autumn	winter	spring	summer	autum
bacteria	outdoor air	18	117	114	53	91	305	140	256
	pipe air	12	108	117	35	47*	69*	27*	144*
	supply air	8	22	37*	17*	24*	7*	8*	3*
fungi	outdoor air	89	724	1160	383	103	303	1557	596
	pipe air	72	810	871*	228*	56*	256*	982*	430*
	supply air	20*	338*	528*	115*	3*	9*	6*	6*

(all the concentrations are averages of ten successive samples)
*significantly lower concentration compared to the previous sampling point (two-tailed t-test; $p<0.05$)

bers of Actinomycetes (Figure 2 bacterial concentrations in buildings C and D). No differences were observed between piping systems made of plastic or of concrete/cement.

Effects of filter

The quality of the built-in filters greatly influenced the number of molds and bacteria removed from the air. The mold concentration was reduced 80–100% by fine filters and 40–80% by coarse filters. Bacteria were also partially retained, but the influence of the quality of the filters was not as pronounced. Fine filters removed as many as 50–100% of the bacteria, coarse filters 0–80%.

Room air quality

Since the supply air carried very few spores and no intramural sources of molds were present, the concentration in the indoor air was low compared to the concentration in the outdoor air. The bacterial concentration rised rapidly in the presence of human activities. The obtained concentrations in the indoor air of all buildings were low to intermediate according to a scale used in an European collaborative report (ECA, 1993).

Effects of air temperature and relative humidity

The ranges of relative humidity (winter: 40–6 spring: 60–90%; summer 50–100%; autumn: 65–8 and air temperature in the pipes (3–9°C; 8–17°C; 24°C; 13–17°C) seemed to have no influence on the duction of fungal spores in the air during the pass through the pipes. The decrease in the number spores in relation to outdoor air concentration similar throughout the whole year, which means deposition in the pipe-systems is substantially hanced in summer. On the other hand, the relative crease of bacterial germs shows a correlation to relative humidity. At 50 % RH the concentration of b teria is reduced by 50%. At 100% RH the bacte numbers at both ends of the piping system remai unchanged. The increases in Actinomycetes were ticed in pipe-systems of one-family houses with r tive humidity between 78% and 99% in spring, su mer and fall.

Influence of building age

No differences in the concentration of microorganis in the air of the pipes could be established betw ground-coupled air systems which were in use more than 5 or even 10 years and those recently c

Table 3 Reduction in percentages of the airborne microorganisms in the earth pipes and total reduction, after pipes and filters, in supply air compared to outdoor air for each building. For the buildings D, E and G, which were investigated four times a year, average reduction percentages are listed since there were no significant differences between the seasons. The standard deviation these buildings is included in parentheses

concentration reduction		one-family houses					dwellings, offices etc.						
	(%)	A	B	C	D	E	F	G	H	I	K	L	M
within the pipes	bacteria	11	29	6	18 (18)	36 (41)	76	63 (19)	57	59	69	40	[illegible]
	fungi	+30[a]	17	14	18 (21)	34 (6)	57	32 (12)	28	31	31	77	[illegible]
total reduction	bacteria	43	61	41	68 (10)	93 (1)	91	92 (11)	72	58	92	63	–
(pipe plus filter)	fungi	52	80	54	64 (11)	96 (2)	97	98 (1)	65	87	99	96	–

[a]increase in concentration noted

structed. However, a continuos development in the technical construction and design of such systems does take place.

Discussion

This study was carried out because of concerns that the air flowing through ground-coupled air systems could become contaminated by microorganisms which may proliferate within the pipe-systems. The results however demonstrate that, with few exceptions, the microbial concentrations even decreased after passage through the pipe-system and that the composition of the microflora basically remained unchanged. In some of the ducts the number of Actinomycetes, *Penicillium* or *Aspergillus* increased slightly during the passage through the ducts; this could indicate the presence of growth on the duct wall.

All of the investigated buildings are equipped with filters through which the preconditioned air has to pass and which further reduce the microbial content. The moderate temperatures and the high relative humidity in some of the pipe-systems (up to 100% RH in one-family houses in summer) might support microbial growth on the filters. Elixmann et al. (1989) as well as Martkainen et al. (1990) reported microbial growth on filters above 70% or 75% relative humidity. Kemp et al. (1995) observed microbial growth on loaded filters within a month of continuous exposure to 90% RH. However, other authors were unable to confirm these results on aerated filters (Ohgke et al., 1993). In addition, dust accumulation on filters and in HVAC ducts is known to enhance the possibility of fungal growth (Chang et al., 1996). A coarse filter at the air inlet as implemented in building F reduces not only the concentration of airborne microorganisms but also the accumulation of bioaerosols and dust inside the pipe-system. It can be concluded that ground-coupled air systems probably do not present hygienic hazards to human health and that together with built-in filters they provide good supply air quality as long as they are kept dry and clean.

In general, Schneiders (1994) and Feist and Werner (1994) showed similar results for the microbial concentrations of the supply air in residential houses equipped with ground-coupled air systems. None of the investigated buildings showed an increase in total bacterial or fungal counts in the supply air. This applies also for the present study. However, the identification of the fungal genera showed that even when the total number of spores decreased an increase in the concentration of one mould genus can occur. The same is true for bacteria and Actinomycetes. In the above mentioned studies, the supply air was investigated after the filter units. Since filters retain substantial proportions of microorganisms, we collected microorganisms also from the air within the pipes before the filters in order to obtain data of the microbial contamination of the ducts. In this way changes in the composition of the microflora in the air in the ducts compared to the number in outdoor air could be detected. Another potentially important factor is the size of the ground-coupled air system and the total airflow. In this respect great differences could be shown in our study between one-family houses and large commercial buildings which have collecting and distributing ducts between pipes forcing the air to flow around right angles and at lower velocity.

The low amount of airborne fungi in the supply air after passage through a ground-coupled air system is reflected in very low indoor air concentrations. The indoor/outdoor ratios are even lower than in some other mechanically ventilated buildings (Kodama and McGee., 1986; Reponen et al., 1989; Mouilleseaux and Squinazi., 1994). The occupants and their activities however are more decisive for the total bacterial counts in the indoor air than the bacterial concentrations in the supply air.

The fate of microorganisms deposited within the pipe-systems and absorbed on the filter screens has not been investigated. Degradation products and metabolites such as microbial volatile organic compounds (MVOCs) might be released from microorganisms (Bjurman et al., 1997; Wilkins et al., 1997) and cause adverse health effects (Mølhave et al., 1986) or contribute to the load on a filter, potentially causing sensory problems (Pejtersen, 1996). This, however, is a phenomenon noticed also within conventional ventilation systems.

Recommendations

Based on the results from twelve representative buildings the operation of ground-coupled air systems can be recommended as long as regular controls are undertaken and if accurate cleaning possibilities of all components are available. However, suitable measures should always be implemented in the construction, operation and maintenance of ground-coupled air systems:

- The **air inlet** should preferably be high above the ground and be placed away from bioaerosol sources. A screen may prevent the penetration of larger dirt particles and small animals. With a coarse filter at the air inlet dust and bioaerosol accumulation inside the pipes could be further reduced.

- The **pipes** should have a flat surface and an incline to let condensation water flow off. They should be buried in well-compressed ground to prevent partial subsiding.
- **Filters** should retain the spores of fungi like *Penicillium* and *Aspergillus* (diameter: 2–5 µm) which are most likely to be able to grow within the pipes.
- **Maintenance:** The ground-coupled air system and all other components of the ventilation should be controlled regularly. Air inlet, collecting and distributing ducts and especially ducts with ground water leakage as well as ventilation devices should be checked periodically. The pipes should also be checked for leakage of ground water. The filters should be washed or replaced when changes in air pressure are noticed.

Acknowledgements
The authors would like to thank all the people and companies located in the buildings investigated for their cooperation and the architects and engineers for their active involvement. This study and the comprehensive report were supported by the Swiss Federal Office of Energy (BEW) and the Department of Technical Facilities and Air Hygiene (ATAL), Canton of Zurich, Switzerland.

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