



Effect of air-conditioner on fungal contamination[☆]

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Abstract

Air-conditioners (AC) produce much dew and wet conditions inside their apparatus, when in operation. We studied the fungal contamination in AC and found that the average fungal contamination of AC filters was about 5-fold greater than that of a carpet, and *Cladosporium* and *Penicillium* were predominant in AC filters. The fungal contamination inside AC, which were used everyday, increased more markedly than those not used daily, e.g. a few days per week or rarely. Moreover, the airborne fungal contamination in rooms during air-conditioning was about 2-fold greater than one in rooms without AC, and was highest when air-conditioning started and decreased gradually with time. We recognized that the airborne fungal contamination was controlled by the environmental condition of the rooms, in which AC were used. It is suggested that AC might promote mold allergies in users via airborne fungal spores derived from the AC. On the other hand, AC was estimated to remove moisture in the room atmosphere and carpets, and reduce the relative humidity in rooms. It was found that the average fungal contamination in the house dust of carpets with AC was suppressed by two-third of that in rooms without AC. The use of AC for suppressing fungal hazards was discussed.

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1. Introduction

Fungal contamination is often found not only on the walls of household bathrooms and kitchens, but also in household electric machines such as dishwashers and washing-machines.

Recently, fungal contamination has become a health issue, where previously it was merely a source of unsightly dirt. Although the indoor environment, where we spend long hours each day, is very important for our health, there have been few studies on the relation between household fungal contamination and airborne fungal contamination. Among these, Hunter et al. (1988) reported on airborne fungal counts in rooms

where fungal contamination had been detected on the wall.

However, indoor air heavily contaminated by fungi was suggested to induce mold allergy and fungal disease (Al-Doory and Domson, 1984; Samson et al., 1994). The common fungi *Alternaria* and *Cladosporium*, as well as the xerophilic fungi *Aspergillus restrictus* and *Wallemia sebi* are well known as causes of fungal allergy (Tariq et al., 1996; Sakamoto et al., 1996).

In offices and factories, air-conditioning systems are essential to maintain a comfortable indoor environment, but are often contaminated with microbes, which they discharge into the indoor environment with strong air currents, causing fungal contamination of the air. A relation between bronchial asthma and fungal contamination by air-conditioning systems was reported previously (Banaszak et al., 1970; Hodgson et al., 1987). Bacterial, actinomycetial or fungal contamination in the humidifier component of air-conditioning systems has

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been reported to induce bronchial disease (Pickering et al., 1976).

In households, air-conditioners (AC) also produce much dew and humid conditions within the unit during operation. Fungal contamination of the air-conditioner filter, which the air current passes through, appears to distribute fungal spores throughout the atmosphere of the room. Sometimes an unpleasant smell or cough is experienced when the AC is switched on, which may be related to fungal contamination inside the AC.

Studies on the fungal contamination in AC and clarifying the cause promoting them are essential for controlling the air quality in rooms with AC and protecting AC users from mold allergy. The present study examined the fungal contamination in the filters of household AC and airborne fungal flora in air-conditioned cars.

2. Materials and methods

2.1. Collection of dust on filter

The fungal flora in the dust of AC filters in 49 households was examined. Sampling was performed at the end of August and the beginning of September following a filter cleaning in June.

Dust was collected using a vacuum cleaner applied for about 1 min to each filter. The filter was laid on a paper sheet after removal from the body of the AC and the hose of the vacuum cleaner applied to collect as much dust as possible. The dust sample was trapped using a commercial coffee filter or an experimental thimble filter (Advantec Co.).

Fungal contamination of house dust in carpets in the 49 households was also examined. Sampling of house dust was performed twice at the same time as sampling of AC filter dust in order to study the effect of air-conditioning on fungal contamination of house dust.

Two rooms, with and without AC, were examined in each sampling household. Two rooms similar in environmental location affecting humidity, for example floor level and room direction, were selected for comparison of house dust in the same dwelling. No significant difference was recognized between the average fungal concentration in house dust of carpets with and without AC in June. Moreover, inhabitants used each room in similar way and frequency regardless of the season, spring and summer.

AC, ranging 2.2–4.5 kW in cooling power, was used in rooms, ranging 9.9–23.1 m², and cooling power paralleled approximately to the area of room. No effect of the various manufacturer models and types of AC on fungal contamination of AC was detected.

2.2. Air sampling

Air sampling was performed in July in the passenger seat of 111 cars with an AC rather than in households. The car interior was considered a more appropriate environment for examination of airborne fungi derived from AC because airborne fungi in households may include those derived from house dust. It was suggested that the results obtained in cars would be similar to those from households.

Airborne fungi from car interiors were examined using an air-sampler (SY pin-hole air-sampler, Sanki Co.), which absorbs about 30 l of air per minute and blows it onto the agar of a petri-dish where all fungi are trapped under reduced pressure. Airborne fungi were collected for 2 min before the AC was switched on, and from 0–2, 4–6 and 8–10 min after switching on. The last sampling was performed after switching off. Sampling was performed 5 times per car.

2.3. Detection of fungi

The xerophilic fungi *Aspergillus restrictus* and *Wallemia sebi* are often found in AC, so DG18 (Dichloran-glycerol) medium was used for detection. Fungi generally grow more slowly on DG18 medium than on PDA medium, and the number of fungal colonies is quantifiable without overlapping (Hamada and Yamada, 1994). DG18 medium is convenient for establishing a fungal count in air samples, which are impossible to dilute.

Fungal contamination was expressed as fungal count per dust weight (CFU mg⁻¹) on the AC filter, or as fungal count per unit volume of air (CFU m⁻³) in car interiors.

3. Results

3.1. Fungal contamination in AC filters

The total fungal count in AC filter dust was about 1.3×10^5 per household on average. Households with greater than 1.0×10^6 fungi represented about 32% of those examined and those with greater than 1.0×10^7 about 14%.

The fungal count per weight of filter dust showed an exponential increase (Table 1). A level of greater than 10,000 fungi mg⁻¹ was detected in 9 of 49 households examined, with a maximum of 15,135 mg⁻¹. In these cases, one or two species of fungus predominated heavily, with *Cladosporium*, *Aspergillus* and *Penicillium* detected most frequently. The average fungal count per unit of filter dust was 452.6 mg⁻¹, and was between 3- and 5-fold higher than that in house dust, in which fungi grow well in the household.

Table 1
Distribution and average of fungal number in house dust and filter dust of air conditioner (AC)

Fungal numbers	House dust (without AC)		House dust (with AC)		Filter dust
	June	Aug.–Sep.	June	Aug.–Sep.	Aug.–Sep.
–10	5	4	3	3	5
10–100	21	17	27	29	11
100–1000	23	22	17	16	14
1000–10000	2	7	3	2	10
10000–	0	1	0	0	9
Total sample numbers	51	51	50	50	49
Average/mg	96.4	157.7	79.9	81.2	452.6
Avg $\pm$ S.E. (log)	(1.98 $\pm$ 0.09)	(2.20 $\pm$ 0.10)	(1.90 $\pm$ 0.09)	(1.91 $\pm$ 0.08)	(2.66 $\pm$ 0.16)
Ratio (A-S/J)		1.64*		1.02	

Sampling was performed twice in the former part of the peak AC use season (June) and in the latter part (Aug.–Sep.). Numbers in upper part of table indicate the number of sampling sites for each fungal count range. Asterisk (*) indicates a significantly different average between June and Aug.–Sep.

3.2. Fungal contamination of air in cars

A level greater than 1000 fungi m^{-3} was found in about 24% of cars examined and more than 2000 m^{-3} in 13%. The average airborne fungal count in summer was about 200 m^{-3} ; a level greater than 1000 m^{-3} , or 5-fold the normal value, was designated as fungal contamination in this study.

The change in airborne fungal count with duration of AC use was examined (Table 2). In the case of contaminated AC, the airborne fungal count was highest immediately after switching on, and decreased gradually with duration of use. For example, the average fungal count from 8 to 10 min after the start of use was about 23% of that from 0 to 2 min.

Airborne fungal count during the first use of the day was about 2.24-fold higher than before use, a significant increase; but during the second and later uses, the increase was only about 1.12-fold greater and was not significant.

Cladosporium and *Penicillium* were predominant both as the fungi discharged from AC and as those in AC filters.

3.3. Effect of moisture on fungal contamination

Fungal contamination in AC filter dust increased with the frequency of use (Table 3). The average number of fungi was 733.3 mg^{-1} in AC used every day in summer, but 85.1 mg^{-1} in those used rarely.

Similarly, the airborne fungal count immediately after switching on was 436 m^{-3} in AC used for more than 20 days during the summer, about 4-fold the 107 m^{-3} recorded in those not used during the summer (Table 4).

We examined fungal contamination in various parts of the AC filters (Table 5). The fungal count mg^{-1} of dust was 5.62-fold greater in the lower than in the upper

Table 2

Change in airborne fungal content during air conditioning

Time (min)	0–2	4–6	8–10
Ratio	1.00	0.39 $\pm$ 0.04	0.23 $\pm$ 0.04

Ratio is that of fungal number per m^3 of air to that recorded during the first two (0–2) minutes of AC operation.

parts, and the total fungal count in the lower parts was 16.6-fold greater than in the upper parts.

3.4. Relation of age of AC to fungal contamination

Fungal contamination of the filter was very low during the first year of use, and increased with age. The fungal count in the first year was one-fifth that at after 3 years.

The discharged fungal number was also smaller in new AC than in old models (Table 6). Average number of airborne fungi was 257 m^{-3} of air in the room in the first year, but 692 m^{-3} in the sixth year, a near 3-fold increase.

3.5. Circumstances affecting fungal contamination

The level of fungal contamination of filters differed significantly from floor to floor. Namely, fungal contamination of AC in first floor locations, which are more humid than second or higher floor locations, was greater (Table 7). For example, the fungal count in the first-floor filter was 454.7 mg^{-1} , about 5-fold greater than the 97.3 mg^{-1} for third-floor filters.

Fungal contamination in cars parked outside was significantly lower than in those parked under a roof. The average fungal number in cars with sunshine was 339 m^{-3} and that under shadow was 724 m^{-3} .

Table 3
Effects of frequency of AC use on fungal count in AC filter dust and house dust

Frequency		House dust (with AC)		Filter dust
		June	Aug.–Sep.	Aug.–Sep.
Every day	Average mg^{-1}	92.6	82.2	733.3
	Arg. $\pm$ S.E. (log)	1.97 ± 0.11	1.91 ± 0.10	2.87 ± 0.18
	Ratio (A-S/J)		0.89	
A few days/week	Average mg^{-1}	47.3	70.8	283.2
	Arg. $\pm$ S.E. (log)	1.68 ± 0.26	1.85 ± 0.15	2.45 ± 0.38
	Ratio (A-S/J)		1.50	
Rarely	Average mg^{-1}	76.5	91.1	85.1
	Arg. $\pm$ S.E. (log)	1.88 ± 0.18	1.96 ± 0.13	1.93 ± 0.50
	Ratio (A-S/J)		1.19	

Sampling of house dust was performed twice in the early season of peak AC use (June) and in the late season (Aug.–Sep.).

Table 4
Relation between fungal contamination and frequency of use

Used days	%	Avg. $\pm$ S.E. (log)	Average (m^{-3})
0	0	2.03 ± 0.16	107
1–20	33.3	2.78 ± 0.09	602
20+	22.2	2.64 ± 0.07	436

Days of use indicate number of days AC was used during the summer. Percentage of contaminated cars are those with greater than 1000 fungal spores per m^3 of air. Average of airborne fungi indicates the number during the first two (0–2) minutes of AC operation.

3.6. Fungal growth during periods of disuse

Filter weight before and after AC use was compared in order to calculate moisture increase (Table 8). Filter weight immediately after switching off was 5.5 mg less than before switching on. One hour later, the filter weight had increased by 4.9 mg. This effect was reinforced by applying a gauze to the filter, and that weight increase was 99 mg.

3.7. AC suppresses fungal contamination in house dust

The average fungal count in the house dust of rooms with AC was 81.2 mg^{-1} in the latter part of the peak AC use season, or about half that in rooms without AC, which was 157.7 mg^{-1} , although no difference was recognized between those in two rooms with and without AC in the former part (Table 1). Two rooms were similar in environmental location and were used similarly, regardless of season. No effect of various models of AC was recognized.

Moreover, the fungal count in house dust, unlike in AC filters, was reduced by high frequency of AC use (Table 3).

This effect was reinforced under humid conditions (Table 7). That is, unlike with filter dust, the fungal contamination in house dust was suppressed more significantly on the first than the third floor.

4. Discussion

4.1. Factors affecting fungal contamination of AC

Fungal contamination in AC filters distributed exponentially (Table 1). In AC filters with severe fungal contamination, the fungi were suggested to actually grow on the filter rather than simply alight and accumulate there.

More fungal contamination was found in AC used with higher frequency (Tables 3 and 4) and in lower parts of the AC filter, which absorbed more dew with dust (Table 5). These results support the idea that dew, produced by air-conditioning, promotes fungal contamination of the AC filter.

Humidity around AC as well as internally produced moisture thus appears to affect the levels of fungal contamination. A higher floor level and sunshine appear to dry the AC, and suppress fungal contamination (Table 7, Hamada and Yamada, 1994). Houses on a slope are more humid than those on flat land, and fungal contamination of AC in such households was also higher (Hamada, 2000). It is necessary to pay attention to environmental circumstances of use to control fungal contamination.

The weight increase of AC filters after switching off was suggested to result from moisture cooled by

air-conditioning (Table 8). In other words, accumulation of dust on the filter, as well as gauze applied to the filter, is suggested to promote moisture retention and growth of fungi. Filters are suggested to be dried by the strong air current of the AC fan during use, so that fungi grow best during intervals of disuse. Ozawa (1996) also reported that the number of fungi discharged by an AC out of use for 2 weeks was about 10-fold greater than with one out of use for 3 h. Thus fungi appear to grow during intervals of disuse.

Dirt, in addition to moisture, may be a factor of the fungal contamination. Dirt accumulates in various parts of the AC with length of use. Fungi find nutrients in this dirt and this may be the reason why fungal contamination increases with the age of the AC (Table 6).

In recent years, fungicides such as TBZ (Tiabendazole) have been applied to AC filters. This appears to be effective in new AC; and fungal contamination of the filter is very low. However, the effect has been shown not to continue for more than two years (Hamada and Yamada, 1993).

4.2. Drought of house dust by AC

Fungal contamination in house dust (of carpets) decreased by AC use, although that in AC filter

increased (Table 3). This suggests that AC absorb moisture inside rooms, and dry the air of rooms and house dust. As a result, fungal contamination was promoted inside the AC, but was suppressed outside it.

AC are suggested to discharge more fungi under humid conditions, but these fungal spores appear not to promote contamination of house dust. The main factor in the control of fungal contamination of house dust is suggested to be indoor moisture and not the number of airborne fungi, which are the origin of contamination.

Table 6
Relation between fungal contamination and car age

Age	%	Avg. $\pm$ S.E. (log)	Average (m^{-3})
0–1	11.1	2.41 ± 0.09	257
2–3	12.0	2.56 ± 0.09	363
4–5	25.0	2.80 ± 0.11	631
6+	48.3	2.84 ± 0.11	692

Percentage of contaminated cars are those with greater than 1000 fungal spores per m^3 of air. Average of airborne fungi indicates the number during the first two (0–2) minutes of AC operation.

Table 5
Comparison of fungal contamination between upper and lower parts of AC filters

	Upper half	Lower half	Ratio (Lower/Upper)
Dust weight	31.6 mg	93.3 mg	2.95
Avg. $\pm$ S.E. (log)	1.50 ± 0.20	1.97 ± 0.22	0.47 ± 0.12
Fungal count/Dust weight	263 mg^{-1}	1510 mg^{-1}	5.62
Avg. $\pm$ S.E. (log)	2.42 ± 0.20	3.18 ± 0.31	0.75 ± 0.38
Fungal count	8510	141000	16.6
Avg. $\pm$ S.E. (log)	3.93 ± 0.36	5.15 ± 0.44	1.22 ± 0.44

Each filter was divided into two parts and examined.

Table 7
Effect of AC floor location on fungal count in house dust and AC filter dust

Floor		House dust (with AC)		Filter dust
		June	Aug.–Sep.	Aug.–Sep.
1st	Average mg^{-1}	112.2	97.8	454.7
	Avg. $\pm$ S.E. (log)	2.05 ± 0.14	1.99 ± 0.12	2.66 ± 0.33
	Ratio (A–S/J)		0.87	
2nd	Average mg^{-1}	76.0	88.0	871.3
	Avg. $\pm$ S.E. (log)	1.88 ± 0.16	1.94 ± 0.13	2.94 ± 0.19
	Ratio (A–S/J)		1.16	
3rd +	Average mg^{-1}	42.2	44.4	97.3
	Avg. $\pm$ S.E. (log)	1.63 ± 0.17	1.65 ± 0.13	1.99 ± 0.24
	Ratio (A–S/J)		1.05	

Table 8
Change in filter weight after switching off

	Time lapse after switching off	Balance
Filter	0 min	–5.5 mg
	60 min	–0.6 mg
Filter with gauze	0 min	–77 mg
	60 min	+ 22 mg

Balance was obtained after comparing with weight of the filter before using AC.

4.3. Control of fungal contamination in AC

Cleaning is the simplest treatment for controlling fungal contamination of AC, because contaminating fungi on the filter can be removed together with dust by vacuum cleaning or by washing with water and detergent.

Fungal contamination of AC is found not only in the filter, but also in fan and heat exchanger (Abe, 1998). In the case of these parts, cleaning is difficult, because only professionals can access them. Their services should be engaged.

The number of fungi discharged from the AC is greatest immediately after switching on (Table 2). Similarly, Ozawa (1996) reported that the number of fungi discharged from the AC during the first 10 min of use is 10-fold greater than that during the 30–40 min use. Opening the window for about 10 min is therefore very effective to prevent human ingestion of fungal spores.

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