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Characteristics of indoor and outdoor bioaerosols at Korean high-rise apartment buildings

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Abstract

This study attempted to evaluate the bioaerosol exposure of apartment residents at high-rise apartment buildings in a Korean city. The characteristics associated with the bioaerosol exposure included the apartment floor, seasonal variation, summer survey period (seasonal rain-front period (SRFP) or no rain-front period (NRFP)), and room location inside an apartment. Four most prevalent fungal genera detected in both the indoor and the outdoor air were *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria*. The outdoor bacterial concentrations were significantly higher in the low-floor apartments than in the high-floor apartments. However, the bacterial and fungal concentrations in the interior air of the apartments were not significantly different between the low- and the high-floor apartments. The current bioaerosol concentrations were comparable to those in other reports, with geometric mean (GM) bacterial values between 10 and 10^3 CFU m^{-3} and fungal aerosol concentrations in homes ranging also from 10 to 10^3 CFU m^{-3}. The indoor and outdoor fungal concentrations and the outdoor bacterial concentrations were usually higher in the summer than in the winter. The indoor and outdoor bioaerosol concentrations were both higher for the SRFP than for the NRFP. The difference in the total bacterial concentrations was not significant among the surveyed five rooms. The GM total fungal and *Cladosporium* concentrations, however, were significantly higher for the kitchen than for the other rooms.

Keywords: Bacteria; Fungi; Fungal species; Apartment floor; Room location

1. Introduction

There has been a growing concern about exposure to microbial aerosols (bioaerosols) because of the related adverse health effects. Previous investigations have reported that exposure to large concentrations of airborne microbes is often associated with asthma and rhinitis (Beaumont, 1988), hypersensitivity pneumonitis (Siersted and Gravesen, 1993), sick-building syndrome (ACGIH, 1989; Dales et al., 1991), and a number of other health effects, including infections (Ren et al., 1999). Owing to their ubiquitous presence in nature, the presence of bioaerosols is inevitable in many microenvironments (Ren et al., 1999; Pastuszka et al., 2000; Górny and Dutkiewicz, 2002; Jones and Harrison, 2004). As such, the past decade has been characterized by a significant increase in the scientific database on residential exposure and occupational exposure to bioaerosols in many developed countries for the purpose of evaluating the relationship between exposure and health effects (Górny and Dutkiewicz, 2002). However, for Korea there is only a limited amount of information currently available on the residential exposure to bioaerosols, although there have been a few reports on certain nonresidential exposure to bioaerosols, such as exposure in hospitals and public facilities (Hong et al., 2003; Lee et al., 2004). Information on the residential exposure can contribute to a decision for the need of any mitigation strategies in the home.

Recently, many people in Korean urban areas prefer to live in high-rise apartment buildings. According to the Korea National Statistical Office, about 22 million people live in the eight largest cities and about 10 million of these live in high-rise apartment buildings (defined as apartment buildings with 10 or more stories). Consequently, the present study attempted to evaluate the bioaerosol

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exposure of apartment residents at high-rise apartment buildings in Daegu, the third largest city in Korea with a population of 2.5 million and density of 2812 people km^{-2}. About 1.1 million Daegu residents live in the high-rise apartments. This study focuses on viable bacteria and fungi, which exist in the airborne state as single cells or clumps (Pastuszka et al., 2000). The characteristics associated with the bioaerosol measurements included the apartment floor, seasonal variation, summer survey period (seasonal rain-front period (SRFP) or no rain-front period (NRFP)), and room location inside an apartment. A vertical variation in ambient bioaerosol concentrations has been reported by previous studies (Gruber et al., 1998; Jones and Harrison, 2004), and the ambient bioaerosols can penetrate into the apartments, influencing the indoor levels of bioaerosol. Accordingly, the high-rise apartment residents may be subjected to different exposure levels to bioaerosols according to the floor. However, until now this hypothesis has not been examined. It is further assumed that the two characteristics (seasonal variation and summer survey period) reflect the effects of relative humidity or temperature, which are important parameters for microbial growth (Jones and Cookson, 1983; Ren et al., 2001), on the residential microorganism levels. The household room location has also been suggested to be an important parameter for the residential bioaerosol levels (Li and Kendrick, 1995; Ren et al., 1999). As such, the present study focused on these characteristics associated with the bioaerosol exposure of apartment residents.

2. Methods

2.1. Survey protocol

The current study sampled airborne viable bacteria and fungi from the outdoor and indoor air of high-rise apartment buildings for two seasonal temperature extremes: winter, between December 15, 2002 and February 26, 2003, and summer, between June 8 and August 13, 2003. For each season, 40 apartment buildings were selected from the initial 45 apartment buildings where the residents granted permission to measure the bioaerosol levels. The surveyed residences were dispersed geographically throughout the city. A criterion for the selected apartments was as follows: the apartment buildings should be high-rise apartment buildings with 10 or more stories. The apartments were constructed with concrete and iron frames, and each residence was occupied by a single family with three to six persons.

As previously indicated, four characteristics associated with the bioaerosol measurements were examined. With regard to the floor height, one low-floor apartment (1st or 2nd floor) and one high-floor apartment (between 10th and 15th floor) were concurrently surveyed at each building. The same apartment buildings were used for both the winter and the summer measurements. The summer sampling was separately conducted for two survey periods (SRFP and NRFP). Five locations (living room, adult bedroom, child bedroom, bathroom, and kitchen room) were simultaneously or consecutively surveyed. The sampling from the kitchen room was done during normal cooking hours. The rooms were inspected for the presence of mold, and visible mold on the walls, ceilings, floors, or furniture was not detected. No residents declared that they live in moldy homes. The residents were further interviewed at the end of the 24-h air measurement period about factors that could be associated with household bioaerosol levels. Two homes have employed humidification appliances during nighttime, but not for sampling hours. No homes reported the use of a dehumidification system during any sampling period. There were four apartments having a pet(s) and all residents were classified as healthy. The residents were defined as healthy if they did not report any health complaints, although their health records were not inspected.

2.2. Sampling and analytical methods

Viable bioaerosol sampling was conducted using single-stage Anderson samplers with 400 0.25-mm holes, drawing air at a flow rate of 28.3 L min^{-1} (corresponding to velocity of 24 m s^{-1} (Jones et al., 1985). Indoor samples were collected in the center of each room at a height of 1.0–1.5 m above the floor during an afternoon period (nominally 3–8 pm). Outdoor air samples were collected outside the apartment porches right after indoor air sampling. Samplers were calibrated prior to and following the collection of each sample with a flow calibrator (DCL-H; Bios, Butler, NJ). The average of these two rates was then used as the sample flow rate for all volume calculations. No samples departed more than 10% from the initial flow rate during the study. During sampling, the temperature and relative humidity were recorded.

Each bioaerosol sample was nominally collected for 2 min, following Nevalainen et al. (1992), on nutrient media (specific to either fungi or bacteria) in petri dishes located on the impactor. Malt extract agar (MEA) and dichloran glycerol 18 agar (DG-18) were both applied for fungi, with chloramphenicol added to inhibit baterial growth. Trypticase soy agar (TSA) was used for bacteria, with cycloheximide added to inhibit fungal growth. The MEA, DG-18, and TSA plates were incubated at room temperature for 3–5 days, 5–7 days, and 2–3 days, respectively. The counts for the air sample plates were corrected for multiple impactions using the positive hole conversion method (Andersen, 1958) and reported as colony forming units per cubic meter of air (CFU m^{-3}). The genera of certain cultures of fungi were identified based on their micro- and macromorphological characteristics, using standard taxonomic keys (Atlas and Bartha, 1981).

2.3. Statistical analyses

The statistical analyses were performed using the SAS program (Version 8) on a personal computer. The Shapiro–Wilk statistical test was employed to evaluate the normality of the data, then the data were analyzed using a paired t test or a nonparametric test (Wilcoxon rank-sum test). The geometric mean (GM) and geometric standard deviation (GSD) were used to characterize the log-normally distributed data when this was indicated by the Shapiro–Wilk statistical test. The criterion for significance in the procedures was $P<0.05$.

3. Results and discussion

3.1. Bioaerosol occurrence

Regardless of the season, bacteria and fungi were detected (total counts $\geqslant 1$ CFU m^{-3}) in most of the indoor and outdoor samples. However, the occurrence of individual fungal species varied with the season and agar type (Table 1). The occurrence of 18 viable fungal genera was identified from the indoor and outdoor air at high-rise apartment buildings for two seasons (summer and winter). For most of the fungal genera, the occurrence level was usually higher in the summer than in the winter. Four most prevalent fungal genera detected in both the indoor and the outdoor air were *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria*, which is consistent with previous studies conducted in Denmark (Gravesen et al., 1986), the United

Table 1
Occurrence of viable fungi genera identified in indoor and outdoor air of high-rise apartment buildings for two seasons according to agar type[a]

Fungi	Season	% Occurrence			
		Indoor		Outdoor	
		MEA	DG18	MEA	DG18
Cladosporium	Winter	84	90	85	94
	Summer	88	94	94	98
Penicillium	Winter	70	74	70	75
	Summer	74	76	80	83
Aspergillus	Winter	34	75	40	70
	Summer	44	90	53	81
Alternaria	Winter	11	13	32	37
	Summer	17	22	34	38
Aureobasidium	Winter	ND	ND	3	ND
	Summer	9	6	8	13
Fusarium	Winter		ND		
	Summer	23	5	15	8
Paecilomyces	Winter		ND		
	Summer	11	3	13	8
Streptomyces	Winter	ND	37	16	19
	Summer	ND	39	3	23
Arthrinium	Winter	3	ND	3	ND
	Summer		ND		
Stachybotrys	Winter	3	ND	ND	ND
	Summer	ND	ND	ND	ND
Botrytis	Winter	ND	ND	6	ND
	Summer		ND		
Phoma	Winter		ND		
	Summer	6	ND	ND	ND
Mucor	Winter	ND	ND	6	ND
	Summer		ND		
Rhizopus	Winter		ND		
	Summer	6	ND	3	ND
Epicoccum	Winter		ND		
	Summer	ND	ND	ND	3
Pestalotia	Winter		ND		
	Summer	3	ND	5	ND
Exosporiella	Winter		ND		
	Summer	3	ND	ND	ND
Nigrospora	Winter		ND		
	Summer	ND	ND	3	ND

ND, not detected.
[a]Number of samples for each agar; $N = 38$ for winter-indoor; $N = 35$ for winter-outdoor; $N = 36$ for summer-indoor; $N = 36$ for summer-outdoor.

States (Ren et al., 2001), and Korea (Hong et al., 2003). The current paper focuses on these four major fungal genera, along with the total bacteria and the total fungi. For the other fungi, no reliable information was expected because of their low prevalence.

Moreover, the following reports only the values obtained on the DG-18 agar for the fungal concentrations, since for the total fungi and the individual fungal species, a higher CFU m^{-3} was usually found on the DG-18 agar than on the MEA (Table 2). Higher levels were found on the DG-18 agar than on to the MEA for the four major fungal species, revealing that the DG-18 agar produced better counts of the target fungal species. In particular, the occurrence of *Aspergillus* from indoor air for the winter period was more than two times higher on the DG-18 agar (75%) than on the MEA (34%). This pattern is consistent with the Ren et al.'s (2001) result. However, Ren et al. (2001) also reported significantly higher concentrations of total fungal concentrations on the MEA than on the DG-18 with means of 1034 and 846 CFU m^{-3} ($P < 0.0005$), respectively. Nonetheless, they asserted that the use of only DG-18 to collect fungal samples may still be adequate to represent the residential levels of those fungi that might be more directly related to health concerns, because the advantages of using one medium for sampling are that it can save time and be economical and practical. Moreover, it was known that the DG-18 agar slows growth of the faster-growing fungal taxa that sometimes obscure accurate counts of the slower-growing fungal taxa.

3.2. Indoor and outdoor bioaerosol at high-rise apartment buildings

The indoor and outdoor bioaerosol concentrations of high-rise apartment buildings according to floor are presented in Table 2. The indoor concentrations included only the living room data. The indoor concentrations of total bacteria, total fungi, and individual fungi species were all similar for the low- and high-floor apartments. One exception was that during the winter *Aspergillus* exhibited significantly higher indoor concentrations at the low-floor apartments than at the high-floor apartments. Unfortunately, all necessary information to explain this exceptional result was unavailable. However, the outdoor bacterial concentrations during both seasons were significantly higher in the low-floor apartments than in the high-floor apartments, whereas the outdoor fungal concentrations were still similar. One possible cause is that the soil surface would be a significant source of bacteria, since higher concentrations of bacteria were present when dust was raised (Jones and Harrison, 2004). Moreover, the variation of outdoor bioaerosol concentrations according to atmospheric height are closely related to local meteorological parameters such as turbulence and mixing height (Hirst et al., 1967). Mandrioli et al. (1983), who measured bioaerosol concentrations at heights from the ground to 6000 m, reported a similar decreasing trend with height in bioaerosol concentrations. However, Mandrioli et al. (1983) also found that, on another day under a different meteorological condition, a profile of culturable bacteria concentrations with height showed little variation. As such, the current variation in the bioaerosol concentrations according to apartment floor height might reflect the specific results obtained under a certain or combined local meteorological condition. Nonetheless, it was noted that, regardless of the floor, the high-rise apartment residents were similarly exposed to bacteria and fungi, because the bacterial and fungal concentrations in the interior air of the apartments, which the residents actually inhale at their

Table 2
GM indoor and outdoor concentrations of bioaerosols (CFU m^{-3}), temperature (Temp, °C), and relative humidity (RH, %) measured at low and high floors of high-rise apartment buildings according to season[a]

Bioaerosol/Temp/RH	Season	Indoor		L/H[b]	S/W[c]		Outdoor		L/H[b]	S/W[c]	
		Low	High		Low	High	Low	High		Low	High
Total bacteria	Winter	280	288	1.0	1.2	1.1	106	75	1.4[g]	2.1[f]	1.9[f]
	Summer	331	319	1.0			219	145	1.5[g]		
Total fungi	Winter	93	112	0.8	4.9[f]	4.3[f]	158	188	0.8	2.7	2.8[f]
(MEA)[d]	Summer	456	476	1.0			423	522	0.8		
Total fungi	Winter	155	154	1.0	3.0[f]	3.7[f]	154	203	0.8	3.9[f]	3.0[f]
(DG18)[e]	Summer	459	567	0.8			601	618	1.0		
Penicillium	Winter	42	47	0.9	1.2	1.1	43	36	1.2	1.1	1.2
(MEA)	Summer	49	50	1.0			46	44	1.0		
Penicillium	Winter	50	41	1.2	1.3	1.8[f]	41	42	1.0	1.2	1.5[f]
(DG18)	Summer	65	73	0.9			49	64	0.8		
Aspergillus	Winter	46	31	1.5[g]	1.2	1.2	23	29	0.8	1.3	1.2
(MEA)	Summer	54	46	1.2			31	35	0.9		
Aspergillus	Winter	70	40	1.8[g]	1.3	2.0[f]	36	35	1.0	0.9	0.9
(DG18)	Summer	88	78	1.1			40	38	1.1		
Cladosporium	Winter	44	45	1.0	2.7[f]	2.7[f]	95	85	1.1	1.4[f]	1.4[f]
(MEA)	Summer	119	121	1.0			129	122	1.0		
Cladosporium	Winter	56	50	1.1	2.2[f]	2.5[f]	105	102	1.0	1.4	1.5[f]
(DG18)	Summer	121	124	1.0			148	149	1.0		
Alternaria	Winter	17	13	1.3	1.5[f]	2.1[f]	12	10	1.2	2.4[f]	2.5[f]
(MEA)	Summer	25	27	0.9			29	25	1.2		
Alternaria	Winter	14	17	0.8	1.9[f]	1.4[f]	15	20	0.8	2.4[f]	1.5[f]
(DG18)	Summer	27	23	1.2			36	29	1.2		
Temp	Winter	21	21	1.0	1.3[f]	1.3[f]	7.6	8.2	0.9	4.1[f]	3.6[f]
	Summer	28	28	1.0			31	29	1.1		
RH	Winter	35	40	0.9	1.9[f]	1.8[f]	31	29	1.1	2.1[f]	2.3[f]
	Summer	68	73	0.9			64	68	0.9		

[a]Number of samples for each agar: $N = 19$ for winter-low; $N = 19$ for winter-high; $N = 17$ for summer-low; $N = 17$ for summer-high. For the Temp and RH, the arithmetic mean and standard deviation are presented instead of the GM and GSD values, respectively.
[b]Geometric mean concentration ratios of low-floor air to high-floor air.
[c]Geometric mean concentration ratios of summer air to winter air.
[d]Collected using MEA plate.
[e]Collected using DG-18 plate.
[f]Indicates that the data sets measured in two seasons were significantly different for the matched floor height at $P<0.05$.
[g]Indicates that the data sets of the low and high floors were significantly different at $P<0.05$.

apartments, were not significantly different between the low- and the high-floor apartments.

The indoor bacterial concentrations were significantly higher than the outdoor concentrations, while the indoor and outdoor fungal concentrations were similar (Table 3). Similarly, Scheff et al. (2000) reported that in a middle school of Springfield, Illinois, which had no known environmental problems, for total bacteria, the indoor concentrations (arithmetic mean (AM): science room, 561 CFU m^{-3}; art room, 811 CFU m^{-3}; lobby, 482 CFU m^{-3}; cafeteria, 460 CFU m^{-3}) were significantly higher than the outdoor concentrations (AM: 389 CFU m^{-3}). Moreover, Pastuszka et al. (2000) found that, in healthy homes of Upper Silesia, Poland, the indoor bacterial concentrations (GM: 1021 CFU m^{-3}) were significantly higher than the outdoor bacterial concentrations (GM: 671 CFU m^{-3}). Conversely, Scheff et al. (2000) also

Table 3
GM concentration ratios of indoor bioaerosol to outdoor bioaerosol according to floor height of high-rise apartment and season[a]

Bioaerosol	Floor height	Winter	Summer
Total bacteria	Low	2.6	1.5
	High	3.8	2.2
Total fungi (DG18)	Low	1.0	0.8
	High	0.8	0.9
Penicillium (DG18)	Low	1.2	1.3
	High	1.0	1.1
Aspergillus (DG18)	Low	1.9	2.2
	High	1.1	2.1
Cladosporium (DG18)	Low	0.5	0.8
	High	0.5	0.8
Alternaria (DG18)	Low	1.0	0.8
	High	0.8	0.8

[a]Number of samples: $N = 19$ for winter-low; $N = 19$ for winter-high; $N = 17$ for summer-low; $N = 19$ for summer-high.

found that the indoor fungal concentrations (AM: science room, 561 CFU m^{-3}; art room, 811 CFU m^{-3}; lobby, 482 CFU m^{-3}; cafeteria, 460 CFU m^{-3}) were significantly higher than the outdoor fungal concentrations (AM: 389 CFU m^{-3}). Hargreaves et al. (2003) reported also that in non-air conditioned homes of Brisbane, Australia, the outdoor fungal concentrations (AM: 1133 CFU m^{-3}) were significantly higher than the indoor fungal concentrations (AM in living room with normal ventilation: 810 CFU m^{-3}; AM in living room with normal ventilation: 692 CFU m^{-3}).

In contrast to the total fungi, for the individual fungal species, the concentration difference between the indoor and the outdoor air depended on the fungal species (Table 3). The indoor concentrations of *Cladosporium* and *Alternaria* were usually lower than the outdoor concentrations, whereas the result was reversed for *Aspergillus* and *Penicillium*, whose patterns are consistent with Ren et al.'s (1999) study. The elevated indoor concentrations of *Aspergillus* and *Penicillium* would be due to the potential indoor sources such as plants, soil, and planting activity (Li and Kendrick, 1995; Burge et al., 1982), whereas for *Cladosporium* and *Alternaria* the outdoor levels penetrated into the apartment interiors would be significant enough to outweigh the indoor sources strength. Meanwhile, it is noted that the present study has measured culturable fungi only. Thus, the indoor and outdoor concentrations of nonculturable fungi might exhibit a trend different from that of the current study.

The current bioaerosol concentrations are comparable to those in other reports, with GM bacterial values between 10 and 10^3 CFU m^{-3} (DeKoster and Thorne, 1995; Pastuszka et al., 2000) and fungal aerosol concentrations in homes ranging also from 10 to 10^3 CFU m^{-3} (Kuo and Li, 1994; DeKoster and Thorne, 1995; Li and Hsu, 1997; Pastuszka et al., 2000). However, the total fungal concentrations were much lower than those of a Taiwan home study (Su et al., 2001), which reported that average total fungal concentrations ranged from 10^3 to 10^4 CFU m^{-3} in nonasthmatic homes and in asthmatic homes. Moreover, the total fungal counts of the present study were not as high as the maximum during each season reported in other studies; for example, the research of Solomon (1976) in the US reported maxima of approximately 20,000 CFU m^{-3} and Pastuszka et al. (2000) reported maxima of almost 17,000 CFU m^{-3} in Upper Silesia, Poland.

3.3. Seasonal variation of bioaerosol concentrations

Table 2 also compares the GM bioaerosol concentrations in the indoor and outdoor air from the high-rise apartments for two seasons (summer and winter). The microbial concentrations in both the indoor and the outdoor air were usually higher in the summer than in the winter, except that there was no significant seasonal difference in the bacterial concentrations in the indoor measurements, regardless of the apartment floor height. The GM bacterial concentration ratio of summer to winter increased to about 2 for the outdoor air, while the GM total fungal concentration (on DG-18 agar) ratio of summer to winter was about 3–4 for both the indoor and the outdoor air. This seasonal trend is consistent with previous studies (Pastuszka, et al., 2000; Ren et al., 1999). The temperature and relative humidity measured along with the microbial measurements in the current study were significantly higher for the summer than for the winter. Typically, a higher environmental temperature and relative humidity favor microbial growth (Ren et al., 2001). Accordingly, it is suggested that the temperature and relative humidity were important factors causing the seasonal difference in the current microbial concentrations. Meanwhile, regardless of the season, the outdoor GM concentration order of individual fungal species was *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria* in a descending order. However, this order is not the case for the indoor air concentrations. The GM indoor air concentration of *Aspergillus* was the highest during the winter and the second highest after *Cladosporium* during the summer.

3.4. Bioaerosol concentrations during SRFP and NRFP

The summer sampling was separately conducted for two survey periods (SRFP and NRFP). Table 4 compares the bioaerosol concentrations in the indoor and outdoor air for the two summer survey periods. For both the total bacteria and the total fungi, the indoor and outdoor air concentrations were both higher for the SRFP than for the NRFP. The SRFP/NRFP ratios were 1.9 and 2.2 in the indoor air and 1.4 and 3.9 in the outdoor air for the total bacteria and total fungi, respectively. Similarly, the relative humidity was significantly higher for the SRFP (75% for both the indoor and outdoor air) than for the NRFP (68% and 61%

Table 4
GM bioaerosol concentration (CFU m^{-3}), temperature (Temp, °C), and relative humidity (RH, %) measured during seasonal rain-front period (SRFP) and no rain-front period (NRFP) according to sample type (indoor and outdoor sample)[a]

Bioaerosol/Temp/RH	SRFP		NRFP	
	Indoor	Outdoor	Indoor	Outdoor
Total bacteria	427(3.4)	218(3.7)	224(3.0)	153(3.4)
Total fungi (DG18)	675(1.7)	959(1.4)	313(2.7)	245(2.5)
Penicillium (DG18)	74(1.7)	65(2.4)	61(2.4)	52(2.0)
Aspergillus (DG18)	87(2.1)	40(1.6)	80(3.2)	35(2.1)
Cladosporium (DG18)	153(2.3)	173(1.7)	93(3.1)	126(3.6)
Alternaria (DG18)	27(1.6)	31(1.5)	25(1.7)	32(2.4)
Temp	26(1.1)	26(2.0)	29(1.6)	32(3.4)
RH	75(11)	75(8.3)	68(7.0)	61(11)

[a]Number of samples: $N = 12$ for SRFP-indoor; $N = 12$ for SRFP-outdoor; $N = 22$ for NSRFP-indoor; $N = 22$ for NSRFP-outdoor. For the temperature and RH, the arithmetic mean and standard deviation are presented instead of the GM and GSD values, respectively. Values in parentheses are GSD.

for the indoor and outdoor air, respectively), whereas the temperature was similar (Table 4). As such, the current findings support the previous assertion that a higher relative humidity favors microbial growth (Ren et al., 2001). However, for the individual fungal species, the difference between the two periods depended on the fungal species. *Cladosporium* and *Penicillium* exhibited significantly higher indoor and outdoor air concentrations for the more humid period, SRFP, than for the NRFP, while the indoor air concentrations of *Alternaria* and *Aspergillus* did not differ significantly between the two periods. These findings are also supported by Ren et al.'s (2001) study, where the indoor air concentrations of *Cladosporium* and *Penicillium* were found to be highly associated with the relative humidity and those of *Alternaria* and *Aspergillus* were not.

3.5. Bioaerosol concentration in different locations inside apartments

Five locations (living room, adult bedroom, child bedroom, bathroom, and kitchen room) inside apartments were simultaneously or consecutively surveyed during both the winter and the summer. The in-apartment bacterial and fungal concentration distributions are summarized in Table 5. Regardless of the room location, the GM indoor total fungal concentrations were usually significantly higher in the summer than in the winter, whereas the GM indoor total bacterial concentrations were similar. The difference in the total bacterial concentrations was not significant among the surveyed five rooms for both seasons, at the GM values between 284 and 465 CFU m^{-3} for the winter and between 326 and 449 CFU m^{-3} for the summer. The GM total fungal and *Cladosporium* concentrations, however, were significantly higher for the kitchen than for the other rooms, but there were no significant differences among the other rooms. Since the kitchen samplings were conducted during periods of food preparation, the elevated fungal levels at kitchens appear to be due to the food handling activities. This assertion is supported by Lehtonen et al. (1993), who noticed that washing vegetables and other food handling activities could increase spore counts by several times. On the other hand, Li and Kendrick (1995) reported that the fungal concentrations were higher for the bathrooms than for the bedrooms, mainly due to the dampness in the bathrooms, which is not consistent with the current finding. For the present study, there was no significant difference in the fungal concentrations among the rooms except the kitchen room or in the relative humidity among all the rooms. Similarly, neither the relative humidity nor the temperature measured in this study differed significantly among the rooms for each season. Human activities can also precede retrieval of significantly higher concentrations of airborne fungal spores by resuspending settles fungal spores by air movements caused by them (Buttner and Stetzenbach, 1993). Buttner and Stetzenbach (1993) reported that the airborne fungal concentration was higher in the living rooms than in the bedrooms, primarily due to more activity occurrences in the living rooms. However, there was no significant difference in the current total fungal concentrations between the living rooms and the bedrooms, and there were no significant human activities in the surveyed rooms, except the cooking activity in the kitchen room.

Table 5
GM bioaerosol concentrations (CFU m^{-3}) at different locations inside apartments during winter and summer[a]

Bioaerosol	Location	Winter	Summer
Total bacteria	Living room	284(2.2)	326(3.2)
	Adult bedroom	383(2.7)	358 (2.8)
	Child bedroom	377(2.4)	341(2.6)
	Bathroom	465(2.4)	449(2.9)
	Kitchen	430(2.2)	423(2.5)
Total fungi (DG18)[e]	Living room	155(3.3)	503(2.7)
	Adult bedroom	176(4.2)	500(2.8)
	Child bedroom	150(2.7)	550(1.7)
	Bathroom	179(3.5)	450(2.5)
	Kitchen	576(3.2)	663(1.9)
Penicillium (DG18)	Living room	47(3.3)	70(2.2)
	Adult bedroom	63(4.1)	65(3.1)
	Child bedroom	34(2.5)	67(2.3)
	Bathroom	57(3.8)	59(2.5)
	Kitchen	51(3.0)	53(2.3)
Aspergillus (DG18)	Living room	59(3.7)	83(2.8)
	Adult bedroom	62(4.1)	72(3.6)
	Child bedroom	55(2.9)	55(2.3)
	Bathroom	58(3.1)	44(2.7)
	Kitchen	56(4.3)	64(2.1)
Cladosporium (DG18)	Living room	52(2.6)	123(2.9)
	Adult bedroom	47(3.3)	174(2.6)
	Child bedroom	53(2.6)	239(2.1)
	Bathroom	39(2.0)	163(2.5)
	Kitchen	156(3.1)	331(2.2)
Alternaria (DG18)	Living room	15(1.0)	25(1.6)
	Adult bedroom	11(1.0)	19(1.1)
	Child bedroom	10(1.1)	22(1.4)
	Bathroom	12(1.2)	25(1.6)
	Kitchen	13(1.1)	29(1.8)

[a]Number of samples: $N = 38$ for winter-living room; $N = 34$ for summer-living room; $N = 24$ for winter-adult bedroom; $N = 27$ for summer-adult bedroom; $N = 29$ for winter-child bedroom; $N = 14$ for summer-child bedroom; $N = 38$ for winter-bathroom; $N = 34$ for summer-bathroom; $N = 28$ for winter-kitchen room; $N = 24$ for summer-kitchen room. Values in parentheses are GSD.

4. Conclusions

The present study found that three (seasonal variation, summer survey period, and room location inside an apartment) of four parameters influenced the bioaerosol exposure of apartment residents at high-rise apartment buildings, whereas the other parameter (apartment floor) did not. The indoor and outdoor fungal concentrations and the outdoor bacterial concentrations were usually higher in

the summer than in the winter. The indoor and outdoor bioaerosol concentrations were both higher for the SRFP than for the NRFP. The GM total fungal and *Cladosporium* concentrations were significantly higher for the kitchen than for the other rooms. The outdoor bacterial concentrations were significantly higher in the low-floor apartments than in the high-floor apartments. Nonetheless, it was noted that the low- and the high-floor apartment residents were similarly exposed to bacteria and fungi, because the bacterial and fungal concentrations in the interior air of the apartments, which the residents actually inhale at their apartments, were not significantly different.

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