

# Indoor and outdoor pollen concentrations in private and public spaces during the *Betula* pollen season

Timo Hugg · Auli Rantio-Lehtimäki

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**Abstract** Although the number of studies of pollen concentrations inside and outside buildings is increasing, little is known about the efficiency of penetration of pollen from outdoor to indoor air, and further. We studied indoor and outdoor pollen concentrations in the town of Lappeenranta and in the municipality of Rautjärvi in SE Finland from May 3–23, 2004, i.e. throughout the *Betula* pollen season, and assessed the risk of exposure to pollen grains. Pollen concentrations were measured inside and outside a block of flats, a detached house, and the regional central hospital, using rotorod-type samplers; in the town of Joutseno data were compared with Burkard counts. Outdoor concentrations of *Betula* pollen grains ranged between low and abundant (0–855 grains m<sup>-3</sup>). The corresponding indoor concentrations near the main front doors varied from low to moderate (0–17 grains m<sup>-3</sup>) in the central hospital and were low (<10 grains m<sup>-3</sup>) in both residential buildings. Indoor concentrations further from the main front door were low (<10 grains m<sup>-3</sup>) at all study sites. The concentrations of *Betula* pollen decreased substantially from outdoors to indoors, and further toward the centre of the building, probably

indicating relatively poor penetrating properties of the pollen grains and/or the short-lived presence of pollen grains in indoor air. The concentrations of *Betula* pollen inside the buildings during the peak flowering period were mostly at a level barely inducing reactions even in the most sensitive persons.

**Keywords** *Betula* · Exposure · Indoor air · Outdoor air · Pollen grain · Rotorod sampler

## Abbreviations

rpm Rotations per minute  
I/O Indoor/outdoor  
SD Standard deviation

## 1 Introduction

The prevalence of atopic diseases has increased during the last few decades in Finland (Haahtela et al. 1980; Rimpelä et al. 1995; Huurre et al. 2004). The current prevalence of allergic rhinitis among the Finnish population is estimated as 15–25% (Rimpelä et al. 1995; Remes et al. 1998; Huurre et al. 2004). Birch (*Betula*) pollen is regarded as a major cause of seasonal allergic reactions in Finland and other Scandinavian countries (D'Amato et al. 1998; Rasmussen 2002; Moverare et al. 2005). It is

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T. Hugg  
South Karelia Allergy and Environment Institute,  
Joutseno, Finland

T. Hugg (✉) · A. Rantio-Lehtimäki  
Department of Biology, University of Turku, Turku  
20014, Finland  
e-mail: Timo.Hugg@dnainternet.net

estimated that 10–15% of Finns are allergic to *Betula* pollen (Kilpeläinen et al. 2002; Vartiainen et al. 2002). In Finland, three species of birch tree (*Betula pendula*, *B. pubescens* and *B. nana*) are common throughout the country as a mixed forest tree, and birch-dominated forest covers approximately 7.6% of the total land area (Korhonen et al. 2006).

Although long-distance-transported birch pollen, mainly originated from South Scandinavia, Russia, Byelorussia, Poland, Germany, and the Baltic countries (Sofiev et al. 2006) can be detected from the end of March, the flowering period of local birches is usually in May in South and Central Finland, where millions of pollen grains are released by each catkin (Taylor et al. 2004). During the first two weeks of May, daily mean values of 2,000–10,000 pollen grains per cubic metre of air are observed at roof level (The Finnish Pollen Bulletin Summary 2005). The greatest number of pollen grains is released and recorded in the afternoon and evening, but numerous pollen grains can be found throughout the day during the peak days of pollination (Käpylä 1984; Rantio-Lehtimäki et al. 1991a; Clot 2001). Pollen grains  $18\text{--}26 \times 21\text{--}30 \mu\text{m}$  in size are dispersed efficiently by air movement (Nilsson et al. 1977; Hjelmroos 1991).

The outdoor environment is the main source of indoor pollen. Airborne pollen grains are believed to pass indoors through air shafts, open windows, and doors. Particles can also be carried in by occupants or pets. Because people spend plenty of time in different indoor spaces and pollen allergens may retain their potency until the next season in dry conditions (Yli-Panula and Ahlholm 1998), it is important to analyse and control pollen concentrations inside buildings. Although the number of studies of pollen concentrations inside and outside different types of building is increasing, little is known about the efficiency of penetration of pollen from outdoor to indoor air and further (Sterling and Lewis 1998; Cariñanos et al. 2004; Lee et al. 2006). We have studied indoor and outdoor pollen concentrations in private and public spaces throughout the *Betula* pollen season and assessed the risk of exposure to pollen grains. The effect of meteorological conditions on pollen concentrations was also studied, and the relationship between regional pollen data collected by use of a Burkard sampler and local pollen data collected by use of a rotorod-type sampler was assessed.

## 2 Materials and methods

### 2.1 Study areas

The study was conducted in the town of Lappeenranta ( $61^{\circ}04' \text{ N}$ ,  $28^{\circ}1' \text{ E}$ ) and in the municipality of Rautjärvi ( $61^{\circ}27' \text{ N}$ ,  $29^{\circ}09' \text{ E}$ ) in SE Finland from May 3–23, 2004 (Fig. 1). Lappeenranta is the centre of the South Karelia region, with 60,000 inhabitants, and Rautjärvi, with 4,000 inhabitants, is located approximately 80 km north-east of Lappeenranta.

The study areas, located between the Baltic Sea and the Eurasian continent, have the characteristics of both maritime and continental climates. The mean annual temperature is approximately  $5.5^{\circ}\text{C}$  and mean precipitation is between 600 and 700 mm. Both study areas are temperate coniferous-mixed forest partly surrounded by vegetation composed of birch trees 10–71 cm in diameter measured at breast height.

### 2.2 Rotorod data collection and sample analysis

Pollen concentrations were measured inside and outside the three buildings by use of rotorod-type samplers (Rantio-Lehtimäki et al. 1992). The samplers were equipped with a U-shaped metal rod (1.7 mm in diameter) and a power source (battery: Yuasa Corporation VdS No. G101094). Transparent



**Fig. 1** Map of the study area. The locations of rotorod measurement sites are indicated by numerical codes: 1 block of flats, 2 central hospital, 3 detached house. The location of the meteorological station (*Ms*) is shown by an open square and the location of the Burkard sampler (*Bu*) in Joutseno by an open triangle

Melinex tape coated with an adhesive (Vaseline; <http://www.polleninfo.org/>) was fixed to the upper ends of the rods. The speed of rotation of each sampler was monitored with an Ebro Electronic (Ingolstadt, Germany) DT 2234 digital tachometer to ensure correct performance. The average speed of rotation of the arms was 2,369 rpm, varying between 2,273 and 2,537 rpm. Because different results were obtained from the two ends of the U-shaped rods, mean values calculated for the two ends were used for analysis. Measurements were conducted in two residential buildings, a ground-floor apartment in a block of flats in the town of Lappeenranta and a detached house in the municipality of Rautjärvi, and in the regional central hospital in the town of Lappeenranta. The characteristics of the buildings are summarised in Table 1.

The Rotorod sampler is regarded as appropriate for indoor/outdoor sampling because the effects of wind speed and orientation have been shown to be relatively small and the efficiency of collection of particles of pollen size by the device is good (Solomon et al. 1980a; Frenz 1999, 2000). Samplers were placed in front of the main door (outdoor samples), in the hall/entrance hall (near the main front door; Indoors I) and in the living room/entrance hall (further away from the main front door; Indoors II) at a height of 1.4 m, corresponding to the average inhalation height. Owing to the sampling height used the samplers can be assumed to collect particles mainly from local sources (Local pollen data; O'Rourke and Lebowitz 1984).

Distances between the outdoor sampling sites and the main front doors of the buildings were 10 m for the detached house, 7 m for the block of flats, and 15 m for the central hospital. Sampling sites were selected so there were no major obstacles impeding free circulation of air in the vicinity of the site. Because of ventilation requirements, simulating late spring ventilation habits, and the more efficient penetration of pollen, all ventilation windows were kept open at the residential sites during the measurement period. All ventilation windows of the detached house were equipped with pollen filters (Stoppari pollen filter, Talotekniikka Oy, Oulu, Finland), those in the block of flats with window lattice and mosquito net. The frequency of opening of main front doors was also recorded.

To minimise problems with oversampling (Sterling and Lewis 1998) sampling periods were restricted to 30 min in the afternoon or evening (between 15:00 and 20:00). Measurements were performed so that indoor sampling ( $N = 14$ – $15$ ) was conducted immediately after outdoor sampling ( $N = 13$ – $14$ ) at each site. Outdoor measurements were conducted under rainless conditions only and stopped when it started to rain. Normal activity and movement of residents, customers, or personnel were not restricted during the measurement period.

After each 30-min period sampling tapes were detached and mounted on slides with Gelvatol (<http://www.geocities.com/>) under a cover glass. Before analysis samples were stored at room temperature in dust-proof preservation sheets for microscope slides. Pollen concentrations were determined by systematic sampling of microscopic fields and counted from the tapes under  $400\times$  magnification with an optical microscope (Leitz Wetzlar, Germany). A single transect line from the middle of the sample, comprising 21% of the total sampling area, was examined. Rotorod pollen measurements were converted to volumetric equivalents expressed as the concentration of pollen grains per cubic metre of air sampled (grains  $\text{m}^{-3}$ ; Raynor 1972).

### 2.3 Burkard data collection and sample analyses

As part of the Finnish pollen information network (The Finnish Pollen Bulletin Summary 2005), daily regional pollen counts were measured throughout the pollen season with a Burkard seven-day volumetric sampler (Burkard Manufacturing, Rickmansworth, Hertfordshire, UK; Hirst 1952). The sampler was located on the roof of a 19-m high building, 119 m above sea level, in the town of Joutseno ( $61^{\circ}18' \text{ N}$ ,  $28^{\circ}41' \text{ E}$ ). Because of the sampling height used the sampler can be regarded as collecting particles mainly from regional sources (Regional pollen data; O'Rourke and Lebowitz 1984). The average rate of air suction of the sampler was  $10 \text{ L min}^{-1}$ . Airborne particles were trapped on Melinex tape coated with Vaseline and attached to a clockwork device rotating at 2 mm per hour. The hourly particle content of the air could therefore be calculated. Tape strips were cut into pieces, each 48 mm length corresponding to one day's sampling.

**Table 1** Summary of characteristics of the buildings and the weather conditions during the sampling period

Building characteristics	Central hospital (entrance hall)	Apartment in block of flats	Detached house
Year of manufacture	1954	1990	1990
Number of floors	7 (mean)	3	1
Number of rooms (kitchen included)	–	4	4
Height of rooms/corridors (cm)	245	250	248
Total area/area of entrance hall (m <sup>2</sup> )	397	69.5	75
Living volume/volume of entrance hall (m <sup>3</sup> )	973	174	186
Hall (m <sup>2</sup> )	–	7.5	5
Living room (m <sup>2</sup> )	–	17	17
Heating system	CH	CH	CH
Ventilation system	MVEIA	MVEA	Gravitational
Distance to nearest birch tree (m)	50	40	10
Distance to nearest street (m)	40	15	500
Number of residents	–	4	3
Number of pets	–	–	1 (dog)
Average frequency of cleaning	6×/week	0.5×/week	1×/week
Number of ventilation windows (on the ground floor)	6	3	4
Height from the ground to lower edge of ventilation window (cm)	201 (mean)	157 (mean)	143 (mean)
Area of a ventilation window (cm <sup>2</sup> )	6,663 (mean)	2,860	2,220
Average opening times of ventilation windows (min/day)	0–1,440	120	1,440
Ventilation windows equipped with pollen filters	3/6	0/3	4/4
Number of front doors	2	2	2
Area of a main front door (cm <sup>2</sup> )	42,000	18,000	18,180
Average opening frequency of main front door (x/30 min)	41	3	2
Mean indoor/outdoor air temperature during the measurements (°C)	22.3/14.9	24.0/14.1	24.1/15.3
Monthly mean air temperature (°C; May)	9.7 (at Lappeenranta airport)		
Monthly mean precipitation (mm; May)	33 (at Lappeenranta airport)		
Number of totally cloudy days (coverage >80%)	7	6	5
Number of partly cloudy days (coverage 10–80%)	6	7	3
Number of clear sky days (coverage <10%)	1	1	6

CH, central heating; MVEIA, mechanical ventilation of exhaust and incoming air (filters included); MVEA, mechanical ventilation of exhaust air

These were mounted on slides with Gelvatol under a cover glass.

Pollen concentrations were determined by random sampling of microscopic fields (60 per day) comprising 2.3% of the total sampling area, and counted from the tapes using an optical microscope (400×; Mäkinen 1981). Sampling method, slide preparation, and data interpretation were performed according to standard methodology adopted by the Finnish pollen

information network and following the principles of the European Aeroallergen Network (<http://www.polleninfo.org/>). Pollen concentrations were expressed as a daily mean of pollen grains per cubic metre of air (grains m<sup>-3</sup>) and classified as low, moderate, or abundant (Viander and Koivikko 1978; Rantio-Lehtimäki et al. 1991b). The distance between the Burkard sampler and the rotorod-type sampler study sites was approximately 40 km.

## 2.4 Dust samples

Dust samples ( $N = 96$ ) were collected in the living room, bedroom, kitchen, and hall of both homes. The samples were taken from the surfaces of floors, floor laths, radiators, curtains, window sills, the window frames of ventilation windows, and doorsteps. Using the sticky tape method (Holopainen et al. 2002), two-sided tape (Scotch, 12 mm  $\times$  6.3 m, 3 M USA) was pressed against the sampling surface and ripped away. Pollen grains adhered to the surface of the tape. Using a slide preparation method similar to that used for rotorod sampling, pollen grains were counted under an optical microscope (400 $\times$ ). Ten longitudinal traverses with 204 microscopic fields comprising 10.8% of the total sampling area were examined. The dust-sample measurements, indicative of sedimentation of dust during the longer time periods, were expressed as the number of pollen grains per square centimetre (grains cm<sup>-2</sup>).

## 2.5 Meteorological data

Weather conditions, including the daily mean air temperature and mean wind speed were recorded in parallel with the measurements, using information from a digital thermometer (Thermometer Fabriken Viking Ab, type No. 194) and from the closest meteorological station, at Lappeenranta Airport (61°02' N, 28°10' E). Mean wind speed was expressed as a mean wind velocity recorded over a period of ten minutes from 15:00–15:10. The thermometer probe was placed close to the rotorod-type sampler and temperatures were recorded at the beginning and end of each measurement period. The mean temperatures were calculated and taken into consideration. The distance between the pollen samplers and the meteorological station varied from 5 to 80 km (mean 42.5 km). Cloudiness was also estimated at the moment of measurement and classified as totally cloudy, partly cloudy, or clear sky.

## 2.6 Statistical methods

The Spearman statistical test (correlation coefficients) for nonparametric data was used to evaluate the relationship between regional Burkard and local rotorod pollen data and between indoor and outdoor concentrations of pollen and the relationship between

daily airborne pollen measurements and meteorological conditions. The Wilcoxon Signed Rank test ( $S$ ) for nonparametric data was used to compare the indoor-to-outdoor (mean I/O ratio) and indoors I-to-indoors II ratios of pollen. The Wilcoxon 2-sample test for nonparametric data was used for paired comparison. The results are regarded as significant at  $P < 0.05$ . Statistical analysis was performed with the SAS statistical package (SAS Institute, Cary, NC, USA). Average values are reported as arithmetic means.

## 3 Results

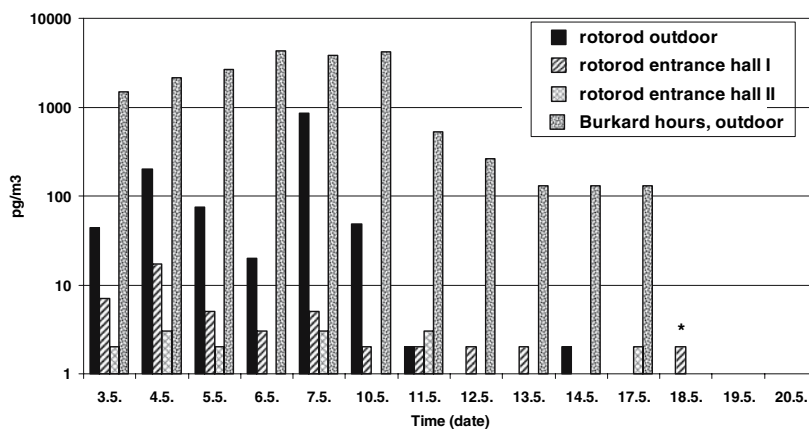
Outdoor concentrations of *Betula* pollen grains ranged from low to abundant at the central hospital (0–855 grains m<sup>-3</sup>; Fig. 2) and block of flats (0–131 grains m<sup>-3</sup>) and from low to moderate at the detached house (0–20 grains m<sup>-3</sup>; Table 2). The corresponding concentrations near the main front door (Indoors I) varied from low to moderate in the central hospital (0–17 grains m<sup>-3</sup>) and were low in both the block of flats (0–7 grains m<sup>-3</sup>) and the detached house (0–3 grains m<sup>-3</sup>). Concentrations further from the main front door (Indoors II) were low at all study sites (0–3 grains m<sup>-3</sup>).

Mean I/O ratios ranged from 0.04 (Indoors I) to 0.01 (Indoors II) in the central hospital, from 0.05 (Indoors I) to 0.04 (Indoors II) in the block of flats, and from 0.16 (Indoors I) to 0.22 (Indoors II) in the detached house (Table 2.). Differences between paired indoor-to-outdoor comparisons of pollen concentrations were significant for all study sites ( $S = -33$  to  $-18.5$ ;  $P = 0.001$ – $0.031$ ). Indoor-to-indoor (Indoors I compared with Indoors II) differences, in contrast, were significant at the central hospital only ( $S = -27.5$ ;  $P = 0.014$ ).

There was no statistical difference between indoor concentrations of *Betula* pollen in the apartment and in the detached house equipped with pollen filters. The mean indoor concentrations were 1.2 (SD 2.1) compared with 1.1 grains m<sup>-3</sup> (SD 1.2; Indoors I) and 1.1 (SD 1.2) compared with 1.5 grains m<sup>-3</sup> (SD 1.2; Indoors II). Positive relationships were observed between rotorod and Burkard data and between pollen concentrations and daily mean temperature (Table 3).

The numbers of *Betula* pollen grains on the indoor surfaces were higher in the less frequently cleaned

**Fig. 2** Indoor and outdoor concentrations of *Betula* pollen grains (grains  $m^{-3}$ ) in the central hospital during the measurement period, 2004. <sup>1</sup>Burkard hours, values measured at 14:00–16:00. Asterisks—because of rainy weather the outdoor rotorod value was not measured



**Table 2** Mean indoor and outdoor *Betula* pollen concentrations, with standard deviations (SD), and indoor/outdoor ratios at the study sites during the measurement period

Study site	Rotorod (outdoor/SD)	Rotorod (indoors I/SD) <sup>a</sup>	rotorod (indoors II/SD) <sup>b</sup>	Burkard (hours/SD)	I/O ratio(Indoors I/II)
Central hospital <sup>c</sup>	95.9/234.8	3.4/4.5	1.1/1.3	1,423.0/1,700.1	0.04/0.01
Block of flats <sup>d</sup>	24.8/37.4	1.2/2.1	1.1/1.2	951.8/1,196.4	0.05/0.04
Detached house <sup>d</sup>	6.8/7.7	1.1/1.2	1.5/1.2	888.3/1,178.8	0.16/0.22

<sup>a</sup> Hall, entrance hall I

<sup>b</sup> Living room, entrance hall II

<sup>c</sup> Burkard hours, values measured from 14:00–16:00

<sup>d</sup> Burkard hours, values measured from 16:00–18:00

apartment in the block of flats than in the more frequently cleaned detached house (Table 1). Within the study sites the numbers of pollen grains were higher in close proximity to ventilation windows (window frames) and/or places cleaned less frequently. Data for dust samples collected from the indoor surfaces are summarised in Table 4.

## 4 Discussion

### 4.1 Summary of the results

Concentrations of *Betula* pollen decreased significantly from outdoors to indoors and further when

windows were open, probably indicating relatively poor penetration efficiency and/or short presence of pollen grains in indoor air. The concentrations of *Betula* pollen inside the buildings during the peak flowering period were usually at a level unlikely to cause reactions even in the most sensitive persons (Viander and Koivikko 1978). Indoor concentrations followed outdoor concentrations, and mean I/O ratios ranged from 0.01 to 0.22. There was no difference in the concentrations of *Betula* pollen in indoor air of residences with and without pollen filters. Numbers of *Betula* pollen grains on indoor surfaces were higher in the less frequently cleaned residence than in that more frequently cleaned.



**Table 3** Spearman correlation coefficient between rotorod *Betula* pollen counts outdoors and other rotorods and Burkard *Betula* pollen counts and meteorological conditions ( $N = 13-14$ )

	Rotorod (indoors)			Meteorological conditions			
	Rotorod (outdoor)	Rotorod (indoors I) <sup>a</sup>	Rotorod (indoors II) <sup>b</sup>	Burkard	Temperature (°C) <sup>c</sup>	Wind speed (m s <sup>-1</sup> ) <sup>d</sup>	Cloudiness (0–3)
Central hospital <sup>e</sup>		0.79300 **	0.58607*	0.84337*** <sup>f</sup> /0.77942**	0.71602**/0.66790*	-0.22340 NS	-0.07636 NS
Block of flats <sup>f</sup>		0.64163*	0.45491 NS	0.54958 NS/0.61785*	0.78391**/0.71754**	0.16917 NS	-0.04391 NS
Detached house <sup>f</sup>		0.44476 NS	0.17434 NS	0.85754*** <sup>f</sup> /0.67965*	0.55684*/0.52066 NS	0.17032 NS	0.03581 NS

<sup>a</sup> Hall, entrance hall I

<sup>b</sup> Living room, entrance hall II

<sup>c</sup> Daily mean temperature/temperature at the time of measurement

<sup>d</sup> Mean wind speed recorded over a period of ten minutes and measured at 15:00–15:10

<sup>e</sup> Daily mean Burkard value/Burkard value during the measurement period (14:00–16:00)

<sup>f</sup> Daily mean Burkard value/Burkard value during the measurement period (16:00–18:00)

\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ , NS = Non-significant

## 4.2 Validity of results

Because of the sampling methods, the limited number of measurements and study sites, the different building types, and the distance between the study sites, the results should be interpreted with caution. The stationary sampling methods used in this study do not directly reflect the amount of potentially inhaled particles and actual risk of exposure (Lee et al. 2006), but Riediker et al. (2000) observed a positive relationship between personal and a stationary samplers. Pollen grains act as carriers of allergenic material, and pollen counts may include pollen grains devoid of allergens and thus may not represent a true allergen load (Schäppi et al. 1997). Good agreement between numbers of pollen grains and the allergen concentration in outdoor air has been observed previously, however (Schäppi et al. 1997).

Although environmental conditions and pollen concentrations can vary substantially between measurements near the ground (rotorod) and at house-roof level (Burkard) and although the distance between samplers was substantial, there was good agreement between rotorod and Burkard data, in agreement with results from a previous study (Frenz 1999), and the distance between samplers is in accordance with previously estimated sample areas covered by a Hirst-type (Burkard) sampler (Comtois and Cagnon 1988). The good agreement between our indoor and outdoor rotorod measurements also increases the reliability of the results. Because of the distance between the pollen samplers and the weather station, however, the results, particularly correlation of daily mean temperature and wind speed with pollen count in the single family house in Rautjärvi should be interpreted with caution.

Dust sample results ought to be interpreted as indicative, because the sampling efficiency of the sticky tape method was not 100% (Holopainen et al. 2002). Sequential sampling was used instead of simultaneous sampling because of the apparent lag in indoor penetration by pollen grains. Sequential sampling might reflect the relationship between indoor and outdoor pollen more accurately than simultaneous sampling.

## 4.3 Comparison with previous knowledge

Pollen grains enter a home by infiltration, through open windows and doors, and can be carried in by

**Table 4** Summary of data for dust samples collected from the indoor surfaces of the apartment and house at the end of the study (Ntot. = 96)

Dust sample site	The number of <i>Betula</i> pollen grains per cm <sup>2</sup>	
	Apartment (23.5.2004) (N = 49)	Detached house (20.5.2004) (N = 47)
Floors	2–65	0–4
Floor laths	2–70	0–21
Doorsteps	2–11	– <sup>a</sup>
Radiators	0–8	– <sup>a</sup>
Curtains	0–11	0–34
Window sills	6–124	8
Window frames <sup>b</sup>	255–2,926	0–99

<sup>a</sup> Not measured

<sup>b</sup> Of ventilation windows

occupants and pets. The penetration and presence of pollen and pollen allergens are affected by a combination of factors, including the pollen itself, geographic location, weather, season, and the characteristics of the home and its occupants (Sterling and Lewis 1998; Fahlbusch et al. 2001). In particular, factors such as outdoor temperature, air-exchange rate, ventilation system, cleaning methods and frequency, and the number and activity of the occupants are important determinants of the indoor concentration of pollen grains and pollen allergens (Sterling and Lewis 1998; Holmquist and Vesterberg 1999; Fahlbusch et al. 2001). Although the distance between sampling sites was substantial and there were differences between the ventilation systems and the types of building at the study sites, indoor pollen concentrations at the study sites at the time of the measurements were quite similar (Tables 1, 2). This could be partly explained by national building standards and regulations, which standardise indoor conditions, such as air flow, irrespective of building type, and the location in Finland (ME 1987/2003). Because of the substantial difference between indoor and outdoor temperatures (Table 1), the air exchange rate was probably high enough to ensure sufficient ventilation and the possible penetration of pollen grains.

The observation that pollen grains were found in higher concentrations outside than inside is consistent with previous studies (O'Rourke and Lebowitz 1984; D'Amato et al. 1996; Cariñanos et al. 2004). The low indoor-to-outdoor ratios observed are also in accordance with previous findings (Stock and Morandi 1988; Lee et al. 2006). According to Lee et al. (2006), indoor concentrations of pollen in urban homes

ranged from 1 to 5 grains m<sup>-3</sup> whereas outdoor levels ranged from 1 to 1234 grains m<sup>-3</sup>. Low I/O ratios could be partially explained by the size of the pollen grains. Because of the moderate size of the particles (20–60 µm), only a small fraction of pollen grains penetrate from outdoors to indoors, especially when doors and windows are closed and the ventilation system is equipped with filters (Solomon et al. 1980b).

Despite the highest cleaning frequency, the highest indoor concentrations of pollen were observed in the central hospital, which had the highest frequency of door opening and a large door. Similarly, D'Amato et al. (1996) observed the highest indoor pollen concentrations when a door was open during the pollen-production season. The indoor-to-indoor (Indoors I vs. Indoors II) difference observed in the central hospital could be explained by the relatively high penetration efficiency of pollen in a situation where large doors (outer and inner doors) were opened at the same time and with high frequency (Table 1). Although the pollen grains probably behave in a similar manner in indoor spaces of different size, because of the relatively high gravitational settling velocity of pollen, the highest numbers are found close to entrances. It seems obvious there is more room for variation in the quantities of pollen grains between sites in larger indoor spaces, for example the entrance hall in the central hospital, than in smaller spaces for example rooms in residential buildings.

Movement of pollen grains should be entirely prevented by the pollen filters (filter class EU5) used in the detached house (Seppänen 1994), and partially prevented by the ventilation window lattice and



mosquito net used in the apartment in the block of flats. The results of our study indicate that, irrespective of pollen filters and other preventive structures, low to moderate pollen concentrations could be found in indoor air. Although numbers of pollen grains were highest in dust samples in close proximity to ventilation windows (Table 4), owing to the relatively high gravitational settling velocity of pollen and lack of air movement, concentrations of pollen grains decreased rapidly in indoor air (O'Rourke and Lebowitz 1984; Lee et al. 2006). Because of the settling velocity of pollen and mostly relatively poor air flows inside homes, the suitability of rotorod samplers for measurement of numbers of pollen grains in indoor air should be the subject of critical discussion and research.

An activity like cleaning by the occupants can increase indoor concentrations of particles larger than 2.5  $\mu\text{m}$  (Jones et al. 2000), and also concentrations of pollen grain size classes (Stock and Morandi 1988). The current result suggest that frequent cleaning of indoor surfaces reduces the number of particles of pollen size, but it does not eliminate them.

Holmquist and Vesterberg (1999) observed higher concentrations of pollen allergens in a room occupied by active children than in a room with not so active children. In this study air movements induced by an active puppy could explain the higher mean concentration of pollen in the living room than in the hall in detached house. Interestingly, differences between concentrations of pollen in the indoor air in the apartment in the block of flats and the detached house were not pronounced, although the numbers of pollen grains were higher on the surfaces in the apartment in the block of flats (Table 4). This result reveals the importance of occupant activity as a factor affecting indoor concentrations of pollen but, in contrast with the study of Sterling and Lewis (1998), normal activity, for example walking, within the home did not lift settled pollen grains back into the air. Ultimately, the relationship between the turbulence and velocity of the air and the adhesion force of deposited pollen determines the concentration of pollen in indoor air.

According to Yli-Panula and Ahlholm (1998), the antigenic activity of birch and grass pollen in the dust remained high throughout the study period of one year, although activity was highest during the birch pollen period. In relatively stable and dry indoor

conditions it is reasonable to assume that the antigenic activity of intact pollen grains in indoor dust remains for longer than it does outside under more variable conditions. A proportion of the allergens of submicron size classes ( $\leq 1 \mu\text{m}$  in diameter; Rantio-Lehtimäki et al. 1994) indoors could be generated in the ventilation system by processes by which intact pollen grains are moistened, dry out, and subsequently easily break down into smaller particles (Solomon et al. 1980b; Taylor et al. 2004). Despite, probably, losing their allergenic potential at least partly during the process, these fractions of particles might penetrate the filtration system into the indoor air. In contrast, particles penetrating directly through doors and windows, which do not become moist during dry weather, settle and retain their structure as an allergenic particle.

In accordance with the current results, positive correlations between indoor and outdoor pollen concentrations (Stock and Morandi 1988; Lee et al. 2006) and between outdoor pollen concentrations at different altitudes (Cariñanos et al. 2004) has previously been observed. According to Sterling and Lewis (1998) up to 67% of the indoor pollen in mobile homes could be explained by outdoor pollen concentrations. A positive relationship between pollen concentrations and daily mean temperature has also been observed previously (Puc and Wolski 2002).

## 5 Conclusions

This study revealed that the concentrations of *Betula* pollen decrease from outdoors to indoors and further toward the centre of the building, probably indicating relatively poor penetration efficiency and/or the short-lived presence of pollen grains in indoor air. Irrespective of pollen filters and other preventive measures, low to moderate pollen concentrations were found in indoor air. More studies are needed, however, to evaluate the significance of different pathways of pollen grains and benefits of different preventive structures in ventilation systems. Concentrations of *Betula* pollen inside the buildings during the flowering period were usually at a level barely inducing a reaction even in the most sensitive persons.

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