CLEANING REDUCES PERSONAL EXPOSURE OF OFFICE STAFF BY TENS OF PERCENTS

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ABSTRACT
Office cleaning is reported to reduce surface and airborne concentrations of PM10 and biocontaminants, and is associated with a reduction in health complaints. It is believed that the lower airborne contaminant levels lead to reduced personal exposure, which could explains the health effects. No data on personal exposure were available, to our knowledge.

We have assessed personal exposure using a particle monitor based on Mie-scattering in a controlled office environment. The obvious dust resuspension by some office activities (document filing, the act of sitting down) was reduced if not nullified by targeted cleaning of files and chairs. Also, thorough office cleaning including vacuuming and damp wiping was able to reduce personal exposure with 25 to 50%, which is consistent with reported data on concentration reductions and health effects.

INDEX TERMS
Cleaning, personal exposure, respiratory particles, biocontaminants, PM10

INTRODUCTION
Evidence is mounting that cleaning improves indoor environmental quality (IEQ) and therefore improves health of the persons working, studying or living there (Mendell and Heath 2005, Daisy et al 2003). This results in reduced absenteeism and improved productivity, which should provide a healthy incentive for professional cleaning.

Cleaning is proven to reduce the surface concentrations of biocontaminants, including bacteria, moulds, endotoxins and allergens of animals (Table 1 and references). Resuspension of particles increases linear with surface concentration (Nicholson 1988; Thatcher and Layton 1995). Thus, indoor air concentration of biocontaminants also fall after cleaning, as is indeed observed in several cases (Table 1), even though the concentrations are difficult to determine and show large temporal and spatial variations (*e.g.* Hines et al. 2003; Munir et al. 2003).

Lower airborne concentration are expected to lead to lower personal exposure, in particular because human activities bring the contaminants into the air (Nicholson 1988, Luoma and Batterman 2001). Reduced personal exposure can result in improved health, in particular when biocontaminant concentrations were high before cleaning. Concentrations have been found in offices and schools that supersede the lower limits for health effects, at least in sensitive individuals. Cleaning is shown to reduce concentrations below such limits (Adilah et al 1997; Franke et al 1997) and is shown to reduce the number of health complaints in a number of cases (Table 1).

Table 1. *Selected literature data on effects of cleaning interventions*

Cleaning intervention	reduction of indoor contaminant concentration on surface	in air	reduction in health complaints
Daily versus weekly carpet vacuuming	60-75% [a]	80% [b]	20-30% [b, c]
Carpet spray-extraction at 70°C	50% [d, e]	50% [e]	35-45% [f]
Daily versus weekly floor cleaning	unknown	unknown	20% [c]
Daily versus weekly table cleaning	20% [g]	unknown	10-20% [c]
Vacuuming of upholstered office chairs	65-80% [h]	unknown	25% [f]

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[a] Adilah et al. 1997; [b] Kemp et al. 1998; [c] Skyberg et al. 2003; [d] Brugge et al. 2003;
[e] Franke et al. 1997; [f] Raw et al. 1999, [g] Smedje and Norbäck 2001; [h] Hines et al. 2003

However, a fundamental keystone in understanding the mechanism of this effect is lacking. To our knowledge, no direct evidence is reported that personal exposure is reduced by cleaning. Here, we aim to provide such evidence.

RESEARCH METHODS

Particle concentrations in office air show large temporal and spatial variation. Therefore, we simulated a typical office (Table 2) and equipped it with a controlled air ventilation system, delivering air of controlled flow, temperature, particle composition and particle concentration into the room. The office was made fully functional with previously used furniture. Two office workers performed normal duties while one of them was wearing a particle monitor. Exposure was measured before, during and after day time cleaning.

Table 2. *Comparison of simulated office features with the results of a survey of 75 offices in 6 office buildings in The Hague, Netherlands*

Office feature	**survey results**[a]	**simulated office**
Floor Area; Height	22 ± 6 m^2; 2,80 ± 0,13 m	22 m^2; 2,7 m
Work stations[b] (Estimated occupancy)	2,2 ± 0,9 (84 ± 18 %)	2 (> 80%)
Air inflow at	wall/ceiling/light fittings	light fittings
Desks & tables (free surface)	4,8 ± 1,7 (41 ± 11%)	5 (50%)
Chairs (upholstered)	4,7 ± 1,9 (100%)	4 (100%)
Cabinets (open shelves)	3,7 ± 2,8 (13,4 ± 11,6)	3 (13,5)
Flooring	100% carpets/tiles	95% tiles

[a] average ± standard deviation; [b] including PC

The ventilation system HEPA-filtered the air. Air flow was 225 m^3/h (air exchange rate 3,2 1/h). Temperature is controlled at 295±2 K. Relative humidity typically remained between 30 and 50%. Standard Arizona test dust ISO 12103-1, Ultrafine Grade (A1) of Ellis Components (UK) was added to the air with a Wright Dust Feeder. The dust consist for 96% of sand and clay particles of 1-10 µm. Density is 2650 kg/m^3, as compared to 1000 tot 1500 kg/m^3 for typical office dust that is made up of organic and inorganic particles, including soot. The Arizona test dust was selected because it is traceable, of controlled particle size, safe for human inhalation in the concentrations used and usable in the Wright Dust Feeder.

Professionally trained janitors performed ‘daily’ and ‘weekly’ cleaning programmes, based on typical Dutch cleaning schedules. The aim of the daily programme (performed on weekdays, except Wednesdays) is to tidy the room. Dust bins are emptied, spots are removed from hard horizontal surfaces with a damp microfiber cloth and visible dirt (*e.g.* paper bits, paperclips and other obvious dirt) is picked up from the floor using a vacuum cleaner. In the weekly programme, performed on Wednesdays, the full floor is vacuumed, and all hard horizontal surfaces within normal reach are wiped with a damp microfiber cloth.

Particle concentrations were determined by Mie-scattering, using a MiniRAM (Aerosol Monitor model PDM-3) strapped to the breast of the office staff to determine the breathing concentration, as a measure for personal exposure, or placed on a table to determine background concentrations. Mie-scattering determines particles from 0,1 to 10 µm and is particularly sensitive around 1 µm (‘fine dust’). The number of 10 µm particles is probably underestimated, so that Mie-scattering will yield lower values than a PM10 measurement.

Relative differences (before, during and after cleaning) can be reliable determined with the MiniRAM. Typically, concentration measurements were averaged over 15 minutes. Extreme high and low values were removed using the Grubbs test, which had little influence on the average, but markedly reduced standard deviations.

RESULTS

Spatial variation of the airborne concentration measured by the MiniRAM was large. High concentrations in the order of 100 µg/m^3 were typically observed below the air inlet and along the walls, along the flow pattern within the room. Average concentrations of about 50-60 µg/m^3 were observed near the desk. Repeatability on one spot was very good (standard deviation of 4 µg/m^3), *i.e.* temporal variations in the background concentrations have been reduced effectively in the simulated office.

Office workers performed normal duties during the measurements, which may cause additional temporal variations. The possible effect on airborne particle concentration of several activities, performed for two minutes, was measured on the active person and on his or her colleague, sitting at 1,5 to 2 meters distance. The effects were measured again after a weekly cleaning, including vacuuming of chairs and document files. The activities included walking around in the office, working with old document files, repeated sitting down on an upholstered chair and repeated opening and closing of the office door. The latter two actions

were repeated 20 to 30 times, until two minutes had passed.

Repeatability of the three repeats was poor, so the results were classified as given in table 3.

Table 3. *Effect of different office activities on personal exposure*[a]

Activity (2 minutes)	**Effect on the active person**	
	before cleaning	**after cleaning**
walking around in the office	↓ > 10 μg/m^3	↓ > 10 μg/m^3
working with old document files	↑ 10-100 μg/m^3	none[b]
repeated sitting down [c]	↑ 10-100 μg/m^3	none
(on an upholstered chair)	↑ 100 μg/m^3	↑ 10-100 μg/m^3
repeated opening of office door	none	↓ > 10 μg/m^3

[a] ↑ denotes a rise in concentration; ↓ a fall; [b] none: no significant or conflicting results; [c] first row: female, 60 kg; second row: male, 90 kg.

Some activities influence the breathing concentration near the active person significantly, but no effects were seen on a person sitting 1,5 to 2 meters away. 'Filing' and 'sitting down' in a dusty environment show a statistically significant increase of the breathing concentration. Cleaning reduced that increase. Walking around reduces the breathing concentration both before and after cleaning. 'Opening doors' had that effect only in a cleaned office.

Daily cleaning or tidying of the room shows no effect on the breathing concentration as determined by the MiniRAM (Figure 1). However, weekly cleaning, involving the vacuum of the total floor and wiping of all relevant surfaces, did show significant effects on breathing concentration (Figure 2). During cleaning, a small increase of breathing concentration is observed (7 ± 15 μg/cm^3; p = 0,10 in a one-sided Student t-test). After cleaning, measured within half an hour, breathing concentration is always lower than during cleaning and almost invariable lower than before cleaning. The average concentration reduction in comparison to before cleaning is significant at -18 ± 15 μg/cm^3 (p < 0,035, two-sided Student t-test). One hour after cleaning the breathing concentration is lowered further to -36 ± 21 μg/cm^3, very significantly lower than before cleaning (p < 0,001, two-sided Student t-test).

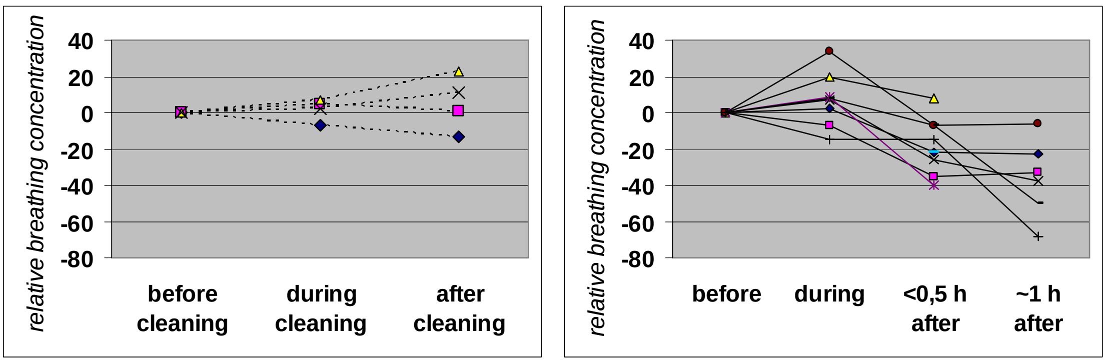

Figure 1. *Breathing concentration relative to the concentration before cleaning (μg/m3)*
Left: daily tidying (emptying dust basket and spot removal) (4 repeats)
Right: weekly cleaning (wiping of all hard surfaces; vacuuming of floor) (6 repeats)

DISCUSSION

Office activities have an very localized effect on breathing concentration, consistent with a personal particle cloud around active an person (Wallace 1996, Owen et al. 1992). It is often found that the particle concentration equals 1,5 to 2 times that of the background. Repeated sitting down and filing documents increase the particle concentration with tens of micrograms per cubic meter. Given that the background concentration is on average 66 μg/cm^3 (Kildesø et al. 1999), that increase is of the expected order of magnitude. Furthermore, the personal cloud is reported to have a radius of less than 1,5 m (Yoon and Brimblecombe 2001). This is consistent with our finding that there were no effects on the breathing concentration at 1,5 to 2 meter distance of the active person.

Walking reduces the breathing concentration because the dusty air around the walking person is replaced with relative clean air from the background. Repeated door opening in a clean office has the same effect, due to the movement of relatively clean air. In an uncleaned office, however, this air cleaning effect is apparently counteracted by the resuspension of dust particles.

Vacuuming the carpet, the upholstered chair and filing documents significantly reduces the resuspension of fine dust particles, crudely by half. This is the same order of magnitude as literature data (Table 1 and references) on indoor air concentration reductions.

The act of cleaning itself, however, tends to resuspend fine dust particles (Thatcher and Layton 1995, Nicholson 1989). That explains the small (about 7 μg/cm^3) increase of the breathing concentration near the office worker. While wiping the desk and vacuuming the floor beneath the desk, the janitor is quite near to the office worker.

Soon after thorough office cleaning, the breathing concentration drops significantly to values below the value before cleaning and an hour after, the concentration has dropped 36±21 μg/cm^3. Possible, the breathing concentration drops even further, but data logging time did not allow for longer experiments. Furthemore, Mie-scattering tends to underestimate PM10. Given that PM10 in European offices is 66μg/cm^3, breathing concentration will be about 1,5 to 2 times that, *i.e.* 100-130 μg/cm^3. Therefore, thorough office cleaning with a vacuum cleaner and a damp microfiber cloth reduced breathing concentration with roughly 25 to 50%.

This reduction is consistent with the data on the effect of thorough cleaning on surface and airborne biocontaminant concentrations (Table 1, 20-80%), and is somewhat larger than health effects typically observed (Table 1, 10-45%). The reduction in health complaints is invariably smaller than the reduction in indoor concentration in comparable cases. Indeed, even when biocontaminants are fully eliminated (100% reduction), other factors will still induce health complaints (less than 100% reduction).

Not all cleaning activities reduce personal exposure. Tidying the room by removing stains and clutter has no significant effect. Wiping with a damp cloth and carpet vacuuming are shown to be effective in this research, so are chair vacuuming and hot spray extraction (Table 1). However, in some cases cleaning was found to be detrimental. Tepid spray extraction or shampooing of carpets in fact increased the number of bacteria and the amount of endotoxins (Wickens et al 2003). Wet mopping reduced floor allergen levels, but increased airborne bacteria count and the number of health complaints (Smedje and Norbäck 2001; Wålinder et al 1999). On wet surfaces, bacteria can grow and form endotoxine. When wet cleaning is necessary, good drying is a must for indoor environment quality.

CONCLUSIONS AND IMPLICATIONS

Direct evidence is given that normal office activities cause increased personal exposure to particles between 0,1 and 10 μm. Cleaning of specific areas (upholstered chair, document files) is shown to reduce the exposure. Also, thorough office cleaning by vacuuming and damp wiping is demonstrated to reduce personal exposure of office workers by 25 to 50%, because less dust is available on the surfaces for resuspension.

Quantification of the effects is not very precise. However, the order of magnitude of the reduction measured ties in very well with reported reductions in surface and airborne particle and biocontaminant concentrations, and is slightly larger than reported health effects. That is expected, because not all causes for health effects are removed by cleaning.

The reduction of personal exposure comes at a price, however. The janitor is probably exposed to rather high particle levels (Thatcher and Layton 1995). This may partly explanation the high frequency of respiratory illness in cleaning workers, along with other ‘dusty’ professions like metal working and agriculture (Kogevinas et al 1999). Cleaning methods that resuspend little fine dust are called for, if only because the resuspended dust will settle on the newly cleaned surface, thus reducing the efficacy of the cleaning. In an accompanying paper, such clean cleaning methods are looked for.

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