EFFECTIVE CLEANING METHODS FOR REDUCING BIOCONTAMINANT LEVELS

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ABSTRACT
Clean surfaces are a key element in lowering personal exposure to fine dust by reducing resuspension. However, it is not known which methods effectively remove fine dust from surfaces whilst not resuspending it. Our objective was to find such methods.

We allowed about 0.3 g/m2 Arizona test dust to settle onto desk top materials. Dust removal was studied microscopically. Dry wiping (e.g. with paper tissue, electrostatic cloth) removes less than 75% of the fine dust. Efficacy decreases within the first 10 cm of cleaning movement. Damp wipers, that use water or mineral oil to bind the particles, completely remove the dust. Dust resuspension measured by PVI showed that roughly a few percent of the settled dust is resuspended by cleaning. Dry methods and at higher cleaning velocity increase resuspension. For optimum protection of office and cleaning staff to fine dust, damp cleaning at a low velocity is preferred.

INDEX TERMS
Cleaning, effectiveness, resuspension, particles, biocontaminants

INTRODUCTION

Exposure to fine dust and biocontaminants can be harmful to the health of office staff. Irritation of eyes, skin and most importantly airways can lead to or exacerbate illnesses, and reduce productivity. In an accompanying paper, it is shown that surface cleaning can reduce personal exposure to fine dust (Duisterwinkel et al. 2005). Therefore, cleaning does not only improve indoor air quality, but also improves health of the persons working, studying or living there (Mendell and Heath 2005). The resulting reduced absenteeism and improved productivity provide a healthy incentive for professional cleaning.

Little is known, however, on the efficacy of different cleaning methods. Rigorous office cleaning was shown to be effective, but a minimal cleaning programme including emptying of dust bins, spot removal from hard horizontal surfaces and removal of visible dirt from the floor with a vacuum cleaner did not reduce personal exposure (Duisterwinkel et al. 2005).

Cleaning itself can bring significant amounts of dust into the air (Nicholson 1988; Thatcher and Layton 1995, Duisterwinkel et al 2005). This may explain the high frequency of respiratory illness in cleaning workers (Kogevinas et al, 1999). Certainly, it reduces cleaning efficacy, since most of the resuspended dust will settle on the freshly cleaned surfaces.

It is the objective of this study to find hard surface wiping methods that on the one hand effectively remove resuspendable fine dust, and on the other hand show minimum resuspension during cleaning. Care must be taken to avoid methods that leave a wet surface behind. Such cleaning methods have been reported to cause an increase in airborne bacteria and endotoxins (Wickens et al 2003) and health complaints (Smedje and Norbäck 2001; Wålinder et al 1999). Wet cleaning obviously is a risk factor because it can induce bacteria growth and endotoxine formation.

RESEARCH METHODS

Cleaning tests were performed on black desk top material (melamine, DIN EN 438), soiled with Standard Arizona test dust ISO 12103-1 (Ellis Components, UK). The test dust consist for 96% of sand and clay particles between 5 and 10 µm. Density is 2650 kg/m3. The test dust was selected because of its controlled particle size. Also, it is easy to detect and hard enough for compression in the Wright Dust Feeder. Using that feeder, a small amount of test dust was blown into a settling chamber. Large particle clusters were allowed to settle for 15 seconds, after which a drawer containing two cleaned desk top samples was pushed into the chamber. The remaining fine dust was

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allowed to settle on the desk top samples.

Surface concentrations were determined with a microscope (Olympus BX-60MF3) fitted with a digital camera (Colorview 8). Data were processed with Soft Imaging Software, to obtain histograms of surface particle concentrations on 16 spots on the substrate, calibrated on the known particle size distribution. Surface concentrations were calculated with the known density, assuming the particles to be spherical.

The resuspension of fine dust was visualised and quantified by PVI (Particle Velocity Imaging), using a Surelite Continuum 25 Hz, 532 nm laser (Santa Clara, USA) and optics and software from Optical Flow Systems (Edinburgh, UK). A field of 45 by 40 cm2 was monitored at 2 Hz. Tests were performed in a blinded room ventilated with HEPA-filtered air at 3,2 1/h. Resuspension was quantified perpendicular to the cleaning movement at 2 cm distance from the cleaning stroke end. Cleaning was simulated with a Braive Washability Tester (Blocklandpack, IJsselstein) that provides a reproducible linear stroke at a controllable velocity (default: 0,3 m/s). At the end of an extension a block of 9 cm wide was provided, to which different cleaning materials were attached. Weights were put onto the block to increase cleaning pressure (default: 16 g/cm2).

RESULTS

The surface dust concentration, or coverage S, was determined for each soiled plate on 16 points. The standard deviation was typically 30% of the average coverage, up to 50%. No pattern in soiling could be detected. Furthermore, coverage varied between 0,25 and 1,2 g/m2 from run to run. Care was taken to select the same 16 locations after wiping. Therefore, dust removal and resuspension were expressed as a percentage of the coverage before cleaning.

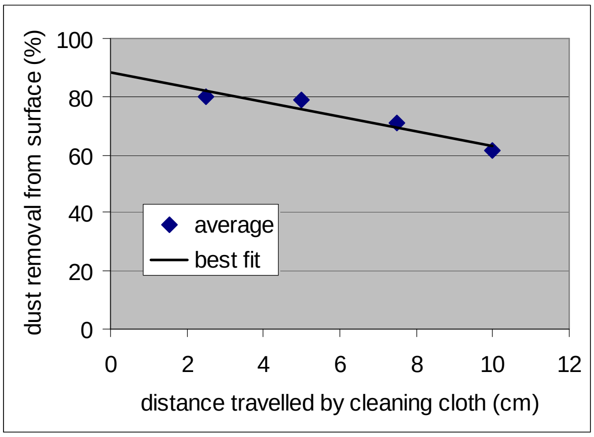

Figure 1. *Particle (5-10 μm) removal versus the length of the cleaning stroke. Dry tissue.*

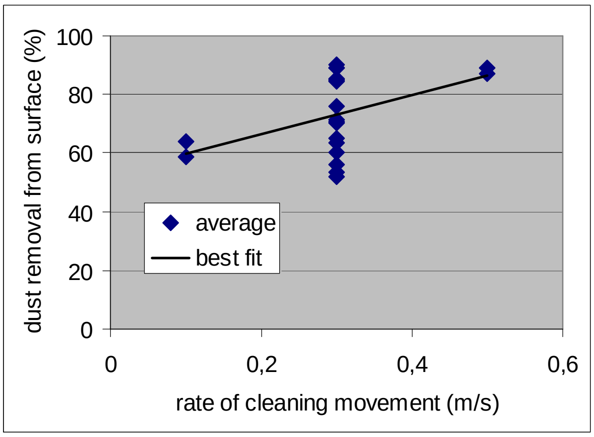

Figure 2. *Particle (5-10 μm) removal versus the speed of the cleaning stroke. Dry tissue.*

Dust Removal

Dry paper tissue was used as a reference wiper. In a total of 18 experiments, dust removal was found to be 73 ± 13% (average ± standard deviation). No correlation with coverage before cleaning was observed. Furthermore, dust removal dropped rapidly with the length of the cleaning movement (Figure 1) to as low as 60% after cleaning only 10 cm. A five times used tissue removed only one third of the dust.

Table 1. *Particle (5-10 μm) removal efficacy from melamine desk top*

Type of cloth	**Application method**	**Efficacy**[a]
Paper tissue	Dry	73 ± 13% (18)
Professional cleaning cloth	damp[b], with 0 to 5% detergent solution	> 99% (9)
Microfiber cloth	damp[b], without detergent	> 99% (2)
Oil-impregnated paper tissue	as received	> 99% (4)
Non woven electrostatic	as received (*i.e.* not pre charged)	40-50% (2)
Soft, longhaired brush with wax	as received	33% and 82%
Sticky cloth (disposable)	as received	94 ± 7% (6)

[a] average ± standard deviation (number of experiments) [b] damp: mass of fluid equals mass of cloth

In fact, all dry systems tested had less than 100% removal rates (Table 1), as opposed to all damp systems and oil-impregnated paper cloths. The sticky cloth shows the same behaviour as the dry paper tissue, in that the removal efficiency dropped with distance. Faster cleaning with a dry paper tissue causes a small but significant increase on particle removal efficacy (Figure 2). Cleaning pressure and surface roughness had no effect. The particle size histograms reveals that smaller particles are removed less effectively (Duisterwinkel, 2002).

Dust Resuspension

Perpendicular to the cleaning movement, snapshots were taken with PVI for quantification of the amount of dust resuspended by the cleaning movement. Resuspended mass M_a increases linear with surface coverage S (Nicholson 1988, Thatcher and Layton 1995) when all other conditions remain equal. k is the resuspension constant for those specific conditions.

$$M_a = k\ S \tag{1}$$

We investigated the effect of surface coverage on airborne mass for wiping with a dry paper tissue and a damp domestic non woven cleaning cloth, respectively. Indeed, the mass of dust brought into the air increases with surface coverage (figure 3), for damp and dry wipers.

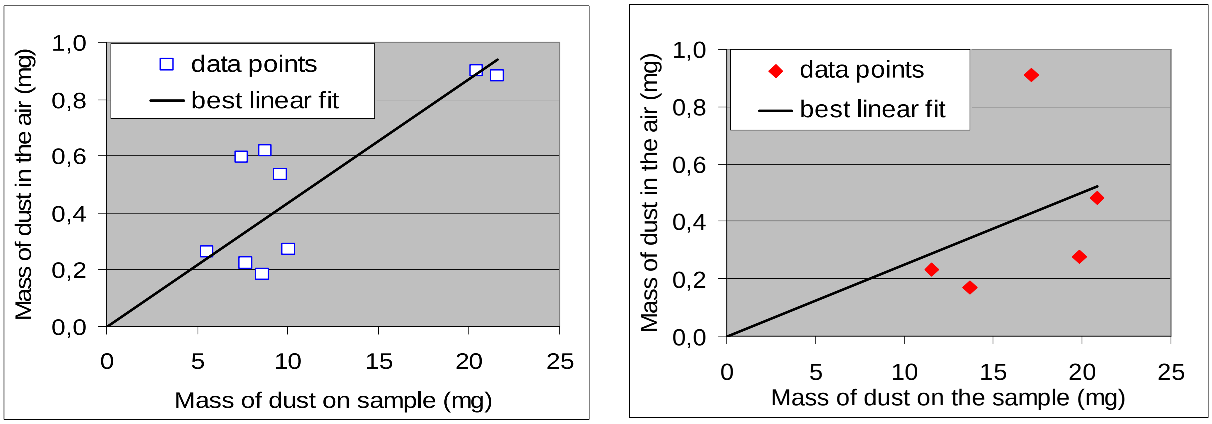

***Figure 3.** Amount of dust resupended versus amount on the cleaned surface area*
Left:Dry tissue at low (<2,5 μg/m3) and high (>2,5 μg/m3) background concentration (C0)
Right: Damp non woven cloth at high (>2,5 μg/m^3) background concentration (C_0)

Statistical significance is difficult to demonstrate due the large variance of about 50% for surface coverage and of more than 25% for airborne mass. Nevertheless, there is no evidence conflicting the validity of equation (1). We used this rule and calculated the percentage of dust resuspension R by dividing the airborne mass with the surface mass M_s (surface coverage times cleaned surface area A):

$$R = M_a / M_s = M_a / SA \tag{2}$$

The airborne mass was calculated by integrating the airborne concentration over time. Thus, we find that high cleaning velocity causes more resuspension (figure 4), whereas the pressure on the cleaning cloth has no significant influence (figure 5). In all cases, the dry paper tissue causes more resuspension than the damp non woven cloth.

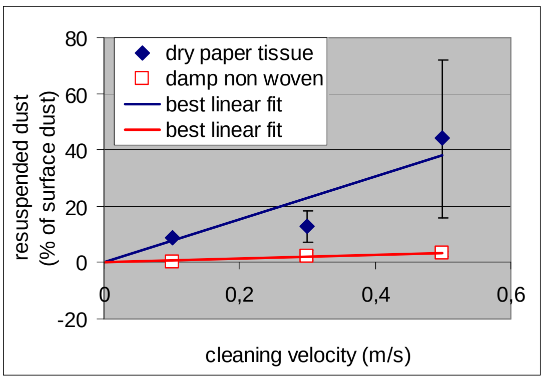

***Figure 4.** Resuspension as a function of cleaning velocity for dry and damp cleaning*

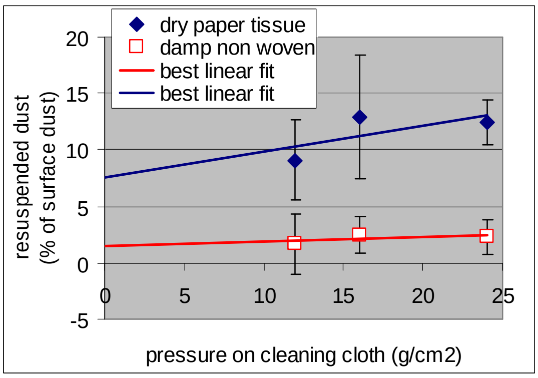

***Figure 5.** Resuspension as a function of cleaning pressure for dry and damp cleaning*

No significant difference was observed between resuspension caused by the electrostatic cloth and the reference cloth (2,9±2,7% versus 4,7±2,3% at low background concentration). No valid results were obtained on the longhaired brush and the sticky cloth. The damp non woven cloth cannot be significantly improved by using a professional cloth (cotton sandwiched in polymeric material), even at high detergent concentration (Table 2). The same applies to the microfiber cloth and to oil-impregnated wipers. The addition of alcohol to the cleaning fluid, used in cleanrooms for cleaning, remarkably enough caused significantly higher resuspension.

Table 2. *Dust resuspension as percentage of dust on surface due to cleaning with damp[a] cloth*

Type of cloth	**Moistening fluid**	**Resuspension[b]**
Non woven	Water	2.5 ± 1.7% (5)
Professional standard[c]	0,1% detergent solution	2.3 ± 1.6% (2)
Professional standard[c]	5% detergent solution	1.1 ± 0.4% (2)
Professional standard[c]	ethanol	7.5 ± 3.4% (2)
Professional standard[c]	IPA containing cleanroom detergent	4.0 ± 1.1% (2)
Microfiber cloth	damp[b], without detergent	2.8 ± 2.1% (2)
Oil-impregnated paper tissue	as received	1.2 ± 0.8% (2)

[a] damp: mass of fluid equals mass of cloth; [b] average ± standard deviation (number of experiments); [c] cotton sandwiched in polymeric material

DISCUSSION

To our knowledge, no research data have been published previously on the efficacy of fine dust removal from hard surfaces. Schneider et al. (1994) published data on dust removal efficiency as measured by the BM-dust detector. In that technique, dust is transferred to a gelatinous sticky tape. The reduction of light transmitted through the tape is taken as a measure of dustiness, thus predominantly measuring large, visible, dust particles. Schneider et al. observed that damp cloths and oil-impregnated cloth removed dust most effectively, rather than dry systems – although in their case one dry cloth with polyethylene floss also performed fairly well. Their results were repeated on furniture and polyvinyl flooring material.

The microscopic method we use here enabled us to study fine dust (5-10 μm) specifically. It appears that that the main reason for the poor results with dry cloths is the small capacity of these cloths for binding dust. Finally, we were able to show that the efficacy is lower for the finest particles. It is well known that below 5 μm are more difficult to remove and therefore are resuspended less easily (Thatcher and Layton 1995, Schneider et al. 1994).

Our finding that cleaning brings fine dust particles into the air, comes as no surprise (Thatcher and Layton 1995, Duisterwinkel 2005). Quantification of resuspension, however, was troublesome. In experiments parallel to the wiping movement, we observed circulating patterns of airborne particles, allowing the possibility of double counting. On the other hand, particles may not have been counted because they missed the analysed area or did not pass it during the experiment. Airborne particle size distribution is not exactly known. Moreover, the large variance in surface concentration reflects directly on the resuspension percentage, as does the influence of background airborne concentration that is not understood well. All in all, the observed variance in R is about 70% (standard deviation divided by average) and a bias in the absolute resuspension levels cannot be excluded.

Schneider et al. (1994) also observed substantial variations in particle resuspension (from carpet). They were not able to demonstrate a significant difference in resuspension by dry and damp cleaning methods in a very limited number of experiments. However, we are satisfied that dry wiping causes more dust resuspension than damp wiping or wiping with oil-impregnated cloths. Cleaning velocity should be low to prevent heavy resuspension. Cleanrooms are cleaned at a very low velocity for exactly this reason. Remarkably, and unexplained, addition of alcohol appears to enhance resuspension, although cleanrooms are often cleaned with (detergents containing) iso-propanol.

CONCLUSIONS AND IMPLICATIONS

In order to reduce personal exposure of both cleaning staff and office workers to fine dust, we have looked for cleaning methods that remove fine dust effectively from surfaces while causing as little resuspension as possible. We have found that dry wipers (paper, electrostatic cloth, paraffin wax brush, stocky disposable cloth) do not fully remove fine dust. Damp wipers, which use liquid (water, detergent solution, mineral oil) on the cloth to bind particles, fully remove the fine dust.

Moreover, the dry methods tend to bring more fine dust into the air in our controlled experiment where only a cleaning movement on a desk top was simulated. We expect the difference to be even larger in a practical situation, where dirty cloths are handled and may loose dust particles that are insufficiently bonded.

Thus, damp wipers should be used for cleaning furniture, rather than dry ones. On flooring, although vacuuming may also be an option that needs further investigation, damp wiping is also preferred. Mops that leaves the surface wet after cleaning should not be used, to prevent bacteria growth and additional health problems.

Dust resuspension can be reduced even further by lowering cleaning velocity. That is a costly measure, as it reduces production rates. However light weight broad wipers can be used without a problem to compensate for this production loss.

ACKNOWLEDGEMENTS
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