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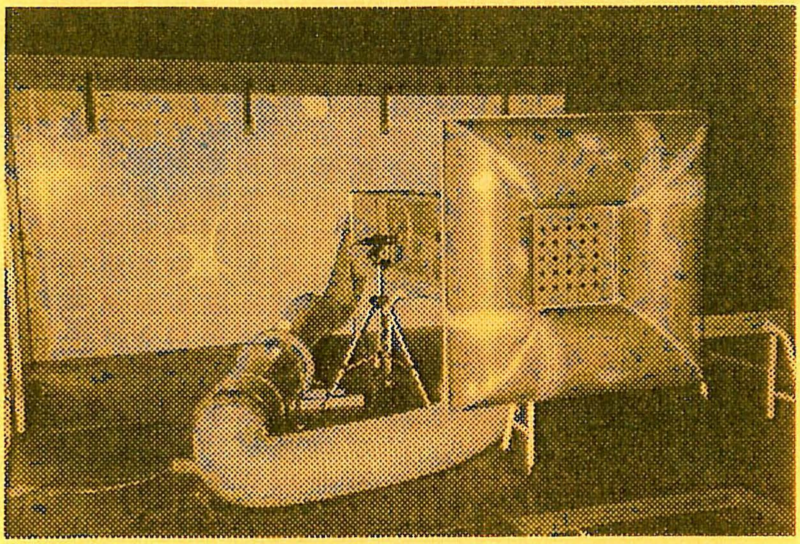

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PAPER NO. 77

Proceedings of Healthy Buildings/IAQ '97. Global Issues and Regional Solutions, Washington DC, USA, Vol. 1, pp. 501-506, September 27 - October 2, 1997

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DEPOSITION AND RESUSPENSION OF PARTICLES

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ABSTRACT

To investigate the physical process of deposition and resuspension of particles in the indoor environment, scale experiments are used and a sampling method is established. The influences of surface orientation and turbulence and velocity of the air on the dust load on a surface are analysed.

It is found that the surface orientation is the parameter which influences the dust load most. The dust load is highest on the floor but some dust is also sampled on the walls and the ceiling. The measurements indicate that the air velocity has a non-linear influence and that the turbulence has a larger effect on the deposition than on the resuspension. Therefore high turbulence causes high dust load. However, the influence of turbulence and velocity are strongly dependent on each other and cannot be analysed in isolation.

INTRODUCTION

Indoor air contains particles which can affect the health of people. To study the health risk of a room it is necessary to find out which kind of particles are suspended in the air, where they come from and how they are transported and distributed in the air. According to Goddard et al. [1] airborne concentration can be reduced significantly by deposition on surfaces. Therefore the physical process of deposition and resuspension has to be well understood before predictions of the health risk in a room are attempted by e.g. Computational Fluid Dynamics simulations (CFD).

A large number of experiments and CFD simulations are reported in the literature to describe type and size of particles, sources of the particles and their distribution and transport in the air. But only in a few experiments deposition is considered and in even fewer resuspension. To the authors knowledge, the existing CFD models contain no or only a very simple model for the deposition, e.g. 100 % deposition on floors and none on walls and ceilings. And many authors ignore resuspension altogether.

To improve these models, the deposition and the resuspension have to be defined as a function of the environmental and surface conditions and the type of particles.

$$dust_{deposited} = f_1(air\ flow, surface\ conditions, type\ of\ \ particles, other\ \ forces) \tag{1}$$

$$dust_{resuspended} = f_2(air\ flow, surface\ conditions, type\ of\ particles, dust\ load, other\ forces) \quad (2)$$

where $dust_{deposited}$ = rate of settling particles on the surface [μg/m²/h],
$dust_{resuspended}$ = rate of removal of particles from the surface [μg/m²/h].

In a first step deposition and resuspension are not analysed individually but combined, and the net deposition rate is:

$$\Delta_{dust} = dust_{deposited} - dust_{resuspended} \quad (3)$$

$$dust\ load = \int \Delta_{dust} dt + initial\ dust\ load \quad (4)$$

where Δ_{dust} = rate of change of the dust load [μg/m²/h], dust load = amount of particles on the surface per unit area [μg/m²], t = time [h].

METHODS

To get well defined environmental conditions close to the test surfaces, the experiments are carried out in a measuring channel (Figure 1) and not in a full-scale room. The channel has the dimensions 3.0x0.5x0.5 m. The dust load is measured on surface panels placed inside the channel facing up (floor), vertical (wall) and facing down (ceiling). They have an area of 1.15x0.45 m and the distance to the channel inlet is 1 m. Painted wood-fibre boards are used as surface material. The channel itself is placed in a room where the particle concentration is controllable and stable.

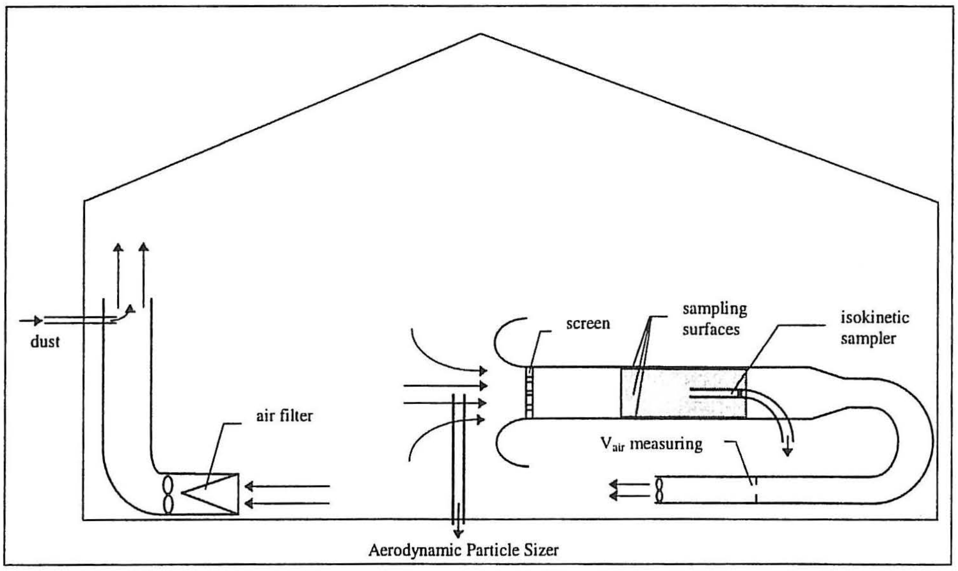

Figure 1 Schematic experimental set-up

The air is drawn through the channel by a ventilator with adjustable speed to get different air velocities. The mean air velocity in the channel over the cross-section is defined by the air volume flow. The main part of the experiments are made at mean velocities of 0.1 m/s and 0.5 m/s. A few measurements are also made at higher velocities like 1.1 m/s and 1.5 m/s.

To produce different levels of turbulence, screens with different perforation levels can be installed at the channel inlet. The two nominal turbulence intensities are 20 % (low turbulence) and 60 % (high turbulence).

The local air velocity and the local turbulence above the sampling surfaces are measured by Laser Doppler Anemometry (LDA). Therefore the channel has windows upstream, along and downstream of the sampling surfaces. The airborne concentration in the room is measured by an Aerodynamic Particle Sizer (APS) at 0.5 m in front of the channel inlet and by isokinetic sampling in the middle of the channel. By running the experiments for 30 minutes a concentration around 5×10^5 particles per litre air gives a reasonable amount of dust load on the surfaces. The relative air humidity and the air temperature are not controlled but both are very constant in the test room, namely 30 ±3 % and 22 ±2 °C, respectively.

The particles are generated with a multi-point dust generator, developed by the Research Centre Bygholm [2]. They are distributed in the room by a ventilator which draws the air through a filter to get a constant particle concentration in the room (Figure 1). At all experiments Talcum powder is used as particles. It has a mean particle size diameter of 1.2 μm and a density of 2700 kg/m^3. Its particle size distribution and characteristics are similar to indoor dust.

The dust load itself is measured by vacuum cleaning with a special head for the vacuum cleaner (Figure 2). The particles are collected in glass fibre filters.

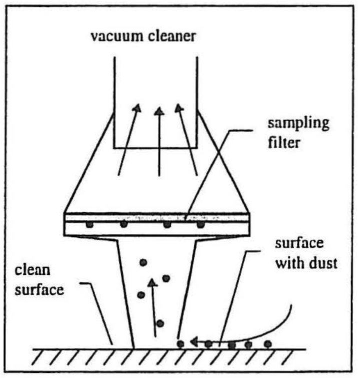

Figure 2 Dust sampler system with vacuum cleaner and glass fibre filter

To determine the dust load, the filters are weighed before and after sampling and the background level of dust in the air during the sampling is subtracted.

$$dust\ load = \frac{dust_{sampled} - dust_{background}}{A} \qquad (5)$$

where A = sampling area [m^2].

It is difficult to resuspend all the particles, especially the small ones, from the surface by vacuum cleaning. To know how many particles are left on the surface after vacuum cleaning, the tape technique is used [3].

The resuspension rate is supposed to be constant versus time, at least until the dust load reaches a certain level. Since the deposition is also constant and according to equation (3) the dust load is directly proportional to time up to this level (Figure 3).

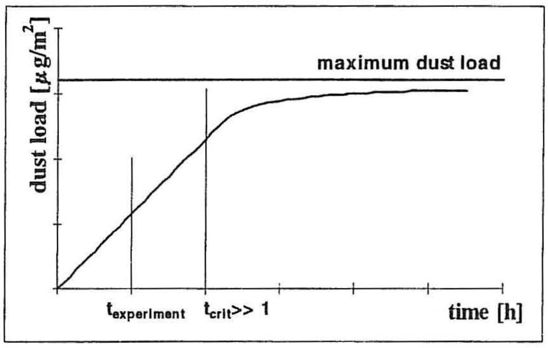

Figure 3 Dust load versus time.

It is assumed that the duration of the experiments is smaller than the critical time where the dust load is no longer proportional to time. And it is also assumed that the deposition is proportional to the airborne concentration but independent of time. These assumptions are important for comparing the experiments with each other since it is not possible to get exactly the same dust concentrations in every experiment. Hence, Δ_{dust} is not dependent on time and equation (4) can be integrated and solved for Δ_{dust}. The integration constant is zero because the initial dust load is also zero.

$$\Delta_{dust} = \frac{dust\ load}{t} \qquad (6)$$

RESULTS AND DISCUSSIONS

The parameter which influences the dust load most is obviously the orientation of the surface (Figure 4 and 5). Actually the surface orientation describes the gravity force normal to the surface. Therefore no dust would be deposited on the walls and on the ceiling without turbulence or other forces. As expected the highest dust load is found on the floor, but unlike assumed in most models in literature, the dust load on the walls and the ceiling is not equal zero. It is about 10 % of the dust load on the floor.

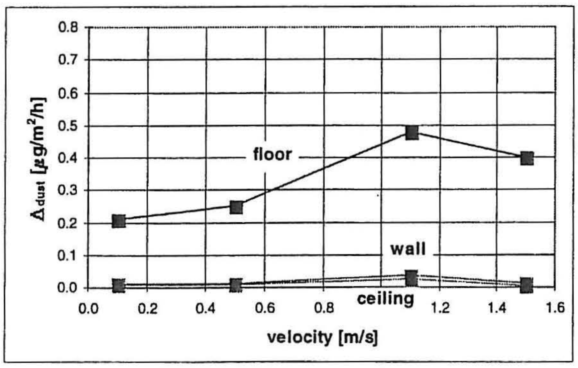

Figure 4 Δ_{dust} with low turbulence

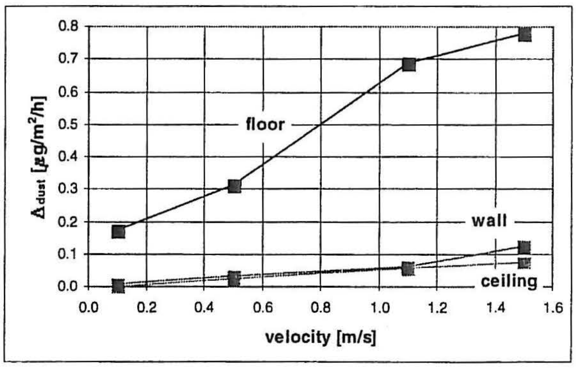

Figure 5 Δ_{dust} with high turbulence

An increased velocity level yields some unexpected results. It was supposed that the resuspension rate would be proportional to the velocity and therefore the dust load would decreases with an increased velocity level. But the dust load increases with higher velocity. For low turbulence it decreases after a maximum dust load. Because there is only one measurement each at the velocities 1.1 m/s and 1.5 m/s, this decrease has to be interpreted with care. However, Shaw [4] found the same characteristics in his research. He explains this phenomenon with electrostatic forces which are induced by the moving air. At a low velocity these forces are small and the drag force can resuspend the particles. At higher velocities the static charge is sufficient to make the small particles adhere to one another and behave as larger particles so that the drag force is not strong enough to resuspend these large aggregates. Finally, although the induced electrostatic force is strong, for high velocities the drag force is sufficient to resuspend the aggregates. Since the experiments of the present paper give only values for Δ_{dust} and not for the deposition and the resuspension individually, it is not possible to say if the above mentioned phenomenon is caused by increasing deposition or by decreasing resuspension.

The influence of the turbulence cannot be analysed separately from the other parameters. E.g. at a velocity of 0.1 m/s low turbulence results in a higher dust load than high turbulence, but at higher velocity it is the other way round (Figure 6 and 7).

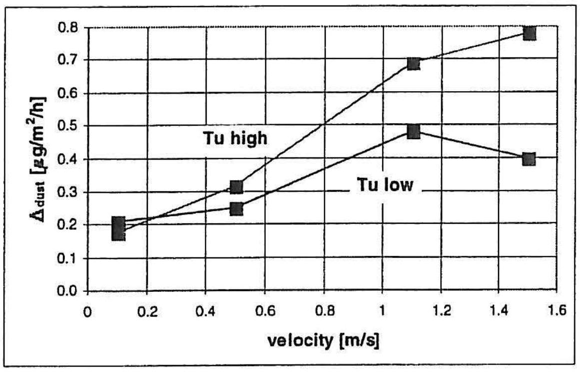

Figure 6 Δ_{dust} on the floor

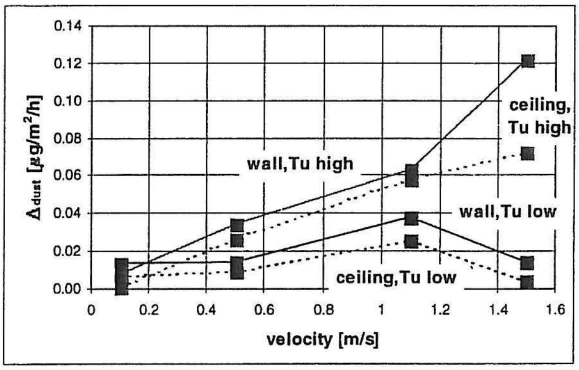

Figure 7 Δ_{dust} on the wall and the ceiling

To analyse this phenomenon it would be necessary to measure the deposition and the resuspension individually. But it seems if the deposition caused by turbulence is dependent of the velocity because at a higher velocity more particles are transported which can be deposited by the turbulence. On the other hand, the resuspension caused by turbulence is less dependent or independent of the velocity.

The present conclusions are based on a very few experiments. Therefore they cannot yet be generalised. However, there is a high correspondence between experiments and also with the thesis of Shaw [4]. The applied method gives reproducible results. The samples by the tape technique show that only a very few particles cannot be picked up by the vacuum cleaning system and that these particles have a very small diameter. Hence they do not influence the mass of the sampled dust very much.

It is very important not to analyse the parameters isolated from each other because they are dependent, e.g. the influence of the turbulence to the dust load is dependent of the velocity.

In future work the method should be verified with more experiments. Additionally, parameters like surface type, electrostatic force and mechanical force can be analysed and also the transferability of the data to a full-scale room. Methods to measure the deposition and the resuspension individually have to be found. E.g. with a sticky foil that has no resuspension the Δ_{dust} is equal to the deposition. And with a surface on which the particles are deposited before starting the experiment, the resuspension could be measured.

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