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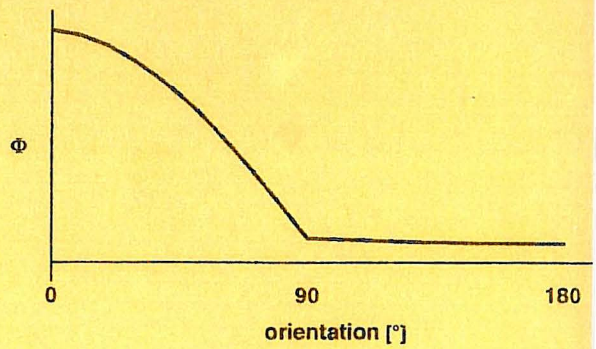

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DEPOSITION AND RESUSPENSION OF PARTICLES: WHICH PARAMETERS ARE IMPORTANT

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ABSTRACT

A new experimental set-up to investigate the physical process of dust deposition and resuspension on and from surfaces is introduced. Dust deposition can reduce the airborne dust concentration considerably. As a basis for developing methods to eliminate dust related problems in rooms, there is a need for better understanding of the mechanism of dust deposition and resuspension.

With the presented experimental set-up the dust load on surfaces in a channel can be measured as a function of the environmental and surface conditions and the type of particles under controlled laboratory conditions.

Results of a first series of measurements are shown. It is found that the surface orientation is the parameter which influences the dust load most. The measurements indicate that the air velocity has a non-linear influence and that high turbulence causes high dust load.

KEYWORDS

Air quality, deposition, measuring technique, particles, resuspension.

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. (1996), airborne dust 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 transportation 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.

In order 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 as showed in Equations (1) and (2).

$$s_a = f_1 \begin{pmatrix} \textit{air flow, surface conditions,} \\ \textit{amount and type of airborne} \\ \textit{particles, other forces} \end{pmatrix} \quad (1)$$

$$s_r = f_2 \begin{pmatrix} \textit{air flow, surface conditions,} \\ \textit{type of airborne particles,} \\ \textit{dust load, other forces} \end{pmatrix} \quad (2)$$

where:

s_a = rate of depositing particles on the surface [g/m²/h]

s_r = rate of removal of particles from the surface [g/m²/h]

Ideally, knowledge of both mechanisms is needed, but as a first step the focus is set on improved knowledge of factors that influence the dust load. The dust load on a surface, Φ, is the amount of dust building up as the balance between dust deposition on and resuspension from the surface.

$$\frac{d\Phi}{dt} = s_a - s_r \quad (3)$$

$$\Phi = \int_\theta (s_a - s_r)dt + \Phi_0 \quad (4)$$

where:

Φ = amount of dust on the surface per unit area [g/m²]

Φ_0 = initial dust load [g/m²]

θ = duration of experiment [h]

METHODS

A wind tunnel was designed for the dust load investigation (see Figure 1). Unlike in a full-scale room, the environmental conditions close to the test surfaces are well defined in the channel. The channel is composed of three parts, namely, the inlet, the working section and the outlet.

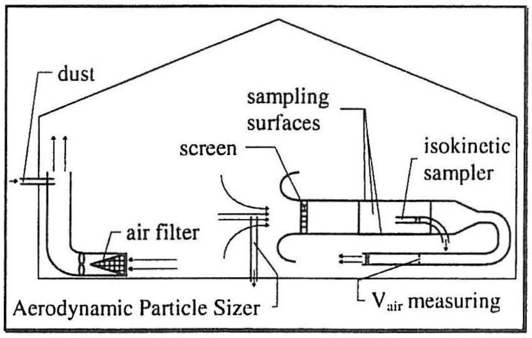

Figure 1 Schematic experimental set-up.

The inlet, placed upstream of the working section, is well rounded in order to obtain a uniform velocity and turbulence profile in the working section. It can hold screens with different perforation to produce different turbulence levels in the working section.

The surfaces of the working section, facing up (floor), vertical (rear wall) and facing down (ceiling), are covered with the working material. The second vertical surface (front wall) is made of Plexiglas, allowing observation of the working section and velocity and turbulence measurements at any point of the section using Laser Doppler Anemometry (LDA). To have good access to the working section, its sides can be folded out.

The air is drawn through the channel by a fan placed at the end of the outlet section which is speed controlled in order to adjust air velocity to pre-set values.

The channel itself is placed in a closed room where the airborne dust concentration is controlled to stable levels. The dust is produced with a multi-point dust generator, developed by the Research Centre Bygholm (Takai et al. 1996). The dust is blown into the room and distributed with a fan. To maintain constant dust levels over time, room air is circulating through a filter to remove dust before adding new dust.

Measuring methods

The airborne dust concentration is measured at the channel inlet by an Aerodynamic Particle Sizer (APS) and in the working section by isokinetic sampling.

The air velocity and turbulence in the working section are measured by Laser Doppler Anemometry (LDA) over the whole cross-section. In addition, a reference velocity is determined by measuring the volume flow rate through the channel with an orifice plate.

Moreover, air temperature, humidity and electrostatic charge of the room air are measured during the experiments.

Dust sampling on the surfaces

The dust load is measured by vacuum cleaning the experimental surfaces with a special cleaning head (see Figure 2). This head is a simple, commercial filter holder that fits on any commercially available vacuum cleaner hose (Petersen-Bach).

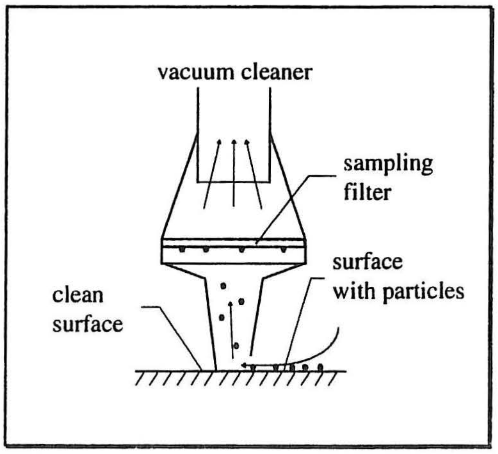

Figure 2 Dust sampling system with vacuum cleaner and glass fibre filter.

It is composed of three parts, where the middle one contains the filter box with the glass-fibre filter. The amount of sampled dust is determined as the difference in weight of the filter before and after sampling.

$$\Phi = \frac{m_{filter\ after\ sampling} - m_{filter\ before\ sampling}}{A} \quad (5)$$

where:

m = weight of filter [g]
A = sampling surface area [m^2]

It is assumed that the deposition is proportional to the airborne dust concentration and that the resuspension is independent of that concentration. The airborne dust concentration is constant over time. These assumptions are important for comparing the experiments with each other since it is almost impossible to get exactly the same airborne dust concentration in every experiment. On the other hand, the resuspension is not constant over time since it is dependent on the actual dust load on the surface. Therefore only experiments with the same duration can be compared with each other.

It is difficult to resuspend all the particles by vacuum cleaning, especially the small ones. To know how many particles are left on the surface after vacuum cleaning, a special tape technique is used (Schneider et al. 1987). A sticky foil, pressed on the cleaned surfaces, removes the left particles. The amount of particles collected with the foil can be counted under a microscope or determined by measuring light extinction.

To know the particle size distribution of the dust on the surfaces, dust samples are analysed with a Small Scale Powder Disperser which can determine the diameter of particles.

EXPERIMENTS

In a first step, an investigation of the environmental parameters and the surface orientation is done. For that, painted wood-fibre plates are chosen as experimental material at all three orientations. Talcum powder is used as artificial dust. Its particle size distribution and characteristics are similar to indoor dust. Furthermore, talcum is cheap and easy available and since it is inorganic there is no danger of dust explosions. But it has to be handled with care because it can affect the health of people working with it.

The experiments are carried out in summer and winter conditions, i.e. a relative humidity in the air of around 60 % resp. 30 % and an air temperature of around 26°C resp. 22°C. The main air velocities in the channel are 0.1 m/s and 0.5 m/s, but some experiments are also carried out at higher velocities, namely, 0.8 m/s, 1.1 m/s and very few at 1.5 m/s. The two nominal turbulence levels are 20 % (low) and 60 % (high). By running the experiments for 30 minutes, an airborne dust concentration of around $5x10^8$ particles per m^3 air gives a reasonable amount of dust on the surfaces. The airborne dust concentration is supposed to be constant over time and over the working section of the channel. Since all the experiments are carried out with the same duration, no estimation about the time dependence of the dust load can be made.

RESULTS AND DISCUSSIONS

In Figures 3, 5 and 7 the measured dust load is shown as function of the air velocity with a variation of the other parameters. Since the weight of the collected dust is supposed to be proportional to the sampling area and the airborne dust concentration, the dust load shown in these figures is normalized by the sampling area and the airborne dust concentration. In Figures 4, 6 and 8 the dust load is shown as a qualitative function of the respective parameter. To make a quantitative estimation, more experiments have to be done.

Surface orientation

The parameter which influences the dust load most is obviously the orientation of the surface (see Figure 3). Actually, the surface orientation determines 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.

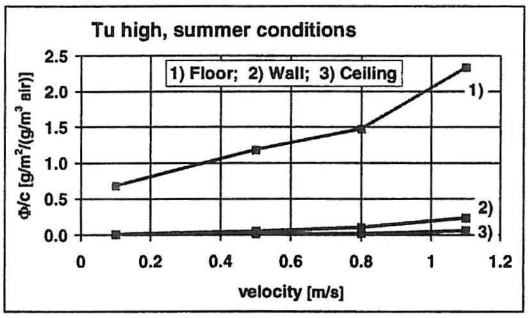

Figure 3 Dust load at different surface orientations.

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. Considering the whole area which is exposed to the airflow, it is found that only around 60 % of all the deposited dust is lying on the floor. The other 40% are deposited on the walls and the ceiling. Hence, these surfaces have an important influence on the airborne dust concentration and cannot be neglected at all.

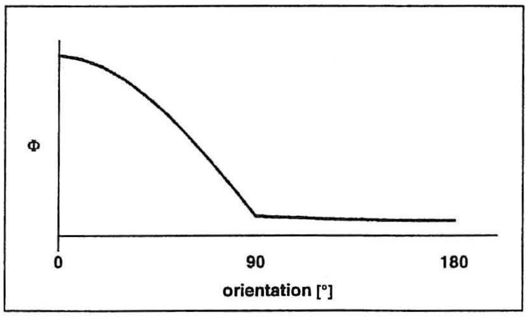

Figure 4 Dust load as a function of the surface orientation.

Moreover, the surface orientation defines the importance of other parameters. On the floor it is mainly the gravity force which determines the dust load, at other orientations the other parameters become more important.

Turbulence

Figure 5 shows that at high velocity an increased turbulence level causes increased dust load. Hence, it seems that the influence of the turbulence is much larger on the deposition than on the resuspension.

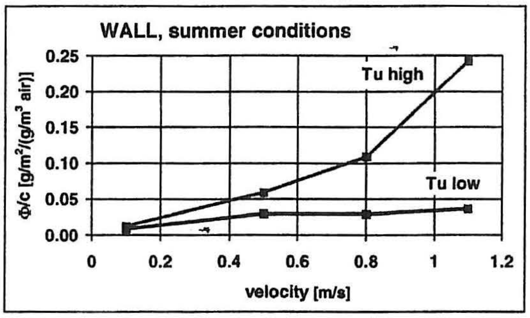

Figure 5 Dust load at different turbulence levels.

On the other hand there is no influence of the turbulence at lower velocities and even a reversed influence at very low velocities.

To analyze this phenomenon the deposition and the resuspension have to be investigated individually. However, due to the velocity effect, mentioned in the section below, the deposition and the resuspension seem to be highly dependent on velocity.

Relative humidity and temperature

The summer conditions, i.e. high relative humidity and high temperature, give a smaller dust load on the wall and the ceiling than the winter conditions (see Figure 6).

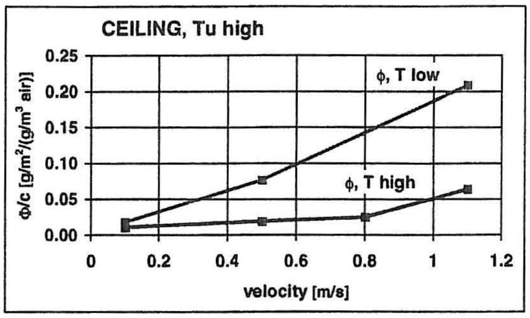

Figure 6 Dust load at different relative humidity and temperatures.

The dust load on the floor seems to be independent on the relative humidity and the temperature. Probably there is also a certain dependency but, as above mentioned, it can be neglected compared to the gravity force.

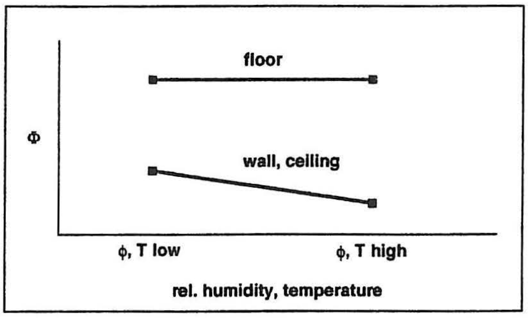

Figure 7 Dust load as a function of the relative humidity and the temperature.

One possible reason for these results could be the higher electrostatic force at winter conditions due to less humidity in the air. This thesis is reinforced by the fact that the measured mean dust diameter at summer conditions is lower than at winter conditions. However, this phenomenon has to be analysed further.

Velocity

The velocity influences the dust load in two different ways. Firstly, it determines the amount of dust which is brought over the sampling surface. This dust is potential dust load and influences all other parameters, especially the turbulence. This means the more dust is brought over the sampling surface the more dust can be deposited by the respective force. Hence, it has mainly an influence on the deposition.

On the other hand, a shear stress is caused by the air movement which influences mostly the resuspension. But, according to Shaw (1996), an increased velocity does not increase the resuspension. He explains this phenomenon with electrostatic forces which are induced by the moving air. At low velocity these forces are small and the shear stress can resuspend the particles. At higher velocities the static charge is sufficient to make small particles adhere to each other and behave as larger particles so that the shear stress is not strong enough to resuspend these large aggregates. Finally, although the induced electrostatic force is strong, for high velocities the shear stress is sufficient to resuspend the aggregates. Hence, it is obvious that there should be a maximum dust load at a certain velocity. The fact that no maximum dust load is observed in these experiments may be due to the limited velocity range applied and due to other parameters which influences the dust load.

Discussion

It is very important not to analyse the parameters isolated from each other because they have coupled effects, e.g. the influence of the turbulence and the velocity on the dust load.

In future work other parameters like surface type, electrostatic forces and mechanical forces, e.g. people walking on a surface, can be analysed as well as the transferability of the data to a full-scale room. The influence of the time has to be analysed with experiments of different duration.

By measuring the dust load at different time steps, the deposition, the resuspension and the time dependence of the dust load can be determined. For that, the presented method has to be improved to sample the dust during an experiment.

CONCLUSIONS

The following conclusions are drawn from this research: (1) The surface orientation is the most important parameter for the dust load, with the highest dust load found on the floor, but due to the large surface area of walls and ceiling its deposition cannot be neglected; (2) the effect of air velocity and the turbulence as well as other parameters are highly dependent on each other; (3) other parameters like the electrostatic charge have an effect that needs further investigation; (4) a refinement of the method is necessary to separate the two processes deposition and resuspension.

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