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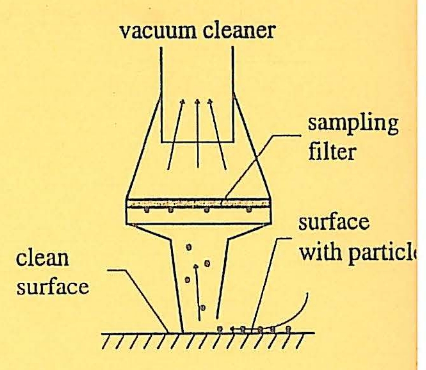

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Philip Lengweiler **Peter V. Nielsen, Ph.D.** *Member ASHRAE* **Alfred Moser, D.Sc.** *Member ASHRAE*

Per Heiselberg, Ph.D. *Member ASHRAE* **Hisamitsu Takai, Ph.D.**

ABSTRACT

A new experimental setup 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 setup, 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 that influences the dust load most. The measurement indicates that the air velocity has a nonlinear influence and that high turbulence causes high dust load.

INTRODUCTION

Indoor air contains particles that can affect the health of people. To study the health risk of a room, it is necessary to find out which kind, size, and concentration of particles are suspended in the air, where they come from, and how they are transported and distributed in the air (Hall 1998). According to Goddard et al. (1995), 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. However, deposition is considered only in a few experiments, and resuspension is considered in even fewer. 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; 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.

$$s_a = f_1\left(\begin{matrix}\text{airflow, surface conditions, amount and} \\ \text{type of airborne particles, other forces}\end{matrix}\right) \quad (1)$$

$$s_r = f_2\left(\begin{matrix}\text{airflow, surface conditions, type of} \\ \text{particles, dustload, other forces}\end{matrix}\right) \quad (2)$$

where

s_a = rate of depositing particles on the surface, $\mu g/(m^2 s)$ ($lb/[ft^2 s]$);

s_r = rate of removal of particles from the surface, $\mu g/(m^2 s)$ ($lb/[ft^2 s]$).

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, Φ, on a surface 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, $\mu g/m^2$ (lb/ft^2);

Φ_0 = initial dust load, $\mu g/m^2$ (lb/ft^2);

θ = duration of experiment, s.

Phillip Lengweiler is a doctoral student and **Alfred Moser** is head of the Air&Climate Group, ETH Zürich, Research in Building Technology, Zürich, Switzerland. **Peter V. Nielsen** is professor and **Per Heiselberg** is associate professor, Aalborg University, Indoor Environmental Technology, Aalborg, Denmark. **Hisamitsu Takai** is senior researcher, Department of Agricultural Engineering and Production Systems, Research Centre Bygholm, Horsens, Denmark.

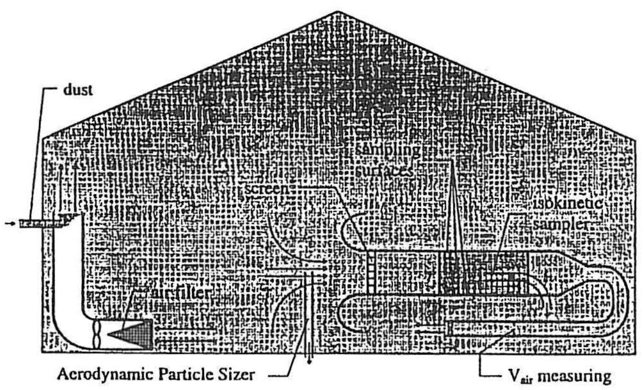

Figure 1 *Schematic experimental setup.*

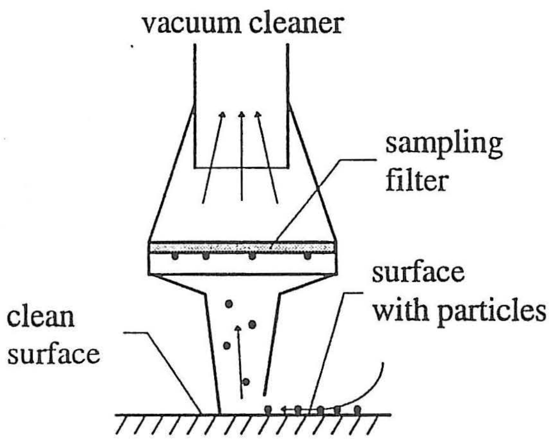

Figure 2 *Dust sampling system with vacuum cleaner and glass fiber filter.*

METHODS

Experimental Setup

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 this test channel. The channel is composed of three parts: the inlet, the working section, and the outlet.

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 perforations to produce different turbulence levels in the working section.

The surfaces of the working section, facing up (floor), vertical (wall), and facing down (ceiling), are covered with the working material. The second vertical surface is made of acrylic plastic, 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 wind tunnel by a fan placed at the end of the outlet section, which is speed controlled in order to adjust air velocity to preset 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 multipoint dust generator (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 circulated 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 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.

Air temperature, humidity, and electrostatic charge of the room air are also 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 (Schneider 1988). It is composed of three parts, where the middle one contains the filter box with the glass-fiber filter. The amount of sampled dust is determined as the difference in weight of the filter before and after sampling.

$$\Phi = \frac{m_{filter\ after\ sampling} - m_{filter\ before\ sampling}}{A} \tag{5}$$

where

m = weight of filter, μg (lb)

A = sampling area, m^2 (ft^2)

It is assumed that the deposition is proportional to the airborne dust concentration and 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 (Thatcher and Layton 1994). 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 (Ranade 1987). 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 analyzed with a small-scale powder disperser that can determine the diameter of particles.

EXPERIMENTS

As an example of the application, painted wood-fiber 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 swine 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., at a relative humidity in the air of around 60% and 30%, respectively, and at an air temperature of around 26°C (79°F) and 22°C (72°F), respectively. The main air velocities in the wind tunnel are 0.1 m/s (0.3 ft/s) and 0.5 m/s (1.6 ft/s), but some experiments are also carried out at higher velocities, namely, 0.8 m/s (2.6 ft/s), 1.1 m/s (3.6 ft/s), and 1.5 m/s (4.9 ft/s). The two nominal turbulence levels are 20% (low) and 60% (high). The turbulence is determined as the variance of the measured air velocity in the channel. By running the experiments for 30 minutes, an airborne dust concentration of around 5×10^5 particles per liter air (1.4×10^7 particles per cubic foot 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.

These experiments have the following aims:

- to verify the suitability of the experimental setup;
- to show the reproducibility of the measurements;
- to investigate the sensitivity to different parameters.

RESULTS AND DISCUSSIONS

Suitability of the Experimental Setup and Reproducibility of the Results

The first series of experiments shows that it is possible to measure the dust load on the surfaces with the presented experimental setup. Different environmental conditions can be produced and repeated. A constant airborne dust concentration and size distribution can be maintained over the experiment duration.

The applied method gives reproducible results if the sampling and weighing of the dust is done carefully.

The verification of the sampling quality with the tape technique shows that only a very few particles cannot be picked up by the vacuum cleaning system and that these particles have a very small diameter compared to the mean diameter of all particles. Hence, they do not influence the mass of the sampled dust considerably.

Reference measurements also show that other influences, e.g., the opening of the working section for sampling reasons or the deposition of background dust during the sampling of the dust on the surfaces, can be neglected.

Influences of Different Parameters

In Figures 3 through 5, the dust load is shown as a 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 amount of dust passing through the wind tunnel, the dust load shown in these figures is normalized by the sampling area and the airborne dust concentration.

The parameter that influences the dust load most is obviously the orientation of the surface. 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. As expected, the highest dust load is found on the floor, but unlike assumptions in most models in the literature, the dust load on the walls and the ceiling is not equal to zero. It is about 10% of the dust load on the floor. Considering the whole area that is covered by the walls and the ceiling, it is found that only around 60% of all the deposited dust is lying on the floor. The other 40% is 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. The dust load on the floor (see Figure 3) is mainly determined by the gravity force.

Hence, the deposition is much larger than the resuspension, at least until the dust load reaches a certain level. The dust load increases with an increased velocity. This phenomenon can be explained with the higher amount of dust blown through the working section at a higher velocity, which leads to higher deposition.

According to Shaw (1994), the resuspension decreases at increased velocity. This would be another reason for the same tendency. He explains this phenomenon with electrostatic forces that are induced by the moving air. At low velocity, these forces are small and the drag force can resuspend the

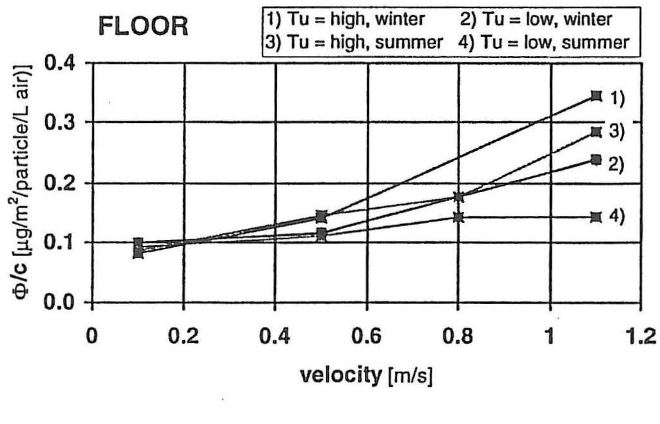

Figure 3 Dust load on the floor.

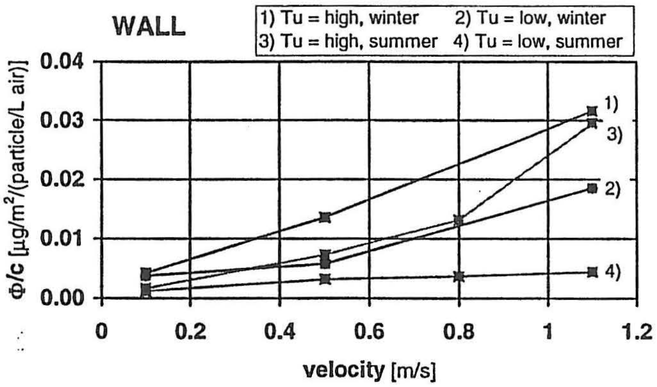

Figure 4 Dust load on the wall.

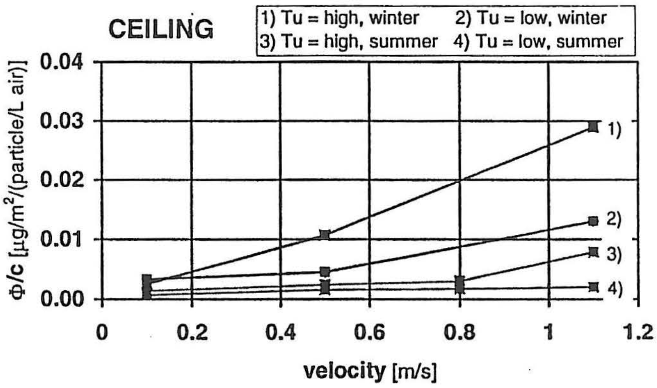

Figure 5 Dust load on the ceiling.

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 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. 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 as well as to the different deposition effects on particles of different size.

The influence of the turbulence cannot be analyzed separately from the other effects. It would be necessary to measure the deposition and the resuspension individually. But it seems that deposition depends on the combined effect of both turbulence and velocity because at a higher velocity more particles are transported that can be deposited by the turbulence. This is also shown by the fact that the dust load increases more with velocity at high turbulence than at low turbulence.

Discussion

It is very important not to analyze 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, such as surface type, electrostatic forces, and mechanical forces, e.g., people walking on a surface, can be analyzed as well as the transferability of the data to a full-scale room. The influence of the time has to be analyzed with experiments of different duration.

Methods to individually measure the deposition and the resuspension have to be found. For example, with a sticky foil that has no resuspension, the change of the dust load is equal to the deposition. On the other hand, with a surface on which the particles are deposited before starting the experiment, the resuspension could be measured.

CONCLUSIONS

The following conclusions are drawn from this research: (1) dust loads on surfaces can be measured by the described method; (2) a refinement of the method is necessary to separate the two processes of deposition and resuspension; (3) 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 the walls and the ceiling, its deposition cannot be neglected; (4) the effect of air velocity and the turbulence, as well as other parameters, are highly dependent on each other; (5) other parameters, such as the electrostatic charge, have an effect that needs further investigation. In addition, the deposition and the resuspension have to be analyzed for dust with other size distributions since the influence of the parameters changes on particles with different diameters.

ACKNOWLEDGMENT

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