

Respiratory effects of experimental exposure to office dust

Abstract The aim of this experiment was to test if healthy persons respond to exposures to normal office dust with objective or subjective effects in a dose-related way. If they did, the importance of their personal characteristics should be investigated. This paper presents the results related to respiratory effects caused by exposures to office dust. The experiment compared the responses of 24 healthy non-sensitive adult subjects with no known hyperreactivity to exposure to normal office dust in the air at 136 and 390 $\mu\text{g}/\text{m}^3$ with their responses in clean air. The exposure duration was 5.25 h in a climate chamber under controlled conditions. The dust had no major identifiable specific reactive compounds. There were no direct effects of dust exposures on nasal lavages or rhinometry. The overall indications of the experiment are that healthy subjects without any hypersensitive reactions seem to respond to exposure to house dust without specific reactive components. The only effect indicated was on eosinophil cationic protein in nasal lavages and peak flow. A delayed effect on peak expiratory flow was observed the day after the exposure. Other effects were seen but in opposite direction of expectations. Several deviations from the original design of the experiment prevent any definitive conclusions from being made from these findings before they have been confirmed in future experiments to come.

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Practical Implications

Reflecting the exploratory status of the study its major implication is to point at possible future hypotheses. The study implies that office dust may have an effect on occupants' lung function even at concentrations found in normal indoor environments. The influences of a multitude of response modifying variables were tested but no consistent pattern was found. The study does therefore not identify a specific risk group but suggests that among normal non-sensitized subjects most of the traditional risk factors can be rejected as single responsible risk factor.

Introduction

Several field and climate chamber investigations have indicated that airborne particulate matter and dust may affect the comfort and health of occupants of normal non-industrial buildings (Armstrong et al., 1990; Gyntelberg et al., 1993, 1994; Hauschildt et al., 1999; Hedge et al., 1989; Hodgson and Collopy, 1990; Kjærgaard and Brandt, 1993b; Lebowitz et al., 1990; Skov et al., 1989a; Wallace, 1996). These studies indicate that most exposures to airborne dust in non-industrial indoor environments of the Western world are in the range from 15 to 200 $\mu\text{g}/\text{m}^3$ but reaches 1000 $\mu\text{g}/\text{m}^3$ in rare situations (TSP, total suspended particulates). Individual exposures may be even higher. The dust can be described as consisting of a relatively inert base dust with the addition of biologically active compounds such as allergens or toxic chemicals (e.g.

Mølhave et al., 2000a). Previous studies have indicated that the number of neutrophile and desquamated epithelium cells increased following exposure to mineral fibers (Stokholm et al., 1982), to tobacco dust (Kjærgaard and Pedersen, 1989) or to office dust (Hauschildt et al., 1999). In addition, changes of foam formation in the eyes (Frank and Skov, 1989) and tear film stability may be affected by dust exposures (Hauschildt et al., 1999; Pan et al., 2000).

The number of airborne exposure factors causing human responses is large and many of these factors manifest themselves with the same biological effects. The occurrence of an effect, therefore, is not alone sufficient evidence to establish a causality. Further, many of these factors are correlated (Skov et al., 1989b, 1990). In consequence, epidemiological field investigations seldom are conclusive and the effects of dust on the air quality of modern buildings and

occupants' health are still only known in few details. The importance of dust for the air quality of modern buildings, therefore, has been a hypothesis for several years. After the development of exposure facilities at the Institute of Environmental and Occupational Medicine at Aarhus University (Mølhavé and Strien, 1993) an experimental test of this hypothesis became possible.

In another exposure study at the same laboratory as the present study it was found that lung function seem to be affected by dust exposures. The FEV_1 (forced expiratory volume in 1 s) decreased after exposures to office dust at $439 \mu\text{g}/\text{m}^3$ (TSP) for 245 min. The effect was significant but inconsistent (Hauschildt et al., 1996, 1998, 1999). No effects were found on forced vital capacity FVC .

Three studies of the effects of dust have been performed at the Department of Environmental and Occupational Medicine, the University of Aarhus, Denmark. The studies have been reviewed in Mølhavé (2003). In conclusion, the three studies showed strong evidence that exposure to dust causes effects. However, only inconclusive evidence was found for acoustic rhinometry/volume, nasal lavage/Eosinophil Cationic Protein (ECP), and FEV_1 .

The aim of this Aarhus Office Dust Experiment was to test if healthy persons respond to exposures to normal office dust with objective or subjective effects in a dose-related way. If they did, the importance of their personal characteristics should be investigated. This paper presents the results related to respiratory and nasal effects caused by exposures to office dust. Previous papers presented the results of analysis of the dust found in Danish office buildings and used in this experiment (Mølhavé et al., 2000a), the sensory and neurogenic reactions found in the study (Mølhavé et al., 2000b) and the effects on eyes (Mølhavé et al., 2002). An extended research report in Danish with English summary has been published (Mølhavé et al., 1995).

Material and methods

The details about the experimental design, subject selection, exposures generation and statistical analyses used in the study are found in (Mølhavé et al., 1995, 2000a,b, 2002). Therefore, only a summary will be given here.

The subjects were selected among 92 candidates who were called in for pre-investigations after having responded to advertisements in the local press. The group of 24 finally selected subjects had an even distribution both of age (range 21.9–64.2 years) with an average of 42.6 years ($SD = 14$) and gender. They had all been non-smokers for at least 6 months. Fifty percent had never smoked. The distribution on educational levels was skewed with about 33% in the group

at or above high school or similar educations. The subjects were all volunteers and their participation followed the rules of the Helsinki declaration. The experimental protocol was approved by the local ethical committee.

In the medical examination during the subject selection asthmatic and allergic persons as well as persons with a continuous medication were identified and excluded. The inclusion criteria were age 18–60 years, non-smoker for at least 6 months, healthy (i.e. no diagnosed disease including asthma and allergy). The subjects should not consider themselves more sensitive to indoor air quality than others but should on the other hand have experienced symptoms associated with indoor air quality. In a pre-investigation they should show normal sensitivity in a histamine provocation test, normal lung function and no reactions in a skin prick test on pollen, fungi, dog, cat, horse, and mites. The examination also included such factors as weight, pulse and blood pressure. The subjects were examined for eye diseases, medication, vision, and pathological conditions, which made them unsuitable for the exposures because they were expected to respond with hyperreactivity. For further details see Mølhavé et al. (2000b). In the examination a mailed health questionnaire was used. Before each exposure session a short medical examination was used to update some of the health data.

The experimental exposures of the subjects were arranged in a 32 m^3 stainless steel climate chamber at the University of Aarhus, Denmark (Mølhavé et al., 1986, 1995). The chamber had a strong mixing of ventilation air with the chamber air. No recirculation of ventilation air was used. The chamber was cleaned before each exposure according to a standard procedure and the background concentrations of dust and other pollutants were monitored before exposures. For further details see Mølhavé et al. (2000a).

An exposure session lasted 7.75 h starting with 1.5 h of exposure to clean air for acclimatization, 5.25 h of exposure in the climate chamber (to either clean air or one of two concentrations of dust, see below) followed by 1 h of exposure to clean air outside the chamber. The subjects entered the chamber when the exposure equilibrium had been established. Most of the exposure time the subjects stayed at a designated chair and table in the chamber. On the following day the subjects came in for examinations of delayed effects of the exposures. Three exposure levels of airborne dust were used. The three median levels in $\mu\text{g}/\text{m}^3$ (TSP) (lower, upper quartiles) were 7 (0, 9), 136 (110, 176) and 390 (311, 546). These levels deviated from the intended 0, 200 and $500 \mu\text{g}/\text{m}^3$ (TSP). Some geographic variations of the dust concentration were found within the chamber. Consequently, the exposure measured closest to the chair of each subject was used in the statistical analysis as the exposure measure for this subject.

The dust was separated from vacuumed office floor dust from seven office buildings (13000 m² floor area). The buildings had no known indoor climate problems. The sampling and separation of the dirt from the bags has been described by Mølhave et al. (2000a). Full details about the dust collection and exposure generation is found in Mølhave et al. (1993) and Mølhave and Strien (1993). The bulk dust was examined for its content of specific biologic or chemical agents. The results of the analyses are published by Mølhave et al. (1995, 2000a). The content of mite-, dog and cat allergens were insignificant as were the contents of micro-fungi. The organic fraction was 66%. The distribution of sizes had more than 95% of the number of particles smaller than 2.5 μm and less than 0.3% bigger than 10 μm . The content of fiber was $< 320/\text{m}^3$. Analyses of the dust and inspections in the buildings did not indicate that the dust included components with high biologic activity. The dust therefore is not expected to cause health effects because of specific constituents with high toxicity.

The variables of the controlled experimental environment

The controlled indoor climate variables included, apart from the level of dust exposure, the air change (4 ACH, 180 m³/h), air humidity ($40.4 \pm 0.6\%$ RH), air speed (10–15 cm/s), and lighting (170 lux). The CO₂ concentration in the chamber did not exceed the atmospheric normal level of 0.04%. Measurements of these factors have been described by Mølhave et al. (1995, 2000a). The subjects were wearing clean standard dress supplied by the laboratory (*c.* 0.75 CLO) and their activity levels were from 75 to 100 W. Except for the temperature and noise level (see below) these parameters were held constant at the target levels within the intended ranges of variations.

The median air temperature variations were within 2.2°C (range 20.8–23.1°C), which was more than planned. The reason for the deviation was an unexpected high body heat production of the subjects. Therefore, the ventilation and thus the injection of cold air had to be increased to the limit of what could be counteracted by increasing the production rate of the dust generator. The temperature variation was included in the statistical analyses.

On 4 of the 7 days with the highest exposure level an unintended noise was caused by a dust concentration measuring instrument (Real-time aerosol monitor RAM-1, CGA Environmental Instruments, Bedford, MA, USA) used within the chamber during these exposure sessions. The normal average noise level was increased from 51 to 59 dB(A). The instrument was started after the first acute measurements during the exposure had been made. The noise exposure was included in the statistical analyses.

The experimental design

Details about the experimental design are found in (Mølhave et al., 1995, 2000a,b, 2002). Each subject was his or her own control. They were all exposed three times in groups of four each time to one of the three concentrations of dust. The design was balanced with respect to subject age, gender, and week day. For all other factors the subjects were allocated to the groups at random. Deviations from the intended design included a few subjects of slightly deviating age and a few subjects being exposed on extra exposure days because they did not show up on the date originally planned.

The measurements of biologic effects

The measurements included both measurements of indicators of the subjects' sensitivity to air pollutants weeks before the experiment, baseline measures just before the exposures and measurements of effects of dust exposures a few minutes after having left the chamber and entered clean air conditions (subacute responses). The next day, 17 h after having left the exposure chamber, the subjects came in again for an examination of delayed effects of the exposure, in the following called late measurements. The details of the investigations have been described by Mølhave et al. (1995, 2000a,b, 2002). Here the measurements are only summarized. The baseline measurements and sensitivity measurements included data from a health questionnaire and a short medical examination, and skin prick test for responses both to extracts of the dust used for the exposure and to histamine. Furthermore, airway reactivity to inhalation of histamine aerosol and skin sensitivity to lactic acid were measured. The effect measures reported here include measurements of airway function, acoustic rhinometry, ECP and myeloperoxidase (MPO) in nasal lavage, histamine provocation of the airways and peak flow measurements.

Acoustic rhinometry The geometry of the nasal cavity was investigated using acoustic rhinometry (Grymer et al., 1989; Hilberg et al., 1989). The principle of the method is that a sound pulse is emitted into the nasal cavity through a sound tube, which is connected to the nose through a nose piece. The emitted and reflected sound waves are detected by a microphone and are used in a mathematical model to describe the cross-sectional area of the nasal cavity as a function of the distance from the start of the cavity. In the measurements the minimum area was measured. Further, the area curve as function of the distance from the sound tube was integrated to give the nasal cavity volume between 0 and 7.0 cm. The sum of this volumes and minimum areas from the two sides of the nose were

used in the statistical analyses. The method was used during subjects selection including a detumescence with Otrivin and without detumescence during exposures subacutely and the next day. No baseline correction was made.

Nasal lavage Physiological saline water (5 ml) was injected in each nostril and recollected after (10 s) centrifugation, the supernatants were stored at -80°C and the analyses were made months after the experiment. The analyses included measurements of the ECP and MPO using a commercial available kit 'Pharmacia MPORIA' and the Pharmacia CAP-System for ECP and FEIA (Pharmacia, Uppsala, Sweden). Each of the two variables of ECP or MPO were measured both as total amount and concentration in the lavage. The samples were taken in the morning before the exposures as base line measures, subacutely and the next day.

Airway function FEV_1 and FVC were measured using a spirometer (Vitalograph, Buckingham, UK). The best of three technically acceptable measurements was used as the measuring result. These measurements were made as part of the selection process. Subjects with $<75\%$ of the expected values based on international reference values were excluded from the experiment.

Histamine provocation of the airways The change of the FEV_1 after inhalation of Histamine aerosols at different concentrations were measured. FEV_1 was measured using a spirometer (Vitalograph). The best of three technically acceptable attempts was used. After an initial measurement the FEV_1 was remeasured after inhalation of a histamine aerosol following a procedure using stepwise increasing histamine concentrations of 0.6, 1.2, 2.4, 9.6, and 16 mg/ml of histaminechloride in a Wright nebulizer, which was emitting 0.15 ml/min. Each inhalation exposure had duration of 2 min. Each measurement of FEV_1 took place between 30 and 90 s after each inhalation and a following period of 30 s before the next inhalation ensured that the effect of the exposure had been removed before the next Histamine exposure. No inhalations beyond a 20% decrease of FEV_1 were made. Only if the FEV_1 was better than 90% of the baseline value did the procedure progress to the next exposure concentration. Otherwise, the same exposure level was repeated. Only subjects with more than 75% of the expected FEV_1 and FVC were included in the study and all subjects with more than 20% decrease of FEV_1 after exposure to 16 mg/ml were excluded from the experiment. The sensitivity to 16 mg/ml of histamine inhalation was also used as an effects measure. The change of FEV_1 after exposure to 16 mg/ml was reported used as effect parameter (NB: all sensitive subjects had been excluded). These measurements were made subacutely immediately after the exposure and late next day. Baseline correction was

made using the value obtained during the subject selection months before the exposures.

Peak flow measurements Peak flow was measured using a Mini Wright Peak Flow-meter (no. 3103001 (Wright, London, UK)). The peak flow meter was calibrated before the measurements (Pedersen et al., 1983). The best of two attempts was reported. The measurements were made 14 times during exposure session, one time before the exposure (Baseline), five times during exposures (each hour), three times after exposure under clean air conditions the same day and five times the next day. The subjects brought their meter home for measurements in the evening and the morning the next day.

Measures used only as sensitivity measures

Health questionnaires and medical examination The sensitivity measures included both a mailed and a short interviewed questionnaire on personal health and lifestyle factors related to the experiment, and a short medical examination before each exposure. These medical examinations included factors such as body weight, height, pulse, and blood pressure as well as skin diseases, medication, vision and pathologic conditions, which may affect the subjects' responses to exposures or which may render them unsuitable for participation in the exposure experiment.

Indices Several of the sensitivity measures are addressing the same type of sensitivity. To reduce the number of variables in the statistical analyses and because many of the measures came out with only few values different from zero a number of indices were calculated in which these variables were combined into few variables. The sensitivity measures have all been described in previous publications (Mølhave et al., 1995) and will only be summarized here. The measures were made either during the pre-investigation as part of subject selection which took place months before the investigation or on each exposure day during the acclimatization period prior to each exposure. Some of these measurements were used only during subject selection and will not be described here in details. The indices were constructed in such a way that higher values meant more unfavorable condition. The indices addressed eye irritation, infections, nose, throat irritation, physical strain, physical tiredness, and finally stress feeling all measured just before the exposure session. For more information see Mølhave et al. (1995).

Prick tests During the selection process a standard prick test with 11 allergens was used to identify atopic persons. The allergens were three fungi (birch, mugwort and grass pollen), dog, cat and mites. The

subjects' responses were measured after 15 min as the diameter of the papel caused by the provocation. In the tests an additional provocation was included using water extract of the dust used for the exposures (ALK-ABELLO Laboratories, Copenhagen, Denmark). In addition, the results of the prick tests to histamine and dust extracts were used as sensitivity indicators in the statistical analysis. Skin sensitivity to lactic acid was measured using a previously developed method (Mølhave et al., 1986). The intensity of any irritation reported was used as an indication of skin sensitivity to irritants.

Statistical analyses

As no specific hypothesis regarding the quantitative relations between response (effect) and explanatory variables or their interactions could be specified before the study, the study should be considered exploratory, and thus useful only for generating hypotheses for examination in future studies. Details of the statistical analysis are found in Mølhave et al. (1995). Each response variable was analyzed as an independent experiment. Moreover subacute and late measurements on the same response variable were analyzed separately. No formal corrections were made for multiple significance testings. To reduce the between-subject variation, each response variable for which baseline was measured was baseline corrected by subtraction. The corrected response variable was analyzed by multiple linear regression on selected explanatory (predictory) variables, which *a priori* were judged to have a potential causal effect on the response. To reduce the risk of spurious findings, only influences that changed on entrance into the chamber (chamber variables: dust concentration, noise, temperature, and humidity) were included as main effects in the regression model, whereas all the remaining variables were included only in interaction with the dust concentration.

First, to stabilize variances, make distributions more normal, and linearize relationships, the baseline-corrected response variable was transformed following the systematic approach of Box and Cox (1964). The assumptions of normal distribution and homogeneity of variance were checked by residual analysis. Significant explanatory variables were found by backward step-wise regression (Altman, 1991), where insignificant variables were removed one at a time until all those remaining in the model were significant at the 10% level, except for the chamber variables, which were included irrespective of significance to avoid proxying with dust concentration. Subsequently, insignificant variables, including chamber variables, were eliminated by backward regression at the 5% level. In case of a significant interaction between a within-subject variable (e.g. level of eye irritation before exposure) and dust concentration, to reduce the risk of

spurious effects due to regression to the mean, the variable concerned was included as a main effect, and the interaction term was kept in the model only if it remained significant at the 5% level. Finally, the overall effect of dust was tested by simultaneous elimination of all main and interaction effects of dust, and the effect of dust was considered real only if the overall effect was significant at the 5% level.

Results

The effects of exposures to house dust

Several of the effect measures showed effect of the experimental dust exposures and some of these effects appeared in interaction with one or more explanatory variables. In the following the effects of dust on the airways and the interactions between the explanatory variables are summarized. Note that sensitive subjects with more than a 15% decrease in peak expiratory flow had been excluded in the selection process. Table 1 summarizes the significant effects of exposures to house dust on airway functions. Only the statistical significant effects of dust are shown in the table, which also show the response modifiers, which were found to affect these variables.

Acoustic rhinometry The data distribution was approximated with a normal distribution and a normal linear model was used. Baseline correction was made using the measurement before the exposure as reference. There was an acceptable variance homogeneity. In addition to dust exposure, air temperature and humidity, noise, subject age, height, gender, coffee consumption before the exposure, smoking status, reaction to histamine in the prick and inhalation tests, reactions to extract of the dust in the prick test, and index of nose irritation were included in the analyses as explanatory variables in interaction. No direct effect of exposures to house dust was found (neither acute or subacute). Only the late volume showed an effect of exposure to house dust in interaction with age as response modifier. Increased exposure caused an increased volume of the nose the next day. There was a significant interaction from subject age in such a way that increased age potentified the response to dust. The late response to dust was significant for all ages. Increased air humidity caused a decrease of nasal volume and minimum area, but this did not interact with the responses to dust exposures.

Nasal lavage Data were baseline corrected by subtraction of the measurement made before the exposure and were then rank transformed. Twenty-four data were missing. The distribution was approximated with a normal distribution. The normal linear regression model was used. In addition to dust exposure, air

Table 1 Summary of the effects of dust on airways and the interactions between explaining variables. Only significant effects are shown

Effect type	Times of significance	Direct effect of environment or sensitivity indices	Interaction between dust and modifiers	Effect of increased dust exposure
Acoustic rhinometry, volume	Late	Air humidity (–)	Age (+)	Increased volume potentiated by increased age
114 ECP/nasal lavage	Subacute	Air temperature (+) Air humidity (+) Index of nose irritation (–)	Skin prick test to extract of dust (–)	Decrease in both amount and concentration. Strongest for subjects with low sensitivity to dust extract
Peak expiratory flow	Acute, subacute and late	/	Gender Skin prick test to extract of dust (+)	Reduced peak flow caused by exposure. Men respond strongest. High sensitivity in prick test for dust extract causes less change of peak flow subacutely

*+/- 1% < P < 5 increasing response by increasing/decreasing value of variable.

*+/- 1% < P < 1 increasing response by increasing/decreasing value of variable.

‘/’ No effect.

temperature and humidity, subject age, height, gender, coffee consumption before the exposure, smoking status, reaction to histamine in the prick and inhalation tests, reactions to extract of the dust in the prick test, and index of nose irritation were included in the analyses as explanatory variables in interaction with dust.

In nasal lavages no direct effects of exposures to house dust were observed on ECP. However, both the amount and the concentration of ECP decreased subacutely as a consequence of the exposure but in an interaction with sensitivity to extract of the dust in such a way that the subjects with high sensitivity in the prick test to extract of the dust used for the exposures had a lesser decrease of the ECP during exposures. Air humidity, air temperature and index of nose irritation affected ECP but not in relation to dust exposures. No effects of dust exposures were seen on MPO in nasal lavage.

Sensitivity to histamine aerosol inhalation Data were baseline corrected using the measurement from the pre-investigation and subject selection as reference. These results were not transformed. The normal linear regression model was used. In addition to dust exposure, air temperature, humidity, noise, subject age, height, gender, coffee consumption before the exposure, smoking status, reaction to histamine in the prick, and inhalation tests, reactions to extract of the dust in the prick test, and index of nose irritation were included in the analyses. No significant effects were observed following the exposures to house dust. If unintended noise was included in the analyses a tendency to an effect of exposure was found. Data were obtained from all but one subject. Analyses of the baseline corrected data showed inconclusive indications of effects of dust but the final conclusion is that no effects of dust exposure were found.

Peak flow Figure 1 shows the variation of the average peak flow of the three exposure groups. The groups had exposures ranging between (i) 0–40, (ii) 40–260 and

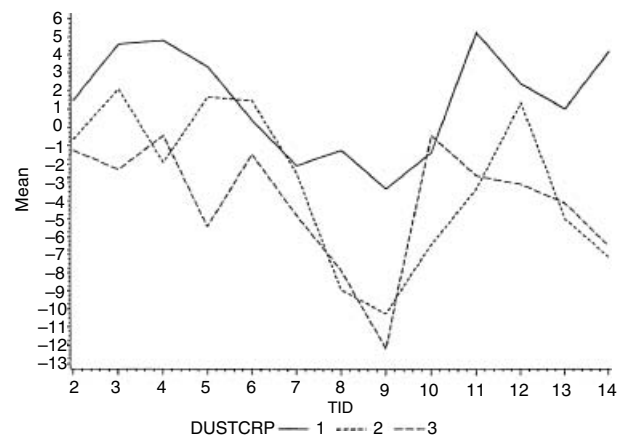


Fig. 1 Time course of mean peak flow (baseline corrected) for the three groups of subjects exposed to 1: 0–40 $\mu\text{g}/\text{m}^3$, 2: 41–260 $\mu\text{g}/\text{m}^3$ and 3: >260 $\mu\text{g}/\text{m}^3$ (STP). The line base is hours. (y-axis L/S)

(iii) more than 260 $\mu\text{g}/\text{m}^3$. The figure indicates a systematic variation with time for the three groups and a systematic lower peak flow among the exposed subjects. This effect appeared both acutely, subacutely and late. Data were available for only 44 of 72 observations because of technical problems. This reduces the efficiency of the statistical analyses. The data were not transformed. The distribution could be approximated with a normal distribution. Several analyses were made. Initial univariate and multivariate analyses showed no strong effect of exposures to dust. The multivariate analyses included all 14 measurements from each subject and time as an explaining factor in addition to the other factors. The analyses showed significant effect of the interactions time $\times$ exposure $\times$ index of infections and time $\times$ exposure $\times$ reaction to histamine in prick test ($P = 3\%$). Additional analyses were made using the first peak flow measurement as baseline. In addition to dust exposure, air temperature and humidity, noise, subject age, height, gender, smoking status, reaction to histamine in the

prick and inhalation tests, reactions to extract of the dust in the prick test were included in the analyses as explanatory variables. Table 1 shows the results of the analyses. Peak flow was reduced both acutely and subacutely and the effect was also measurable on the following day. Men did respond stronger than women who in most cases did not respond at all. The subjects with high sensitivity in the prick test to extract of the dust used for the exposures had a lesser decrease of the peak flow during exposures. In acute and late measurements no effect was seen for women while men had a significant decrease of peak flow during dust exposures.

Discussion

The experimental conditions

A number of deviations from the planned experimental design occurred. A few subjects had to be exposed on additional exposure days as they failed to appear on the scheduled day according to the balanced design. Furthermore, the temperature varied more than planned. Clear effects of this variation were observed. For some of the effects, the initial statistical analyses also indicated effects of varying air humidity (range 39–41% RH) (see below). Finally, the noise level at some days was 59 dB(A), which is higher than the average of the other days [51 dB(A)]. The deviations in exposure conditions are not expected to affect objective measures of effects on lung function. In the interpretation of the study it should further be noted that the analyses of the questionnaire evaluations of air quality and odor (Mølhave et al., 2000b) indicated that the subjects perceived the dust exposures. Although the measurements depend on the subjects' cooperation odor is not expected to have caused a bias on the objective lung function or lavage measurements.

The deviations of exposure, temperature, humidity, and noise from the planned design were included in the statistical analyses. Only air humidity was found to affect the effects of dust exposures on nasal volume (acoustic Rhinometry) but as the variation was only 3% RH this is considered an artifact. In addition, temperature affected NADAR but not the effects of dust on NADAR. However, due to lack of *a priori* hypotheses about the relation between different outcome variables and the exposures the experiment is not conclusive and should be considered as explorative. It follows that not all the identified associations to dust exposures are necessarily causal. In addition, several deviations from the original design of the experiment prevent any definitive conclusions from being made from the findings reported here before they have been confirmed in experiments to come.

The dust is considered not to deviate significantly from dust in offices. No components were identified in concentrations, which are known to be especially

biologically reactive (Mølhave et al., 2000a). Therefore, the dust is expected to have minimal biologic activity. The only argument against this conclusion was a relatively increased release of histamine from leukocytes in laboratory tests (Mølhave et al., 2000a). In addition, the exposure duration of about 315 min is shorter than the average daily exposure in offices, and all candidate subjects with sign of hypersensitivity had been excluded. It follows that the effects observed must be considered to be minimum effects.

The subjects represent a wide range of the healthy part of the Danish population if the lack of subjects aged below 18 and above 64 and hyperreactive is disregarded. Thus the results should be directly comparable with the response of occupants of normal buildings to increased office dust exposures. However, such an extrapolation does not account for the added exposure to other indoor climate factors during real life conditions.

A number of conditions have to be fulfilled for the correct application of each of the statistical analyses used. Generally, this was the case and deviations from this are mentioned in the text. For most variables the data collection was better than 95% and no variable had a collection efficiency below 90%. The missing data were generally caused by technical problems.

The respiratory effects of dust

The nasal volume increased after exposures while amount of ECP decreased during exposure. Increased nasal volume following exposure is in the opposite direction of the expected if irritation cause swelling of the mucous membranes. No effects were found in a similar study of Hauschildt et al. (1996, 1998, 1999). Wålinger et al. (1999) found in a study of settled dust and cleaning routines that the amount of settled dust correlated negatively with nasal volume (more dust – smaller volume). No clear conclusions can be made from this study.

Decreased ECP could indicate a reduced inflammation based on allergic reactions and thus supports an increased NADAR volume found here. Wålinger et al. (1999) found that ECP levels were increased in nasal lavages in schools with lower quality of dust removal/cleaning. Therefore no clear conclusion can be made.

Peak flow was reduced both acutely and subacutely and the effect was also measurable on the following day. This effect of dust at these concentrations indoors has not been reported before. However, they were significant in many repeated measures as seen in Figure 1.

Response modifiers

A multitude of explanatory variables in addition to dust exposure, noise and air temperature were used to

explain the responses in the statistical analysis. These additional variables included interactions with gender, education, infections prior to the experiment, height, age, smoking habits, alcohol consumption, lung function, cornea wounds prior to the experiment, and nose irritations prior to the experiment. The subjects with high sensitivity in the prick test to extract of the dust used for the exposures had a lesser decrease of the peak flow and nasal ECP during exposures. A carry over of effects 17 h after exposures (or appearance of effects the next day with a delay) was seen for peak flow. This finding underlines that this experiment may underestimate the accumulation of effects caused by daily repeated exposures in real life.

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