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Trends in Wood Dust Inhalation Exposure in the UK, 1985–2005

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Objectives: Wood dust data held in the Health and Safety Executive (HSE) National Exposure DataBase (NEDB) were reviewed to investigate the long-term changes in inhalation exposure from 1985 to 2005. In addition, follow-up sampling measurements were obtained from selected companies where exposure measurements had been collected prior to 1994, thereby providing a follow-up period of at least 10 years, to determine whether changes in exposure levels had occurred, with key staff being interviewed to identify factors that might be responsible for any changes observed.

Methods: Analysis of the temporal trend in exposure concentrations was performed using Linear Mixed Effect Models on the log-transformed NEDB data set and expressed as the relative annual change in concentration.

Results: For the NEDB wood dust data, an annual decline of geometric mean (GM) exposure of 8.1% per year was found based on 1459 exposure measurements collected between 1985 and 2003. This trend was predominantly observed in data from inspection visits (measurements collected on a mandatory basis by a Specialist HSE Inspector) (*n* = 1009), while data from representative surveys (measurements collected on a voluntary basis to provide information on current practices and exposures) remained relatively stable. Ten follow-up surveys in individual workplaces in 2004–2005 resulted in 70 new measurements and for each of the companies resurveyed, the GM of the wood dust exposure decreased between sampling surveys.

Conclusion: Analysis of the temporal trend in UK wood dust exposure concentrations revealed declines of 8% per annum. Interviews with key long-serving employees and management suggest that factors such as technological changes in production processes, response to new legislation, and enforcement agency inspections, together with global economic trends, could be linked to the downward trends observed.

Keywords: exposure; inhalation; time; trends; wood dust

INTRODUCTION

Wood dust is a general term covering a wide variety of airborne wood dusts, which are produced during the processing and handling of both hard and softwood, chipboard, hardboard, and other composite materials (HSE, 2003). Exposure to wood dust may cause respiratory diseases and the International Agency for Research on Cancer (IARC, 1995) has classified wood dust as carcinogenic to humans based on epidemiological evidence. In 2000–2003, it was estimated that ~384 000 UK workers were occupationally exposed to inhalable wood dust (Kauppinen *et al.*, 2006). It is estimated that ~81 000 UK workers and over 500 000 workers in the European Union (EU) wood-processing industries may be exposed to dust levels (any type of wood dust) exceeding 5 mg m^{-3} (Kauppinen *et al.*, 2006).

An occupational exposure limit (OEL) of 5 mg m^{-3} (8-h time-weighted average) for inhalable hardwood dust came into effect in the UK in April 1988; this

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being replaced by a maximum exposure limit (MEL) of the same value when the control of substances hazardous to health (COSHH) Regulations came into force in October 1989 (HMSO, 1988). A MEL of the same value was also introduced in January 1997 for softwood. In 2005, the system of exposure limits was changed in the UK, and currently there is a workplace exposure limit of 5 mg m^{-3} for all wood dust (HSE, 2005). It is therefore apparent that since 1988, the 8-h OEL, irrespective of type of exposure limit in place, has remained a constant 5 mg m^{-3}. The Scientific Committee for Occupational Exposure Limits of the EU has stated that exposure to wood dust >0.5 mg m^{-3} induces pulmonary effects and therefore should be avoided (SCOEL, 2002).

We investigate the temporal changes in wood dust exposure in the UK as part of a larger project examining long-term changes in inhalation exposure to various hazardous substances in a number of industries within the UK (Creely *et al.*, 2006).

MATERIALS AND METHODS

National Exposure DataBase wood dust data set and data preparation

Wood dust data held in the National Exposure DataBase (NEDB), which was set up by the UK Health and Safety Executive (HSE) in 1986 (Burns and Beaumont, 1989), was made available for the analysis. Several core data criteria were identified (Ritchie and Cherrie, 2001; Tielemans *et al.*, 2002) and applied to select data to be included in the analysis, these being economic activity (industry), sampling date, sampling device, sample duration, analytical methods, measured concentration, and units used. In total, 1651 wood dust measurements from 168 locations or plants, obtained between 1985 and 2003, were extracted from the NEDB for the analysis. Occupation and industry were coded using Standard Occupational Classification 2000 (ONS, 2000a,b) and Standard Industrial Classification 2003 (ONS, 2003), but these were subsequently amalgamated into five industrial and occupational categories (excluding unknown) for analysis, as detailed in Table 1.

Data were then excluded from the analysis using the following criteria, with steps (i), (ii), and (iii) being repeated as necessary:

(i) Data available for <5 separate years for an industry or occupation;
(ii) Less than 50 measurements available across all years for an industry/occupation;
(iii) Less than 50 measurements available for an individual category of a confounding variable (wood type—soft, hard, or mixed; visit type—inspection or non-inspection; season—spring, summer, autumn, or winter).

There were two types of survey: inspection surveys are those undertaken by a Specialist Inspector as part of the HSE inspection process; representative surveys are traditionally undertaken to provide information on the working practices and exposure levels within an industry. Exposure measurements collected during these representative surveys were collected from companies on a voluntary basis P. Griffin (personal communication).

Table 1. Industry and occupation categories used in the wood dust analyses

#	Industry description	SIC codes	*n*	Years[a]
1	Manufacture of furniture	36.1; 36.12; 36.13; 36.14	849	16
2	Manufacture of wood products (non-furniture)	20.4; 20.5; 36.3; 36.509;	297	10
3	Manufacture of non-wood products	15.209; 24.61; 26.15; 27.51; 28.73; 34.203; 34.3; 35.3; 36.15; 36.2; 36.5; 80.21	71	8
4	Timber industry/mills etc.	20.1	56	4
5	Manufacture of builder/construction wood products	20.3; 45.45	359	14
6	Unknown		19	2
#	**Occupation**	**SOC codes**	***n***	**Years[a]**
1	Carpenter	5315; 5316; 5492; 5499; 8139; 9121	230	13
2	Cleaner	9233	22	9
3	Miscellaneous	1121; 3422; 5241; 5323; 5493; 6124; 8111; 8121; 8125; 8129; 8133; 8139; 8222; 9134; 9149	41	11
4	Sander/polisher	5323; 8121; 8139	349	15
5	Wood machinist	5315; 5412; 8121; 8125; 8139; 9121; 9149	1007	19
6	Unknown		2	1

SIC, Standard Industrial Classification; SOC, Standard Occupational Classification. Manufacture of non-wood products stands for the manufacture of those products where the main raw material is not wood, but the product has some parts or elements which are made of wood. *n*, number of measurements.
[a]Total number of years for which data were available.

Repeat wood dust exposure monitoring surveys

The Institute of Occupational Medicine's (IOM) occupational hygiene consultancy login system and the NEDB were used to identify companies suitable for follow-up where wood dust surveys were carried out prior to 1994 and yielded more than three exposure measurements that fulfilled the core data criteria, as well as further contextual information on the tasks/processes monitored and the control measures in place. Companies were contacted to establish their willingness to participate in the study.

During the monitoring surveys, similar exposure measurements to those collected during the previous surveys were obtained. Wherever possible, the same jobs or tasks as detailed in the original occupational hygiene report were monitored and the same sampling and analytical techniques as those used previously were applied. The majority of the inhalable wood dust samples were obtained using a seven-hole sampling head with the exception of one plant, W6, where IOM sampling heads were used in 2004. The measurements for this plant were reduced by 20% (Boffetta *et al.*, 2003) to be comparable with a seven-hole sampling head.

Key long-serving employees and management were also interviewed using a semi-structured questionnaire to determine whether changes in processes, technology, and control measures had occurred between the monitoring surveys and if so, the reasons for these changes (Creely *et al.*, 2006). The interview included a combination of both closed and follow-up open questions to allow the interviewee to respond as fully as possible.

Statistical analysis

The exposure data were transformed using natural logs prior to the analysis. Analyses were carried out using Linear Mixed Effect Models assuming a hierarchical structure of the data using the Proc Mixed procedure in SAS (version 8.02), with the log-transformed wood dust exposure results as the dependent variable. Plant was included in these models as a random effect.

We considered three types of fixed effects in the model. First, as the variable of main interest in temporal trend analyses, year was included as a continuous fixed effect. Next, we considered variables that were not causally linked with any temporal change in exposure. For example, season during which the measurement was taken cannot be related to any real change in exposure. However, if there was a shift in sampling over time, for example, from predominantly measuring during the winter in the earlier surveys to sampling in the summer during the later survey, then this could lead to a perceived change in exposure if the trend analyses were not corrected for this variable. In this category of potentially confounding variables, the following variables were available for analyses: industry, occupation, wood type, survey type, and season. Finally, we considered fixed effects that could be causally related to changes in exposure over time (exposure modifiers). For example, the introduction of a local exhaust ventilation (LEV) system is likely to result in a change in exposure. However, including these variables in the model would potentially hide any real change in exposure.

The Linear Mixed Effect Model was developed as follows:

Step 1: Inclusion of 'plant' as random and 'year' as fixed effect.

Step 2: Confounding variables were subsequently considered for inclusion in the model using a systematic forward stepwise procedure. Variables were considered for inclusion in the model based on (i) impact on the coefficient for year (>20%) and (ii) statistically significant improvement in the fit of the model. Modelling of the main effects ended when there was no further improvement in fit from systematically testing the main effects.

Step 3: Inclusion of any exposure modifiers, depending on any improvement of fit of the model.

The following model was used to describe the data sets:

$$\ln\left(\mathrm{E}_{(ik)}\right) = \beta_0 + \beta_1 \times \text{Year} + \beta_2 \times \text{Confounders} + \beta_3 \times \text{Modifiers} + \chi_{(i)} + \epsilon_{k(i)}$$

for $i = 1, 2, \ldots, n_i$ plants and n_k measurements (nested within plant). $\chi_{(i)}$ represents the random effect of the i-th plant and $\epsilon_{k(i)}$ represents the random effect of day (k) within plant (i). It was assumed that $\chi_{(i)}$ and $\epsilon_{k(i)}$ are normally distributed with zero means, and that these random effects are statistically independent. It was further assumed that any two measurements within the same plant have equal correlation irrespective of the time interval between the measurements, while measurements carried out in different plants are uncorrelated (compound symmetry covariance structure) (Peretz *et al.*, 2002).

In addition, we also carried out stratified analyses of the temporal trend by industry, occupational group, and type of survey.

The temporal trends were expressed as the annual change in geometric mean (GM) exposure using the following expression:

$$\%\ \text{change per year} = 100 \times (\exp[\beta_1] - 1)$$

RESULTS

NEDB wood dust data set

Descriptive statistics. After applying the data exclusion criteria, results from 1459 measurements from 153 plants were available for analyses (192 measurements were excluded). No details on the actual sampling duration were available, although all the measurements were classified as long-term personal samples. The results ranged from <0.01 (one measurement) to 501.6 mg m^{-3} with a mean (arithmetic mean) of 12.4 mg m^{-3}, a GM of 5.2 mg m^{-3}, and a geometric standard deviation of 3.6. Table 2 describes the wood dust exposure by year. The years with the most data were 1988 (n = 321) and 2000 (n = 345) whereas there was only one measurement available for 1998. The highest average wood dust level (in terms of GM) was observed in 1986 (GM = 15.2 mg m^{-3}). There were no personal identifiers in the database and so we were not able to estimate within- and between-worker variances.

Table 3 shows the results of the wood dust measurements by the various confounders and determinants of exposure considered in the model. These were industry sector, occupation, type of wood dust, type of survey, season, and the potential determinant of exposure being the presence of LEV.

There appears to be very little difference in the mean exposure between the industries, with GMs ranging from 5.0 mg m^{-3} in 'manufacture of furniture' (Industry 1) to 7.7 mg m^{-3} in 'manufacture of non-wood products' (Industry 3). Following exclusions, only data from three occupations were available for analyses. Exposure levels were similar for these three occupations, with the GM ranging from 4.8 mg m^{-3} for 'wood machinists' to 6.1 mg m^{-3} for 'sanders/polishers'. The majority of the measurements were for hardwood dust, with 36% mixed wood dust measurements and only 6% for softwood dust. The exposure levels appear to be lower in cases where workers were exposed to a mixture of hard and softwood (GM = 3.6 mg m^{-3}) compared to 7.8 mg m^{-3} for exposure to softwood and 6.3 mg m^{-3} for exposure to hardwood. The majority of the data (n = 1009; 69%) were collected during inspection visits with 450 data points being collected during representative surveys. The exposure levels found during inspection visits and representative measurement surveys were very similar (GM = 5.5 mg m^{-3} and 4.5 mg m^{-3}, respectively).

Most of the representative surveys were carried out during the late 1980s, although a few measurements were collected in a representative survey in 1996. Data from inspection visits were available throughout the period between 1985 and 2003. Exposure to wood dust appeared to be higher during the autumn (GM = 6.8 mg m^{-3}) and lowest in the winter (GM = 4.0 mg m^{-3}). For the majority of measurements, some form of LEV was present, although the presence of LEV appeared to have little impact on the wood dust exposure levels in this data set, with the GMs being similar whether LEV was present or not.

Linear Mixed Effect Models. After entering year in the Linear Mixed Effect Model, only inclusion of the variable related to the type of survey significantly improved the model. Finally, the inclusion of the variable indicating the presence of LEV was tested to

Table 2. Personal wood dust exposure (mg m^{-3}) by year

Year	$N_{samples}$	N_{plants}	AM	GM	GSD_{tot}	GSD_{bp}	GSD_{wp}	Min	Max
1985	24	4	12.0	6.4	2.8	1.5	2.6	1.1	110.0
1986	125	9	27.1	15.2	2.9	2.0	2.3	1.1	305.5
1987	120	11	12.5	8.0	2.5	1.8	2.0	1.2	83.0
1988	321	26	10.4	4.0	3.1	2.3	2.2	0.4	501.6
1989	125	17	11.3	5.3	3.4	2.4	2.3	0.3	120.0
1990	17	2	14.8	12.1	2.0	1.0	2.0	4.5	35.8
1991	104	14	15.5	10.0	2.6	1.9	2.1	1.3	77.0
1992	81	6	8.1	5.2	2.6	2.0	1.9	0.2	40.0
1993	46	4	11.7	6.5	3.1	2.0	2.4	0.9	65.7
1994	37	5	5.4	4.5	1.9	1.4	1.7	0.5	17.7
1995	20	3	10.6	5.0	3.4	1.9	2.8	0.7	75.7
1996	21	4	6.9	4.6	2.6	1.9	2.0	0.7	23.2
1997	16	2	18.5	11.6	2.7	1.0	2.7	2.1	95.0
1998	1	1	0.1	0.1	1.0	1.0	1.0	0.1	0.1
1999	13	4	4.0	2.5	2.9	2.2	2.0	0.5	12.0
2000	345	40	7.9	2.7	4.1	2.8	2.6	<0.01	305.3
2001	27	4	48.6	11.5	5.5	4.8	1.9	1.2	449.0
2002	5	1	5.7	5.4	1.3	1.0	1.3	4.4	9.2
2003	11	2	8.5	5.9	2.7	1.0	2.7	2.2	21.5

$N_{samples}$, number of measurements; N_{plants}, number of plants; AM, arithmetic mean; GSD_{tot}, total geometric standard deviation; GSD_{bp}, between-plant geometric standard deviation; GSD_{wp}, within-plant geometric standard deviation; Min, minimum exposure; Max, maximum exposure.

determine if this improved the fit of the model; however, this was not the case. Table 4 provides information on the modelling steps. The between-plant variance decreased by 21% after the addition of year and type of survey to the model; however, the within-plant variance showed little change, due to the limited amount of longitudinal data within plant (only 6 of the 160 plants had data for >1 year). After including the type of survey in the model, the effect of year on the log-transformed wood dust exposure was −0.085, which is equivalent to an annual decrease in the GM exposure of 8.1%.

Stratified analyses were also carried out by industry, occupation, and visit type (Table 5). When analysed by industry, statistically significant trends in exposure were observed for manufacture of furniture (−8.9% per year), 'manufacture of wood products (non-furniture)' (−8.8% per year), and 'manufacture

Table 3. Personal wood dust exposure (mg m^{-3}) by confounders and determinant of exposure

	n	AM	GM	GSD_{tot}	GSD_{bp}	GSD_{wp}	Min	Max
Industry								
1. 'Manufacture of furniture'	825	11.6	5.0	3.4	2.5	2.2	0.2	391.0
2. 'Manufacturer of wood products' (non-furniture)	269	14.4	4.9	4.9	3.4	2.7	<0.01	449.0
3. 'Manufacturer of non-wood products'	54	14.4	7.7	3.0	1.7	2.6	0.5	104.0
4. 'Manufacturer of builder/construction wood products'	311	12.3	5.7	3.2	2.4	2.2	0.1	501.6
Occupation								
Carpenters	212	10.6	5.7	2.9	2.2	2.0	0.2	115.0
Sanders/polishers	335	12.7	6.1	3.3	2.3	2.3	0.1	258.0
Wood machinists	912	12.7	4.8	3.8	2.7	2.4	<0.01	501.6
Wood dust								
Mixed	524	8.7	3.6	3.8	2.7	2.5	<0.01	305.3
Soft	82	13.3	7.8	3.0	2.3	2.0	0.2	95.0
Hard	853	14.5	6.3	3.3	2.5	2.1	0.2	501.6
Type of survey								
Representative	450	10.9	4.5	3.2	2.3	2.3	0.3	501.6
Inspection	1009	13.0	5.5	3.7	2.8	2.3	<0.01	449.0
Season								
Winter	478	9.4	4.0	3.8	2.7	2.4	<0.01	305.5
Spring	368	13.0	5.2	3.5	2.4	2.5	0.1	449.0
Summer	249	13.4	5.8	3.5	2.8	2.1	0.4	501.6
Autumn	364	14.9	6.8	3.3	2.2	2.4	0.2	391.0
LEV present								
Yes	779	13.0	5.3	3.5	2.5	2.4	0.1	501.6
No	552	10.7	4.9	3.7	2.8	2.3	<0.01	137.0
Unknown	128	15.9	6.3	3.5	2.4	2.4	0.3	449.0

n, number of measurements; AM, arithmetic mean; GSD_{tot}, total geometric standard deviation; GSD_{bp}, between-plant geometric standard deviation; GSD_{wp}, within-plant geometric standard deviation; Min, minimum exposure; Max, maximum exposure.

Table 4. Information on the mixed effects model during the various stages of model development

Model[a]	−2RLL	AIC	Diff	df	*P*-value	β_{year}	SE	Annual trend (%)	Between plant	Within plant
0	4305.7	4309.7	—	—	—	—	—	—	0.6185	0.9255
1	4289.5	4293.5	16.2	1	$P < 0.001$	−0.058	0.012	−5.7	0.5323	0.9226
2	4274.5	4278.5	15.0	1	$P < 0.001$	−0.085	0.013	−8.1	0.4887	0.9185

−2RLL, −2 Residual Log Likelihood estimate; AIC, Akaike information criterium (smaller is better); Diff, difference in −2RLL associated with the inclusion of the additional variable (i.e. difference with the model in the previous row); Df, degrees of freedom associated with inclusion of the additional model; *P*-value, *P*-value of log-likelihood ratio test to determine improvement in fit; β_{year}, parameter estimate for year; SE, standard error for β_{10}; Between-plant, between-plant variance in exposure; Within-plant, within-plant variance in exposure.

[a]0, no fixed effects included in the model; 1, year; 2, year and type of survey.

Table 5. Results of stratified analyses of trend in wood dust exposure

	β	SE	*n*, years	Range, years	Between plant	Within plant
Stratified analysis by Industry						
Manufacture of furniture						
No fixed effects			16	1985–2001	0.5593	0.8726
+ Year	−0.062	0.016	16	1985–2001	0.4648	0.8708
+ Year, survey type, and occupation	−0.093	0.017	16	1985–2001	0.3779	0.8577
Manufacture of wood products (non-furniture)						
No fixed effects			10	1987–2003	0.9911	1.2205
+ Year	−0.112	0.038	10	1987–2003	0.8289	1.2042
+ Year and season	−0.092	0.046	10	1987–2003	0.7955	1.1681
Manufacture of non-wood products						
No fixed effects			7	1986–2000	0.1430	1.0200
+ Year	−0.043	0.040	7	1986–2000	0.1173	1.0262
Manufacturer of builder/construction wood products						
No fixed effects			14	1985–2002	0.5654	0.7888
+ Year	−0.053	0.023	14	1985–2002	0.5159	0.7851
Stratified analysis by occupation						
Carpenters						
No fixed effects			13	1986–2002	0.6668	0.5598
+ Year	−0.049	0.020	13	1986–2002	0.5931	0.5627
Wood machinists						
No fixed effects			19	1985–2003	0.6872	1.0048
+ Year	−0.060	0.014	19	1985–2003	0.5915	1.0025
+ Year, survey type, and type of wood	−0.058	0.019	19	1985–2003	0.5915	0.9910
Sanders/polishers						
No fixed effects			15	1985–2001	0.6000	0.7733
+ Year	−0.049	0.017	15	1985–2001	0.5320	0.7730
+ Year, survey type	−0.067	0.019	15	1985–2001	0.4996	0.7705
Stratified analysis by type of survey						
Representative data						
No fixed effects			5	1986–1996	0.4280	0.9108
+ Year	−0.002	0.094	5	1986–1996	0.4398	0.9112
Inspection data						
No fixed effects			19	1985–2003	0.6960	0.9302
+ Year	−0.086	0.014	19	1985–2003	0.5085	0.9239

β, parameter estimate for fixed effects; SE, standard error of parameter estimate.

of building and construction products' (−5.1%). When stratified by occupation, survey type was a significant predictor of exposure for the wood machinists and 'sanders/polishers', while type of wood was also a predictor of exposure for the wood machinists. Statistically significant trends were observed for all occupations and ranged from an annual trend of −4.8% for the 'carpenters' to −6.5% for the sanders/polishers. When stratified by type of survey, the final models only included year as a predictor of exposure, and only for data collected during inspection visits was there temporal trend in exposure that was statistically significant (−8.2%).

Figure 1 shows the temporal trends for data collected during representative surveys and during inspection visits. These results indicate that the decline in exposure was predominantly observed for data collected during inspection visits.

Repeat wood dust exposure monitoring surveys

Seven companies from IOMs consultancy login systems and 31 companies from those visited previously to generate NEDB data on wood dust exposure were identified as being potentially suitable for follow-up and contacted. Seven companies declined to participate, there were eight instances where the addressee had moved away and three companies could not help due to being in administration. During the time period available (April 2004–April 2005), 10 follow-up wood dust surveys for plants located in Scotland and England were undertaken. Organizations revisited included an art college woodworking workshops,

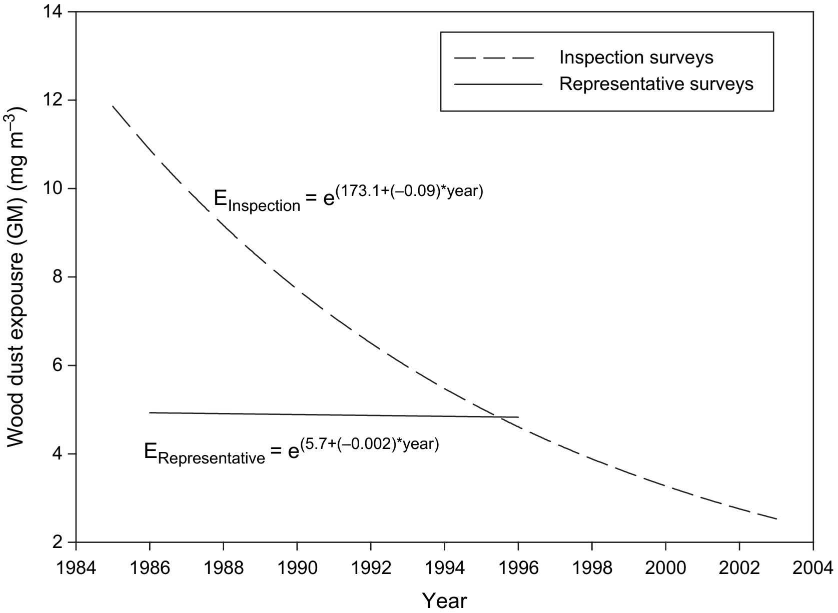

Fig. 1. Temporal trends in wood dust exposure by survey (based on stratified analyses). Note: lines extend for time periods inspection and representative data were available.

manufacturers of workbenches, mallets, furniture frames, educational furniture, bathroom, and kitchen units as well as joinery workshops, with a variety of woods being used within these companies. Table 6 summarizes exposure data and some contextual information for each of the 10 companies that were revisited during this study. Occupational groups with only a few measurements were excluded from the formal statistical analysis and are indicated in italics in Table 6. Note that for companies W1, 4, 6, 7, 8, 9, and 10 data was only available for two sample years. Details of the GM exposure for the occupational groupings included in the analysis for each company are also provided for each year the sampling took place. Table 6 also provides a summary of the changes in exposure, process, controls, and production observed in each of the companies revisited, along with reasons identified during the staff interviews as possibly contributing to these changes. It should be noted that, since it was not possible to interview staff in plant W7, no supporting information was obtained on potential reasons for any trends in wood dust exposures. It is clear from Table 6 that the GM exposures for the occupational groupings in each company decreased over time. The greatest decrease in exposure was observed for company WP2, where exposures for carpenter/joiners decreased from 23.57 to 0.87 mg.m^{-3}.

Figure 2 shows a box plot of the repeat surveys wood dust exposure for the machinist/sander occupational grouping. The highest GM for wood dust exposure was found for 1990 (GM = 8.4 mg m^{-3}; n = 5), although relatively high GMs were also observed for other years in the late 1980s and early 1990s. In contrast, in 2004 and 2005 the GM exposure measured in the repeat visits were much lower than in previous years (2004: GM = 0.7 mg m^{-3}, n = 27; 2005: GM = 0.9 mg m^{-3}, n = 29). For each of the companies resurveyed, the GM of the wood dust exposure decreased between sampling surveys.

DISCUSSION

The aim of this study was to examine the long-term changes in inhalation exposure to wood dust in the UK. Data were obtained from the HSE NEDB covering a period from 1983 to 2003. The years with most data were 1988 (n = 321) and 2000 (n = 345) coinciding with two large wood dust monitoring surveys commissioned by the HSE aimed at collecting representative exposures in the British woodworking industry (HSE, 1990; Dilworth, 2000). Increases in the number of measurements collected annually also appeared to occur in the years close to the introduction of the OEL and MEL in 1988 and 1989, respectively, thus demonstrating that measures were being taken to determine compliance with the new requirements. Follow-up sampling measurements were also obtained from 10 companies where exposure measurements had been collected over 10 years ago. Members of staff were interviewed to identify factors that might be responsible for any changes in exposure, to help inform any observed temporal trends in the large data set.

The overall GM for the NEDB data set was 5.2 mg m^{-3} and ranged from 4.9 to 7.7 mg m^{-3} for the individual industries assessed. Many citations are

Table 6. Summary of changes observed in participating wood dust companies over the sampling periods

Company	Sample years	GM[a] (mg m^{-3})	No. samples	Economic activity	Occupational groups	Production rates	Ownership	Staff levels	Process/task	Controls	Reasons cited for change
W1	1990	8.36	5	Furniture	Machinist/sander	Decreased	Changed	Unknown	Change in items produced. Change in raw materials. Introduction of more efficient equipment.	Extract system upgraded	H&S* legislation.
	2004	0.44	8								
W2	1991	23.57	3	Art college	Carpenter/joiner	Decreased	Unchanged	Decreased	Replacement of older equipment. Less wood processed.	LEV installed	Buying in items instead of manufacturing on-site. H&S legislation.
	1994	1.5	6								
	2004	0.87	4								
W3	1991	4.82	6	Joinery workshop	Carpenter/joiner, *labourer/carpenter–labourer*	Increased	Unchanged	Unchanged	Old equipment replaced with automated machines.	New machines with integral LEV. New vacuums cleaners.	Increase productivity. Compliance with legislation.
	1992	2.56	4								
	2004	0.63	2								
W4	1988	2.11	11	Furniture	Machinist/sander, assembler/woodwork	Decreased	Unchanged	Decreased	Separated workshop. Improved production flow.	Improved local and general ventilation.	Compliance with legislation. Cheaper imports.
	2004	1.0	7								
W5	1985	4.49	16	Furniture	Machinist/sander	Increased	Unchanged	Decreased	Decrease in machining, sanding and polishing tasks. Outsourcing of work. Equipment modifications.	Improved LEV system.	Market forces. HSE inspection. Woodworking regulations.
	1992	5.34	16								
	2004	0.47	7								
W6	1987	4.54	18	Changed—joinery workshop to furniture	Machinist/sander	Increased	Changed	Decreased	Greater automation. Bigger workshop. Change in raw materials used.	New filter system. Expanded extract system.	Market demands. Environmental Protection Act 1990. Waste legislation.
	2004	1.45	7								
W7	1988	1.90	15	Furniture	Machinist/sander	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	2005	0.31	8								
W8	1988	4.78	16	Furniture	Machinist/sander, *assembler/woodwork*	Increased	Unchanged	Increased	Larger premises. More sanding machines.	New extraction system. More information and training.	Widening product range.
	2005	0.94	7								
W9	1988	3.05	15	Joinery workshop	Carpenter/joiner, machinist/sander, *driver/forklift*, *labourer/carpenter–labourer*	Decreased	Changed	Decreased	Smaller workshop. New equipment.	New LEV. Improved general ventilation.	Downturn in industry. Woodworking legislation.
	2005	1.75	10								
W10	1988	2.89	17	Workbench	Machinist/sander, assembler/woodwork, *driver/forklift*, *sweeper*	Unchanged	Unchanged	Decreased	New equipment. Outsourcing of some tasks.	Introduced vacuum cleaners. Modified extract system. Automated waste system.	Market forces. New H&S personnel.
	2005	1.83	10								

H&S*, Health and Safety.
[a]GMs from raw data for the companies' occupational groups where sufficient measurements were collected. Those occupational groups in italics had insufficient measurements and so are not included in the overall analysis.

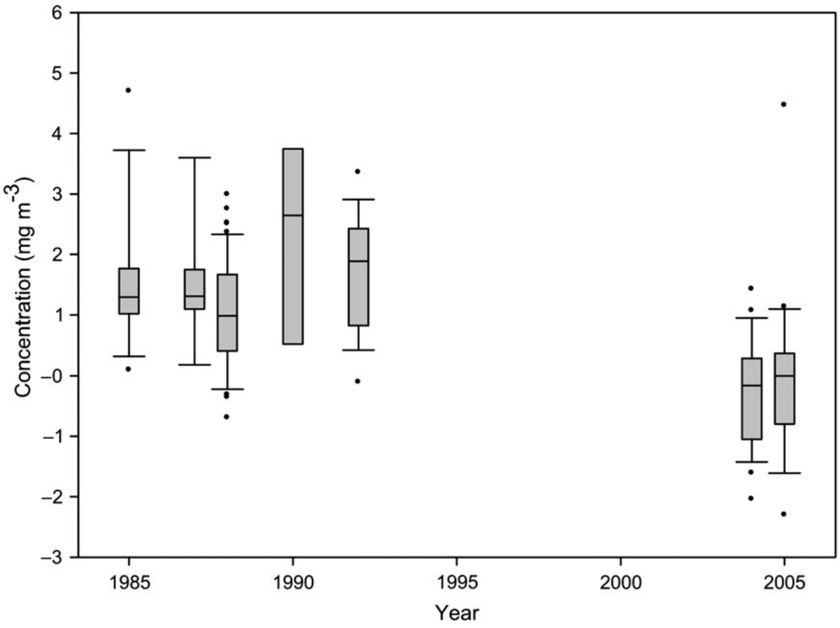

Fig. 2. Box plot of wood dust exposure for machinists/sanders. Note: the boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles.

available which provide details of wood dust exposures in various countries and industries. For example, the overall GM of wood dust exposure data collected in Italy during 1996–2006 was 0.97 mg m^{-3} (based on over 10 000 measurements) (Scarselli *et al.*, 2008). Mikkelsen *et al.* (2002) also reported similar overall GM for 2362 inhalable wood dust data collected in the Danish furniture industry during 1997–1998. Mikkelsen *et al.* (2002) do however acknowledge that their findings are low in comparison to furniture manufacturing in other countries, summarizing literature where GM ranged from 2.9 to 3.7 in Australia (Pisaniello *et al.*, 1991; Alwis *et al.*, 1999) to 4.3 in Sweden (Lidblom, 1997). Given inherent differences in sampling methods, strategies and so forth it is difficult to make direct comparisons with results obtained from NEDB from those obtained from other countries and industries.

Black *et al.* (2007) aimed to assess whether exposures had deceased in the 10-year period between the two HSE wood dust surveys (HSE, 1990; Dilworth, 2000) and although direct comparison was limited due to various differences between the surveys (such as differences in sampling methods, proportions of companies included), overall 60% of the 383 exposures in the earlier study were <5 mg m^{-3} compared with 71% of the 339 samples from the later evaluation. Our assessment of the trends in wood dust exposure is a more comprehensive evaluation given that all the wood dust data contained in NEDB which fulfilled the core data criteria were considered and a more detailed statistical analysis using Linear Mixed Effect Models, taking into account the hierarchical structure of the data, was carried out.

Temporal trends were estimated by including year as a continuous variable in the models, therefore assuming that the exposure levels declined exponentially. Although it is possible that exposure levels within one company may change inconsistently over time, it is unlikely that these changes would all occur at the same time when analysing data across several companies from one or several industrial sectors. It is therefore felt that the use of a continuous variable to indicate the temporal change in exposure will provide a good representation of the actual changes in exposure.

The trends analyses were adjusted for potential confounding factors, such as occupation, department, industry, season, etc. This was done to avoid systematic changes in measurement strategies which may affect these confounding variables over time resulting in artificial declines in exposure. After taking into account the effect of the source of the NEDB data (inspection visit or representative survey), the statistical analyses showed that GM wood dust exposure declined by an average of 8.1% per year. Stratified analyses found that this decline was fairly constant across industry sectors and occupations. However, the stratified analyses by source of data suggested that the declining trends were predominantly caused by a reduction in exposure based on data collected during inspection visits (8.2%). The exposure levels based on data collected during representative surveys remained relatively stable over time, but exposures to wood dust in these factories were already 2-fold lower than in inspected factories at the beginning of the considered period (early 1980s). The lack of a temporal trend in the representative survey data may also be due to the fact that this data was only available during the late 1980s and for 1996, i.e. covering relatively few time points.

Follow-up wood dust surveys were undertaken at 10 companies across the UK, with downward trends being observed in each of the individual companies. The revisits yielded detailed information which may help explain the trends in exposure observed. Modifications or new ventilation systems were implemented in 9 of the 10 companies revisited and new, more automated woodworking equipment was introduced in seven (which in many instances, also resulted in an overall decrease in the number of operators involved in woodworking tasks due to the equipment being more productive and having greater efficiency). Other changes reported included outsourcing of tasks due to a rationalization of the workforce, new vacuum cleaning systems being introduced, changes in the types of wood being processed, and different manufacturing processes being used. One furniture company reported that although production had increased over the time period, there had been a decrease in the amount of machining and sanding of wood undertaken, with greater bulk items being produced and chipboard being used to manufacture bed headboards. Reasons cited by companies for these changes included the need to comply with health and safety and environmental legislation and changes in wood dust exposure limits (even though the wood dust limit of 5 mg m^{-3} remained unchanged over the time period). Changes in market forces were also reported by many companies to result in a decrease in various woodworking tasks being undertaken due to the increased availability of cheaper imports. This will no doubt result in exposure being lowered due to fewer production activities taking place and a corresponding decrease in the number of woodworking operatives. Changes in the numeric value of the OEL did not occur during the observed period and therefore it is felt that enforcement of these values could not have contributed to the observed decline in wood dust concentrations.

Few studies have been published that have focussed on trends in wood dust exposure. Decreases in yearly percentage time trends have been previously reported. Coble *et al.* (2001) reported a 6% annual decrease for data collected in the USA between 1979 and 1994. More recently, Schlunssen *et al.* (2008) reported a 7% annual decrease from data collected during two cross-sectional surveys in the Danish furniture industry over a 6-year period (1997–2004), which is broadly in line with our data. Creely *et al.* (2006) also estimated average annual percentage changes in wood dust exposure from UK data collected during 1976–1983 reported by Jones and Smith (1986) and US data collected during 1979–1997 reported by Teschke *et al.* (1999), with annual decreases of 10 and 11%, respectively, being determined. Significant changes in equipment and production methods in some factories and lower production rates and modification/upgrading capabilities of dust control and extraction equipment were also cited in these articles as being responsible for the observed changes in exposure. While Schlunssen *et al.* (2008) also reported that vacuum cleaning of machines, special cleaning staff, and adequate exhaust ventilation decreased wood dust exposure, sanding, use of compressed air, and small factories (<20 employees) were found to be associated with increased exposure. Scheeper *et al.* (1995) also reported that sweeping and tasks involving the use of router and milling equipment increased wood dust exposures while finishing activities and the presence of LEV were related to lower dust levels.

Although the results of the analysis and the time trends reported by other authors are encouraging, the UK wood dust industry should not become complacent. Black *et al.* (2007) report that the wood dust exposure in nearly 30% of the small businesses surveyed exceeded 5 mg m^{-3} MEL and that a low proportion of companies had written COSHH risk assessments in place. Examples of poor control were reported by Dilworth (2000), which included nearly all companies' brush cleaning even though many sites had vacuum cleaning equipment available. Also, although all sites had LEV fitted on at least some of the woodworking machines, only 21% had maintenance, examination, and testing programmes within the 14-month cycle stipulated by the COSHH regulations. This suggests that there is considerable scope for improvements to be made and for wood dust exposures to be reduced further. The need for improvements and reductions is not just applicable to the UK; for example, in The Netherlands, Spee *et al.* (2007) reported that average wood dust exposures to carpenters at construction sites were estimated to be 1.5 times the OEL in place at the time of publication and >3 times the planned limit of 1 mg m^{-3}.

Analysis of the temporal trend in UK wood dust exposure concentrations revealed declines of 8% per annum. Interviews with key long-serving employees and management suggest various factors which may be linked to the downward trends observed. While these are speculative, this information provides a focus for legislators both in terms of building upon existing programmes and the development and implementation of new strategies aimed at reducing wood dust exposures further.

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