# Occupational Exposure to Inhalable and Respirable Wood Dust of Pedunculate Oak (*Quercus robur* L.) in a Furniture Factory

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Given the well-known carcinogenicity of hardwood dust, occupational exposure to oak wood dust has been determined in a furniture factory on different wood processing machines during sanding, planing, and milling. Determination of the mass concentrations of respirable and inhalable oak wood dust from ambient air was performed using personal sampling pumps and two types of filter holders: the Higgins-Dewell respirable dust cyclone, manufactured by Casella (Bedford, UK), and the inhalable dust IOM sampler manufactured by SKC (Dorset, UK). Out of a total of 30 values of inhalable mass concentration, 7 (23%) exceeded the occupational exposure level (OEL). The highest exposure levels for inhalable and respirable wood dust from the belt sander were 1.569 to 3.710 mg/m$^3$ and 0.243 to 1.342 mg/m$^3$, respectively. Worker exposure may be below the level of increased risk of 2 mg/m$^3$ if a machine such as a planer or router is connected to a suction system. The share of respirable particles in the inhalable fraction ranged between 12% and 31%, and for samples with an inhalable mass concentration exceeding 2 mg/m$^3$, the share was lower than 16%, with a slightly decreasing tendency. Thus, the risk of lower respiratory tract diseases increases with higher exposure to inhalable particles, and the OEL is an indirect measure of protection against exposure to respirable particles.

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## INTRODUCTION

In 1994 the IARC (International Agency for Research of Cancer) classified wood dust into the first group of carcinogenic substances, whereas workers in furniture production exposed to a higher risk of nose and nose cavity cancer were placed into the first risk group. Cancer is the first cause of work related deaths in the EU, and 53% of all occupational deaths are attributed to cancer. An average 2% of workers from over 179 million in the EU25 Member States are exposed to inhalable wood dust, amounting to 3.6 million workers (Kauppinen *et al*. 2006). European Directive 2017/2398 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work prescribes an OEL of 2 mg/m$^3$ (3 mg/m$^3$ until 17 January 2023), which refers to a mass concentration of increased risk.

One of the first reports of occupational risk associated with hardwood dust exposure came from England in 1967, indicating an excessive risk of nasal cavity and sinus adenocarcinoma among woodworkers in the furniture industry (Acheson *et al*. 1968). A study of the impact of exposure to wood dust on occupational health and its implications on the occupational limit value showed that workers exposed to inhalation dust at levels of 2 mg/m$^3$ and above have no adverse effects on the lungs (Holm and Festa 2019). In an industry-based case control study in the German woodworking industries, the authors found an elevated risk of adenocarcinoma of the nasal cavity and paranasal sinuses due to exposure to inhalable wood dust above 3.5 mg/m$^3$. The rareness of the disease does not allow the exclusion of risk below that concentration (Pesch *et al*. 2008). However, the current occupational exposure limit for inhalable wood dust, based on mass, cannot detect a high exposure to ultra-fine particles (UFP), and particles <10 µm that are easily deposited in the smallest parts of the respiratory system (Gu *et al*. 2018). Woodworkers are estimated to have a 500-fold higher risk of developing sinonasal adenocarcinomas compared to the male population and up to 900 times higher than the general population (Llorente *et al*. 2009). In addition to the importance of hardwoods, especially beech and oak wood, both hardwood and softwood dusts can influence the development of the inflammatory process in the airways, by modulating the expression of macrophage derived cytokines and chemokines. Although there are some differences in the magnitude of responses to different wood dust species, they have quite similar effects on the cytokine and chemokine expression in the cell line (Määttä *et al*. 2005, 2006; Bornholdt *et al*. 2007). Cumulative exposure to even softwood-dominated mixed wood dust is strongly associated with an increased risk of nasal adenocarcinoma, but not with other types of nose or nasopharyngeal cancer (Siew *et al*. 2017). Intestinal-type sinonasal adenocarcinoma represents from 8% to 25% of all malignant sinonasal cancers and is etiologically related to occupational exposure to wood dust. Some genetic and chromosomal analyses of wood dust exposure have been found to be causative factors in mutagenesis with a specific transient mutation in non-smokers or smokers only (Llorente *et al*. 2009; Pérez-Escuredo *et al*. 2012). The estimated relative risk of developing sinonasal epithelial cancer after 35 years of exposure to wood dust is about 300, compared to non-exposed people for whom the relative risk is equal to 1 (Soćko 2021).

The results of the random effects model meta-analysis showed that there was a direct relationship between occupational exposure to a high concentration of wood dust and nasopharyngeal cancer (Beigzadeh *et al*. 2019; Meng *et al*. 2020). A strong impact on the risk of laryngeal cancer has been observed for high exposure to hardwood and softwood dust (Ramroth *et al*. 2008). High exposure to hard-wood and softwood dust contributes to the evidence that wood dust, especially hardwood dust, is an independent risk factor for laryngeal cancer, in addition to the influencing factors of smoking, alcohol, and education levels (Ramroth *et al*. 2008).

In addition to the fact that wood dust is a known carcinogen that can cause cancer, mainly in the upper respiratory tract, in recent times, exposure to wood dust has been associated with a significantly increased risk of lung cancer and an increased risk of squamous cells, small cells and lung adenocarcinoma, especially in persons who are regularly exposed to wood dust for a long time (Scarabelli *et al*. 2021). A different study has found that there is no significant association between lung cancer and exposure to wood dust. The risk of lung cancer was slightly increased in those who were professionally exposed to wood dust for more than 10 years, and for whom it was over 40 years since the first exposure (Matrat *et al*. 2019). Quantitative assessments can prevent diseases associated with exposure to wood dust such as sinonasal and lung cancers (Sauvé *et al*. 2019).

Occupational exposure to wood dust presents a risk factor for non-malignant respiratory diseases consistent with both an allergic and a non-allergic origin (Schlünssen *et al*. 2018). Work in the furniture and wood processing sector was associated with a significantly increased risk of respiratory symptoms and asthma (Wiggans *et al*. 2016). In a longitudinal study of the association between exposure to wood dust and emerging chronic obstructive pulmonary disease (COPD) and changes in lung function, the results suggests that female carpenters may be more sensitive to exposure to wood dust than male woodworkers (Bolund *et al*. 2018). A Scandinavian study shows that exposure to wood dust in a previous year increases the risk of re-admission to the hospital for people with asthma, but not for those with COPD (Vested *et al*. 2021). Exposure to wood dust in the workplace is associated with the onset of chronic rhino-sinusitis (Clarhed *et al*. 2020). The presence of asthma and rhinitis was detected in furniture workers exposed to wood dust, and the most useful tests for diagnosing these occupational diseases were determined (Paraskevaidou *et al*. 2021).

Exhaust ventilation in joinery and furniture manufacturing has been shown to reduce dust concentrations, while specific tasks and work processes including sanding, use of compressed air for cleaning, use of hand tools or fully automated machines, dry wiping and cleaning, and the reduced size of a workshop may increase wood dust exposure (Kos *et al*. 2002, 2004a,b; Schlünssen *et al*. 2018). A study of the long term changes in worker exposure to wood dust in the UK found decreasing trends (Galea *et al*. 2009). Workers using conventional sanding systems could use self-generated vacuum sanding system technology to potentially reduce particle exposure and mitigate adverse health effects (Liverseed *et al*. 2013). Sanding, especially hand sanding, nearly always resulted in inhalable exposures above 5 mg/m$^3$ (Scheeper *et al*. 1995). Wood processing with high levels of inhalable dust can emit a large number of UFPs and particles <10 µm (Gu *et al.* 2018). Former studies have suggested that sanding with a hand sander is one of the processes that can cause the highest exposure to wood dust. Softwood generated more dust than hardwood due to the difference in abrasion durability of the wood. A coarse sand paper produced more dust than a fine sand paper. When the specimens were sanded with a fine sand paper, the mass median aerodynamic diameters of beech wood dust and cypress wood dust were 9.0 µm and 9.8 µm, respectively. Respirable wood dust is able to be controlled by general ventilation with an air flow rate of over 0.7 to 4.2 m$^3$/min (Ojima 2016). The mass concentration of the smallest dust particles has a negative linear relation to the total air flow rate of the exhaust system during sawing with a circular saw (Palubicki *et al*. 2020). Woodworking by computer numerical control router (CNC) is often the cause of increased dust in the surrounding air, due to the geometry of the tool, as well as the conditions of its operation. There is no possibility of effective removal of dust particles dispersed in the air during CNC machining, especially as the tool often moves considerably long distances in many directions (Rogoziński *et al.* 2015). The aim of the present research was to contribute to determining the occupational exposure of workers to oak wood dust in furniture production plants at different wood processing machines. New measurement results of respirable and inhalable mass concentration were obtained. By reviewing the share of respirable dust present within inhalable dust, based on mass concentration, indications were obtained of the influence of oak wood processing on worker's exposure in the observed conditions.

## EXPERIMENTAL

### Materials

Determination of wood dust mass concentration by the gravimetric method was carried out at different wood machining places in the furniture factory, during the processing of the dry hardwood species of the pedunculate oak (*Quercus robur* L.). The workspaces observed, selected as a cross section of specific machines in the furniture factory, were near two types of CNC machines, types PRO (Homag, Schopfloch, Germany) and Double Jet (Paulino Bacci, Cascina, Italy), two types of hand sanders, a random orbital sander (Atlas Copo, Nacka, Sweden) and a belt sander (Makita, Aichi, Japan), and near a four-side planer (Weinig, Tauberbischofsheim, Germany). The working parameters of the machines are presented in Table 1. The belt sander (HS II) has a suction bag attached, but the orbital sander (HS I) does not. The sanding work of HS I is done on a downdraft table connected to the central suction system.

The new type of CNC machine is located separately in a newer production plant, and the other machines observed are located in a production plant with older technology.

**Table 1.** Working Parameters of Woodworking Machines in the Furniture Factory

| **Woodworking Machines** | **CNC I** | **CNC II** | **HS I** | **HS II** | **4SP** |
|---|---|---|---|---|---|
| Type or Manufacturer | PRO | Double Jet | Atlas Copo | Makita | Weinig |
| Power, kW | 18.5; 15 | 2 x 7.4 | - | 1.01 | 3; 4; 5.5 |
| Pressure, kPa | | | *630* | | |
| Belt speed, m/min | | | | *210 - 440* | |
| Rotation speed, $min^{-1}$ | | 5000 | 12000 | | |
| Axis number | 4; 5 | 7 | | | |
| Tool number | 4; 5 | 7 | 4; 5 | 7 | 4; 5 |
| Granularity | - | - | 120; 150; 180 | 80 | - |
| Suction | Central system | No | Downdraft table | Bag | Central system |

### Methods

*Determination of wood dust mass concentration*

Determination of the mass concentrations of respirable and inhalable wood dust from ambient air was performed using personal sampling pumps and two types of filter holders: the Higgins-Dewell respirable dust cyclone manufactured by Casella (Bedford, UK) alongside an inhalable dust IOM sampler, manufactured by SKC (Dorset, UK). Recommendations for wood dust sampling include the convention for measuring airborne particles as specified in EN 481:1993 and CEN /TR 15230:2005. When a mixture of particles of all sizes is inhaled, larger particles settle in the upper part of the respiratory system (inhalable fraction) and smaller particles penetrate deeper into the respiratory tract, through the tracheobronchial zone to the alveoli (respirable fraction). The inhalable fraction is the mass fraction of total floating particles inhaled through the nose and mouth. The respirable or alveolar fraction is the mass fraction of inhaled particles that penetrate into the alveoli.

Ten Casella Apex personal sampling pumps per day were used, set at a suction flow rate of 2 L/min, in determining the mass concentration using an inhalable dust IOM sampler, or set at 2.2 L/min using a respirable dust cyclone sampler. The measuring equipment, a personal sampling pump and filter holder, were worn by the worker over a work-suit. The filter holders are fixed in the worker's breathing zone. Each equipment pair was used to collect respirable and inhalable wood dust fraction simultaneously during 8 h of work in a full-time shift.

Whatman 25-mm quartz filters (QM-A) were conditioned in the desiccator at 20 ± 1 °C and 47.5 ± 2.5% relative humidity for 48 h before weighing, and before and after the sampling. After the first weighing, the conditioning was repeated under the same conditions for a period of 24 h and the filters are weighed again. Each filter was electrostatically discharged prior to weighing using a Mettler Toledo U-electrode. The weighing was performed using a micro-scale Mettler-Toledo MX-5 (Mettler-Toledo International Inc., Greifensee, Switzerland) with $10^{-6}$ g scale sensitivity. Whatman 25-mm quartz filters were used for all measurements. The mass concentration of dust was determined using the gravimetric method in accordance with the standard ZH 1/120.41:1989.

In accordance with CEN/TR 15230, the mass limit of detection (LOD) was calculated as three times the standard deviation of field blanks. The amounts were 0.008 and 0.134 mg for samples collected in the newer production plant, and 0.053 and 0.447 mg for samples collected in the older plant, for the respirable and inhalable mass determination respectively. All sample masses of respirable fraction and inhalable samples collected in the new plant were higher than LOD, but three samples of inhalable dust from the old production plant were below LOD, and they were removed from the calculation.

Statistical differences between the compared results were tested using the Student's test. The Mann-Whitney u-test was used when the condition of homogeneity of variance was not fulfilled. All statistical analyses and graphs were made using STATISTICA 14.0.0.15 (StatSoft Inc., Tulsa, OK, USA).

## RESULTS AND DISCUSSION

The geometric mean and range of inhalable mass concentration obtained at different workspaces are presented in Table 2. The geometric mean, as a better indicator of dust emission, was also chosen to show the average value of the mass concentration of wood dust for all groups of samples. All measured values are compared with the European OEL, in accordance with the prescribed value of 2 mg/m$^3$ and transitional limit value of 3 mg/m$^3$ (until 17 January 2023).

**Table 2.** Wood Dust Mass Concentration of Inhalable Dust and Samples Exceeding OEL (n) in the Total Number of Samples (N)

| Woodworking Machines | N | GM | min | max | OEL[a] Exceeding | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 3 | | 2 | |
| | | mg/m$^3$ | | | n | % | n | % |
| CNC I | 6 | 0.220 | 0.145 | 0.317 | 0 | 0 | 0 | 0 |
| CNC II | 7 | 1.887 | 1.075 | 2.569 | 0 | 0 | 4 | 57 |
| HS I | 5 | 1.482 | 0.839 | 3.574 | 1 | 20 | 1 | 20 |
| HS II | 6 | 2.335 | 1.569 | 3.710 | 1 | 17 | 4 | 67 |
| 4SP | 6 | 0.530 | 0.265 | 0.770 | 0 | 0 | 0 | 0 |

[a]: OEL – Prescribed occupational exposure limit of 2 mg/m$^3$ (3 mg/m$^3$ until 17 January 2023);

The highest inhalable mass concentration was measured around belt sander HS II, where 4 samples out of 6 had a higher mass concentration than the limit value 2 mg/m$^3$. Exposure levels for the inhalable fraction of oak wood dust around HS II were 1.569 to 3.710 mg/m$^3$.

Significant exceeding of the limit values for inhalable wood dust was recorded at workspaces at the CNC II (without suction) 4 samples out of the 7 having a higher mass concentration than the limit value of 2 mg/m$^3$. Exposure levels for the inhalable fraction of the oak wood dust around the CNC II were 1.075 to 2.569 mg/m$^3$.

During milling and planing (CNC and 4SP) measured exposures were below the transitional limit value of 3 mg/m$^3$.

The measured values of inhalable and respirable dust mass concentration are shown by a distribution diagram of mean values in Figs. 1a and 1b, respectively. The distribution diagram in Fig. 1a presents two groups of inhalable mass concentration data for woodworking machines, one group with a lower mass concentration (CNC I and 4SP), and the other group with a higher mass concentration and greater data dissipation (CNC II and both types of hand sanders - HS I and HS II). According to the mean values of the respirable mass concentration from the diagram in Fig. 1b, the highest mass concentration and data dissipation was observed for woodworking machine HS II, whilst the other machines are in a group of lower, similar mass concentration levels.

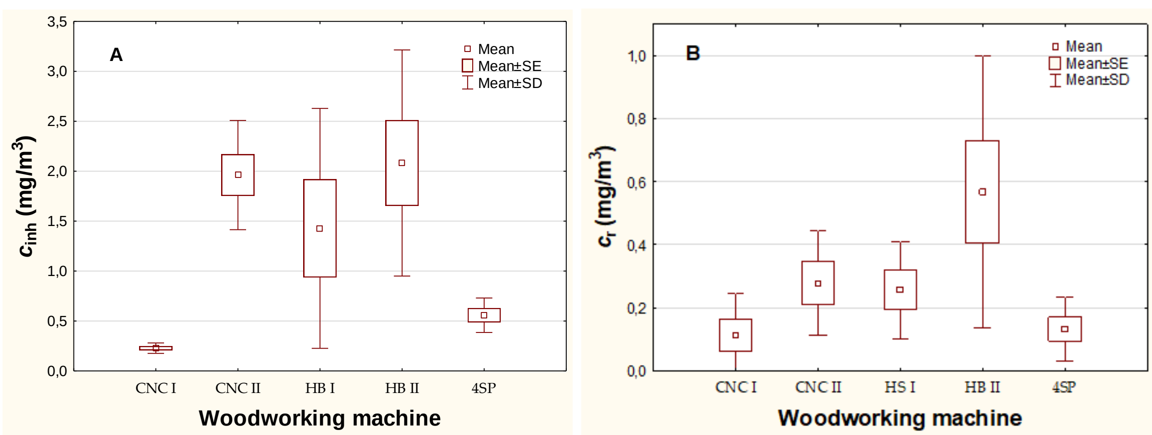


**Fig. 1.** Distribution diagram of mean values and data dissipation of wood dust mass concentration for wood processing machines (**a**) inhalable and (**b**) respirable particles (SD- standard deviation; SE- standard error of mean)

The results of statistical testing of inhalable mass concentration from different woodworking machines showed that not only was there a significant difference between these two groups of samples, but also between the two woodworking machines (CNC I and 4SP), in the group with lower mass concentration (Table 3). The lowest mass concentration of inhalable dust measured near CNC I was lower than the mass concentration measured near the four-side planer ($p = 0.004$). There was no significant difference between the inhalable mass concentration for workspaces in the group with a higher mass concentration (CNC II, HS I and HS II). The mass concentration of respirable fraction measured near all observed machines did not significantly differ, except for HS II in correlation with CNC I and 4SP, from the above-mentioned group with a lower mass concentration (Table 4).

The geometric means and ranges of respirable mass concentration obtained at different workspaces are presented in Table 5. The highest exposure level for respirable oak wood dust was measured around belt sander HS II, and ranged from 0.243 to 1.342 mg/m$^3$. The share of respirable particles in the inhalable fraction ranged between 12% and 31%, which is approximately 19% of the inhalation fraction on average. The highest share of respirable particles in the inhalable mass concentration were recorded at the woodworking places, with the lowest concentration of inhalable dust near CNC I.

**Table 3.** Probability Values From Statistical Testing of Inhalable Wood Dust Mass Concentration

| p < 0.05 | CNC I | CNC II | HS I | HS II |
|---|---|---|---|---|
| CNC II | 0.001 | - | - | - |
| HS I | 0.004 | 0.61 | - | - |
| HS II | 0.002 | 0.22 | 0.23 | - |
| 4SP | 0.004 | 0.001 | 0.004 | 0.002 |

**Table 4.** Probability Values From Statistical Testing of Respirable Wood Dust Mass Concentration

| p < 0.05 | CNC I | CNC II | HS I | HS II |
|---|---|---|---|---|
| CNC II | 0.07 | - | - | - |
| HS I | 0.10 | 0.82 | - | - |
| HS II | 0.01 | 0.15 | 0.23 | - |
| 4SP | 0.77 | 0.08 | 0.11 | 0.001 |

**Table 5.** Wood Dust Mass Concentration of Respirable Dust and $C_r$ / $C_{inh}$ Ratio

| Woodworking machines | N | GM | min | max | $c_r$ / $c_{inh}$ |
|---|---|---|---|---|---|
| | | mg/m$^3$ | | | % |
| CNC I | 7 | 0.069 | 0.011 | 0.403 | 31 |
| CNC II | 6 | 0.233 | 0.077 | 0.492 | 12 |
| HS I | 6 | 0.201 | 0.044 | 0.440 | 14 |
| HS II | 7 | 0.462 | 0.243 | 1.342 | 20 |
| 4SP | 7 | 0.105 | 0.036 | 0.335 | 20 |

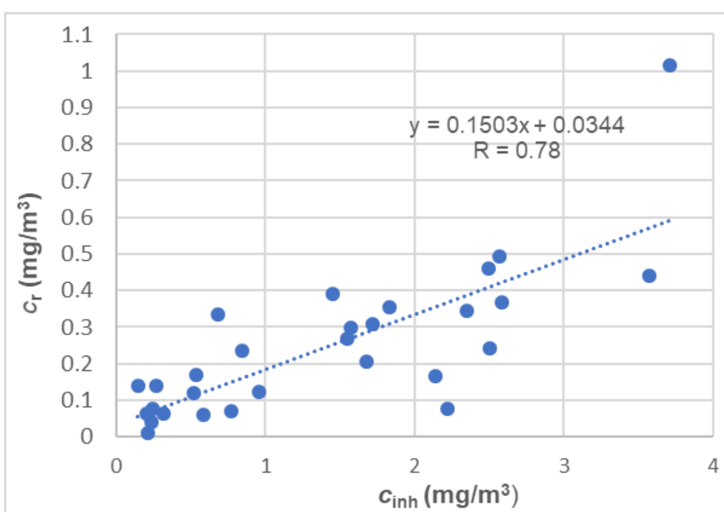


**Fig. 2.** Correlation diagram of respirable and inhalable mass concentration in the furniture factory

The distribution of respirable mass concentration had a very strong correlation (R = 0.78) with the inhalable dust mass concentration for all workspaces in the furniture factory, and is presented in Fig. 2. In a strong linear relationship, the mass concentration of respirable fraction increased with the increase of the mass concentration of inhalable fraction. During sampling of inhalable wood dust fractions in a low-risk working atmosphere, with mass concentration below 2 mg/m$^3$, the respirable mass concentration was below 0.4 mg/m$^3$.

A medium strong correlation (R = 0.51) was found between the share of respirable in inhalable mass concentration and inhalable mass concentration measured in the furniture factory (Fig. 3.) The share of respirable mass concentration in inhalable dust mass concentration decreased with the increase of inhalable dust mass concentration. The share of respirable in inhalable mass concentration for samples with inhalable mass concentration exceeding 2 mg/m$^3$ is lower than 16% with a slightly decreasing tendency.

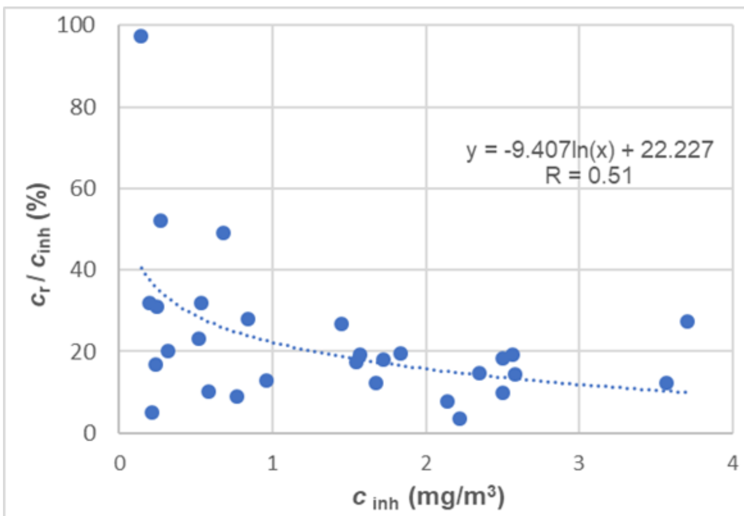


**Fig. 3.** Correlation between the share of respirable in inhalable wood dust mass concentration and absolute value of inhalable mass concentration in the furniture factory

## Exceeding the OEL Exposure

From the results obtained, it is evident that workers at the workspaces of machines without an exhaust are exposed to higher mass concentrations of hardwood dust than 2 mg/m$^3$, which represents exposure to an increased risk. Out of a total of 30 samples collected at 5 workspaces, 7 (23%) exceed the OEL. In the EU25 Member States, an increased risk of worker exposure to inhalable wood dust refers to 41% of workers being exposed to mass concentrations of up to 2 mg/m$^3$. About 280,000 workers (32%) in the European manufacture of furniture were exposed to a level of increased risk, above 2 mg/m$^3$ mass concentration of inhalable wood dust. The probability of exceeding the OEL, when comparing the estimated concentrations against the Dutch OEL of 2 mg/m$^3$, was 75%. For the current OEL of 1 mg/m$^3$ this probability was 95% (Spee *et al*. 2006). In the Italian wood industry, which uses active IOM during the sanding process, 85% of inhalable samples exceeded 2 mg/m$^3$, and in planing and shaping, 16% of samples exceeded 5 mg/m$^3$ (Campopiano *et al*. 2016).

In furniture factories in New Zealand, the occupational exposure limit of 1 mg/m$^3$, recommended by the American Conference of Governmental Industrial Hygienists, was exceeded in 19% of measurements, which represent an average lower inhalable dust exposure of 0.6 mg/m$^3$. Personal exposure to inhalable softwood dust for 7% of workers exceeded the New Zealand workplace exposure limit of 2 mg/m$^3$ (Douwes *et al*. 2017). In the Croatian furniture factory there were 16% of cases with higher mass concentration than the limit value of 1 mg/m$^3$ for respirable hardwood dust, and 19% of cases higher than the limit value of 3 mg/m$^3$ for total hardwood dust (Kos *et al*. 2004). During the processing of dry oak wood and beech wood in the factory and in the carpentry near the four-side planer, drum sander and circular saw, the mass concentrations of the inhalable fraction for 48 samples, of a total 119 inhalable samples (40%), exceeded the limit value of 2 mg/m$^3$ (Čavlović *et al*. 2021).

*Exposure level to respirable particles and its influence on health effects*

Most studies assessing the risk of upper or lower respiratory tract disease due to exposure to wood dust, in odds ratios (OR) calculation, have taken into account the influencing factors (intensity, frequency and duration of exposure to various occupational sources of wood dust, job category, company size, activity sector, geographical location and many others) including tobacco smoking. In risk estimation on the basis of occupational history data collected by hospitals in Italy, with no quantitative assessment of exposure to wood dust, Soćko (2021) found a relationship between the duration of occupational exposure to wood dust and the relative risk of developing cancer in all sinonasal epithelial cancer cases. The most important calculation found here was that, with the increasing duration of exposure, even in the short term, the risk of exposure to wood dust also increases. He found a higher risk for sinonasal adenocarcinoma (OR = 3.49) for a person who works 7.75 years than for sinonasal epithelial cancer (OR = 2.42). The risk calculated is important for discussion because younger workers with a shorter duration of exposure to wood dust, of between 5 and 10 years, participated in our research. A US 12 case-control study found a doubled risk, statistically significant for sinonasal cancer in men employed in any wood-related job (OR = 2.0, 95% CI: 1.6 to 2.5) in comparison to men who had never worked in a wood-related job. The relative risks associated with exposure to wood dust and wood-related jobs indicate a significant risk of developing sinonasal cancer in men employed in any furniture factory (OR = 13.5, 95% CI: 9.0 to 20.0). The exposure categories, zero and low, medium and high exposure, were created in the range from 0 to 5 mg/m$^3$, and OR for risk assessments were calculated to be 0.6, 3.1 and 45.5, respectively (Demers *et al*. 1995). The results from another US based case-control study show that the case of individuals reporting 20 or more years of “regular” wood dust exposure was associated with a statistically significantly increased risk of 32% for all upper aero-digestive and respiratory cancers, and 69% for lung cancer alone (Jayaprakash *et al*. 2008). An industry-based case-control study was conducted in the German woodworking industries and showed that average exposure to inhalable wood dust $\geqslant$ 5 mg/m$^3$ was associated with a high risk (OR 48.47, 95% CI: 13.30 to 176.63) for sinonasal adenocarcinoma, compared to levels below 3.5 mg/m$^3$. Exposure between 3.5 and 5 mg/m$^3$ was also found to pose a risk (OR 10.54, 95% CI: 3.34 to 33.27) (Pesch *et al*. 2008).

In this regard, it could not be concluded from the research in a Croatian furniture factory, based on two of the 30 exposures higher than 3.5 mg/m$^3$, that workers working with sanders have a 10.54 times higher risk of sinonasal adenocarcinoma than those who are not exposed to wood dust at all. However, experts on this type of risk warn that the rarity of the disease does not exclude the risk of exposure even below these concentrations.

In four Nordic countries, by univariate analysis, a strongly increasing risk with increasing cumulative exposure (CE) to wood dust was observed for nasal adenocarcinoma, with a 29-fold increased risk in the highest CE category (28.82 mg/m$^3$-years). In this study, the exposure to wood dust was generally low, below 5 mg/m$^3$. Twenty-five years ago, some authors suggested that dust-related nasal adenocarcinoma could be eliminated in Europe and the United States if exposure to wood dust did not exceed 5 mg/m$^3$ on average, because they assumed that this permissible level was safe, without taking into account cumulative exposure (Siew *et al*. 2017). However, the lack of this assumption is manifested in the fact that today's regulations reduce the lower risk limit to 2 mg/m$^3$.

In a case control study conducted in Germany a strong effect on laryngeal cancer risk was observed for high exposure of hardwood dust (OR = 2.6, 95% CI: 1.1 to 4.2) (Ramroth *et al*. 2008).

Inconsistent findings are often the reason for the conclusion of the IARC as to the lack of connection between occupational exposure to wood dust and the development of lung cancer (Bhatti *et al*. 2011). Some other research results support the hypothesis that wood dust exposure is a potential risk factor for lung cancer (Wiggans *et al*. 2016; Matrat *et al*. 2019; Scarabelli *et al*. 2021). Bhatti *et al.* (2011) observed an increased risk of lung cancer associated with working in a sawmill (OR = 1.5, 95% CI: 1.1 to 2.1), and found no evidence of increased risks with other occupations, working with wood as a hobby, or with an estimated cumulative exposure to wood dust for the highest compared to the lowest quartile of exposure (OR = 0.9, 95% CI: 0.6, 1.3). The adjusted OR for the combined wood dust related occupations and industries associated with the risk of lung cancer was 3.15 (95% CI, 1.45 to 6.86), and for the overall cumulative exposure measure it was 1.60 (95% CI: 1.19 to 2.14) (Barcenas *et al*. 2005). A health study in the USA woodworking industry estimates the effect of mixed wood dust exposure on annual changes in lung function. The only significant effect found was an obstructive effect of the respirable particles in the milling plant (mean exposure of 0.147 mg/m$^3$), and the restrictive effect on annual changes in a worker's lung function in the sawmill-planing plant from plywood (mean exposure of 0.255 mg/m$^3$) (Glindmeyer *et al.* 2008). A number of respiratory symptoms suggestive of airway reactivity were significantly more common among the workers in a plant producing oriented strand board (OSB), where measurements of respirable dust ranged from 0.05 to 0.5 mg/m$^3$ (Herbert *et al*. 1995).

The published level of exposure to respirable wood particles is common to most furniture manufacturing jobs, so harmful health effects to the respiratory system can be expected regardless of the level of exposure to inhalable hardwood dust (Vinzents *et al*. 2001). In this regard, the results of this study show that there is a very low, but present, occupational health risk when working on the two observed machines, CNC I and 4SP, with measured low mass concentrations of respirable particles, where the geometric mean amounts to 0.069 mg/m$^3$ and 0.105 mg/m$^3$. Additionally, occupational exposure to wood dust has a significant impact on allergies due to extractive volatiles and microbial components from certain wood species (Teschke *et al*. 1999; Sabolić Pipinić *et al*. 2010; Ljubičić Čalušić *et al.* 2013; Straumfors *et al*. 2018). The health effects of occupational asthma, pulmonary dysfunction, and elevated respiratory symptom levels have been reported in sawmill workers, despite an average inhalation concentration of pine and spruce dust of 1.35 mg/m$^3$ (range, 0.1 to 2.2 mg/m$^3$), with levels below the current occupational standard (Hessel *et al*. 1995).

*The share of respirable in inhalable wood dust mass concentration*

In the USA wood processing industry, overall geometric mean exposure levels were found to be 1.44 and 0.18 mg/m$^3$, for the inhalable and respirable fractions respectively. On average, for all samples, the respirable fraction accounted for 16.7% of the mass of inhalable dust. Processing of hardwood and mixed woods generally were associated with higher exposures than were softwood and plywood (Kalliny *et al*. 2008). In the Polish furniture industry, the mass concentrations of inhalable dust were from 1.34 to 22.13 mg/m$^3$, and the respirable fractions from 0.38 to 4.04 mg/m$^3$, which is approx. 25% of the inhalable fraction on average (Szewczyńska and Pośniak 2017).

In other research, the share of respirable mass concentration in the total mass concentration is the highest, being over 50% for samples of total mass concentration lower than 1 mg/m$^3$ and rapidly decreasing with the increase of total mass concentration. The share of respirable particles in total wood dust, for samples with a total mass concentration exceeding 2 mg/m$^3$, is lower than 40%, with a slightly decreasing tendency. The highest share of respirable particles in wood dust are recorded at workspaces with a low concentration of total wood dust, and in the vicinity of machines whose cutting parameters result in lowest thickness of wood chips, such as when cutting boards with a circular saw (Kos *et al*. 2004). Some authors confirmed that coarse sand paper produced more dust than fine sand paper (Galea *et al*. 2009). A comparison in this article of these two types of hand sanders, and an orbital and belt sander, shows that less dust is produced when HS I sanded with finer sand paper (120, 150 and 180) than HS II with coarse sand paper (80). The proportion of respirable particles in the inhalable dust produced by the orbital sander is lower (14%) than for the belt sander (20%) (Table 5).

*The influence of wood processing parameters on dustiness*

The highest concentrations occurred in sanding and the lowest occurred during milling processes of materials used in the manufacture of furniture (Kos *et al*. 2004; Ljubičić Čalušić *et al*. 2013). The concentration of respirable dust was affected only by the sanding pressure, and it increased linearly with increasing sanding pressure, while the granulation and sanding direction were not affected (Zhao *et al*. 1999). Dust-generation is higher when sanding low density wood at a high wood removal rate using fine abrasive grits. In the furniture factory, the exposure to hardwood dust during orbital hand sanding was 26 mg/m$^3$, and during manual sanding 19 mg/m$^3$ (Ratnasingam *et al*. 2011). In a typical cabinet-making workshop, slightly higher exposure levels for the inhalable fraction near the hand sander operator were 6.9 to 76 mg/m$^3$ for MDF and 2.5 to 45 mg/m$^3$ for softwood. The respirable fraction levels were 1.3 to 6.4 mg/m$^3$ for MDF and 1.2 to 2.9 mg/m$^3$ for softwood (Hursthouse *et al*. 2004). In previous research, higher concentrations of hardwood dust were generated by sanding than have been observed in this research. Vacuum extraction on hand tools, combined with a downdraft table, reduced exposures by 42.5% for routing and 85.5% for orbital sanding (Spee *et al*. 2006). The orbital sander experiments showed a small reduction in inhalable dust exposure of 8.3% when using the downdraft table (Douwes *et al*. 2017).

In carpentry, the use of hand tools, orbital and band sanding, showed 3.0 to 3.4 times higher exposure to inhalable dust compared to gluing (which was selected as the reference category) (Douwes *et al*. 2017). Higher exposure to dust was also found for CNC work, averaging 2.4 mg/m$^3$ (ranging from 1.5 to 4.0 mg/m$^3$). The use of hand tools and conventional cleaning methods (dry wiping and sweeping) significantly contributed to high exposures in joinery workers, whilst use of vacuum extraction on hand tools and alternative cleaning methods were shown to have the potential to significantly reduce dust exposures (Kos *et al*. 1999; Douwes *et al*. 2017). Local exhaust ventilation on a hand sander reduces the exposure to wood dust by a factor of 3 to 10. Use of a flat sander instead of a belt sander yields a reduction of exposure by a factor of 5 to 10 (Spee *et al*. 2006). This research provides guidelines for future research that will focus only on certain influencing factors such as the type of sand paper or downdraft table in the sanding process.

## CONCLUSIONS

1. The use of new generation woodworking machines with suction ensures a lower risk of occupational exposure to wood dust, especially the hardwood of oak that is classified as a cancerous substance. Exceeding the occupational exposure limit (OEL) value of 2 mg/m$^3$ for the mass concentration of hardwood dust, occupational safety poses a health risk from a number of respiratory diseases. The results of this research confirmed that the least dust is produced by milling and planing. Worker exposure may be below the level of increased risk if a machine such as a planer or computer numerical control (CNC) router is connected to a quality central suction system. Therefore, there is the least dust in the new production plant with a CNC machine of newer technology connected to a central exhaust. In contrast, a similar older suction-free CNC machine has 57% of samples above the increased risk limit.
2. To reduce the risk of harmful effects of wood dust from sanding with hand sanders, the best solution to reduce the dust is to use a combination of a suction filter bag and a downdraft table. Protecting workers from the risk of exposure to wood dust would be helped by changing the workspace so that an individual worker does not work for more than 10 years at a workspace with a higher risk, especially a worker with poor general health and with a predisposition to disease.
3. Due to the higher risk of upper respiratory tract disease, the protection measures prescribed by OEL apply only to the inhalable fraction of wood dust. The risk of lower respiratory tract diseases also increases with higher exposure to inhalable particles, because it increases the exposure to respirable particles proportionally, so OEL is also an indirect measure of protection against exposure to respirable particles.

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## REFERENCES CITED

Acheson, E. D., Cowdell, R. H., Hadfield, E., and Macbeth, R.G. (1968). "Nasal cancer in woodworkers in the furniture industry," *The British Medical Journal* 2(5605), 587-96. DOI: 10.1136/bmj.2.5605.587

Barcenas, C. H., Delclos, G. L., El-Zein, R., Tortolero-Luna, G. W., Whitehead, L., and Spitz, M. R. (2005). "Wood dust exposure and the association with lung cancer risk," *American Journal of Industrial Medicine* 47(4), 349-357. DOI: 10.1002/ajim.20137

Beigzadeh, Z., Pourhassan, B., Kalantary, S., and Golbabaei, F. (2019). "Occupational exposure to wood dust and risk of nasopharyngeal cancer: A systematic review and meta-analysis," *Environmental Research* 171, 170-176. DOI: 10.1016/j.envres.2018.12.022

Bhatti, P., Newcomer, L., Onstad, L., Teschke, K., Camp, J., Morgan, M., and Vaughan, T.L. (2011). "Wood dust exposure and risk of lung cancer," *Occupational and Environmental Medicine* 68(8), 599-604. DOI: 10.1136/oem.2010.060004

Bolund, A.C.S., Miller, M.R., Jacobsen, G.H., Sigsgaard, T., and Schlunssen, V. (2018). "New-onset COPD and decline in lung function among wood dust-exposed workers: Re-analysis of a 6-year follow-up study," *Annals of Work Exposures and Health* 62(9), 1064-1076. DOI: 10.1093/annweh/wxy075

Bornholdt, J., Saber, A.T., Sharma, A.K., Savolainen, K., Vogel, U., and Wallin, H. (2007). "Inflammatory response and genotoxicity of seven wood dusts in the human epithelial cell line A549," *Mutat. Res.* 632(1-2), 78-88. DOI: 10.1016/j.mrgentox.2007.04.016

Campopiano, A., Basili, F., Angelosanto, F., Cannizzaro, A., Olori, A., Ramires, D., Iannò, A., and Angelici, L. (2016). "Field comparison of two inhalable samplers used in Italy to measure the wood dust exposure," *International Journal of Occupational and Environmental Health* 22(2), 159-166. DOI: 10.1080/10773525.2016.1200206

CEN/TR 15230 (2005). "Workplace atmospheres – Guidance for sampling of inhalable, thoracic and respirable aerosol fractions," Comité Européen de Normalisation (CEN), European Union, Brussels, Belgium.

Čavlović, A. O., Bešlić, I., Zgorelec, Ž., and Ožegović, J. (2021). "Reliability of the measurement method in determining the mass concentration of hardwood dust," *BioResources* 16(1), 643-654. DOI: 10.15376/biores.16.1.643-654

Clarhed, U. K. E., Johansson, H., Svendsen, M. V., Toren, K., Fell, A. K. M., and Hellgren, J. (2020). "Occupational exposure and the risk of new-onset chronic rhinosinusitis - A prospective study 2013-2018," *Rhinology* 58(6), 597-604. DOI: 10.4193/Rhin20.104

Demers, P. A, Kogevinas, M., Boffetta, P., Leclerc, A., Luce, D., Gérin, M., Battista, G., Belli, S., Bolm-Audorf, U., Brinton, L. A., *et al*. (1995). "Wood dust and sinonasal cancer: Pooled reanalysis of twelve case-control studies," *American Journal of Industrial Medicine* 28(2), 151-166. DOI: 10.1002/ajim.4700280202

Douwes, J., Cheung, K., Prezant, B., Sharp, M., Corbin, M., McLean, D., Mannetje, A., Schlunssen, V., Sigsgaard, T., Kromhout, H., *et al*. (2017). "Wood dust in joineries and furniture manufacturing: An exposure determinant and intervention study," *Annals of Work Exposures and Health* 61(4), 416-428. DOI: 10.1093/annweh/wxx020

EN 481 (1993). “Workplace atmospheres – Size fraction definition for measurement of airborne particles in the workplace,” Comité Européen de Normisation (CEN), European Union, Brussels, Belgium.

European Commission (EC) Communication COM (2014). “Communication from the commission to the European parliament, the Council, the European economic and social committee and the committee of the regions EU strategic framework on health and safety at work 2014-2020/* COM/2014/0332 final*/,” European Union, Brussels, Belgium.

European Directive (EU) 2017/2398 (2017). “European Directive (EU) No 2017/2398 of 12 December 2017 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work of the European Parliament and of the Council,” European Union, Brussels, Belgium.

Galea, K.S., Van Tongeren, M., Sleeuwenhoek, A.J., While, D., Graham, M., Bolton, A., Kromhout, H., and Cherrie, J. W. (2009). “Trends in wood dust inhalation exposure in the UK, 1985–2005,” *Annals of Occupational Hygiene* 53(7), 657–667. DOI: 10.1093/annhyg/mep044

Glindmeyer, H.W., Rando, R.J., Lefante, J.J., Freyder, L., Brisolara, J.A., and Jones, R.N. (2008). “Longitudinal respiratory health study of the wood processing industry,” *American Journal of Industrial Medicine* 51(8), 595-609. DOI: 10.1002/ajim.20594.

Gu, J. W., Kirsch, I., Schripp, T., Froning-Ponndorf, F., Berthold, D., and Salthammer, T. (2018). “Human exposure to airborne particles during wood processing,” *Atmospheric Environment* 193, 101-108. DOI: 10.1016/j.atmosenv.2018.08.064

Herbert, F. A., Hessel, P. A., Melenka, L. S., Yoshida, K., and Nakaza, M. (1995). “Pulmonary effects of simultaneous exposures to MDI formaldehyde and wood dust on workers in an oriented strand board plant,” *J. Occup. Environ. Med.* 37(4), 461-465. DOI: 10.1097/00043764-199504000-00018

Hessel, P. A., Herbert, F. A., Melenka, L. S., Yoshida, K., Michaelchuk, D., and Nakaza, M. (1995). “Lung health in sawmill workers exposed to pine and spruce,” *Chest* 108(3), 642-646. DOI: 10.1378/chest.108.3.642

Holm, S. E., and Festa, J. L. (2019). “A review of wood dust longitudinal health studies: Implications for an occupational limit value,” *Dose-Response* 17(1), 1-3. DOI: 10.1177/1559325819827464. National Library of Medicine.

Hursthouse, A., Fraser A., Rowley, L., and Smith, F. (2004). “A pilot study of personal exposure to respirable and inhalable dust during the sanding and sawing of medium density fibreboard (MDF) and soft wood,” *Inter. J. Env. Res. Pub. He.* 14(4), 323-326. DOI: 10.1080/09603120410001725667

IARC (2012). “A review of human carcinogens: Arsenic, metals, fibres and dusts,” *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans,* World Health Organization, International Agency for Research of Cancer, Lyon, France.

Jayaprakash, V., Natarajan, K. K., Moysich, K. B., Rigual, N. R., Ramnath, N., Natarajan, N., and Reid, M. E. (2008). “Wood dust exposure and the risk of upper aero-digestive and respiratory cancers in males,” *Occup. Environ. Med.* 65(10), 647-54. DOI: 10.1136/oem.2007.036210

Kalliny, M. I., Brisolara, J. A., Glindmeyer, H., and Rando, R. (2008). “A survey of size-fractionated dust levels in the US wood processing industry,” *J. Occup. Environ. Hyg.* 5(8), 501-510. DOI: 10.1080/15459620802194570

Kauppinen, T., Vincent, R., Liukkonen, T., Grzebyk, M., Kauppinen, A., Welling, I., Arezes, P., Blacks, N., Bochmann, F., and Campelo, F. (2006). “Occupational exposure to inhalable wood dust in the member states of the European Union," *The Annals of Occupational Hygiene* 50(6), 549-561. DOI:10.1093/annhyg/mel013

Kos, A., Horvat, D., and Šega, K. (1999). "Dusty influence research in final woodworking companies," *Drvna Industrija* 50, 11-18.

Kos, A., Beljo-Lučić, R., Horvat, D., Šega, K., and Bešlić, I. (2002). "Influential factors on indoor air dustiness in woodworking companies," *Drvna Industrija* 53(3), 131-140.

Kos, A., Beljo Lučić, R., Šega, K., and Rapp, A. (2004). "Influence of woodworking machine cutting parameters on the surrounding air dustiness," *Holz Roh Werkst.* 62(3), 169-176. DOI: 10.1007/s00107-004-0473-2

Liverseed, D. R., Perry W., Logan, P. W., Johnson, C. E., Morey, S. Z., and Raynor, P. C. (2013). "Comparative emissions of random orbital sanding between conventional and self-generated vacuum systems," *Ann. Occup. Hyg.* 57(2), 221-229. DOI: 10.1093/annhyg/mes066

Ljubičić Ćalušić, A., Varnai, V. M., Čavlović, A. O., Šegvić Klarić, M., Beljo-Lučić, R., Prester, Lj., and Macan, J. (2013). "Respiratory health and breath condensate acidity in sawmill workers," *International Archives of Occupational Environmental Health* 86(7), 815-825. DOI: 10.1007/s00420-012-0817-x

Llorente, J. L., Pérez-Escuredo, J., Alvarez-Marcos, C., Suárez, C., and Hermsen, M. (2009). "Genetic and clinical aspects of wood dust related intestinal-type sinonasal adenocarcinoma: A review," *European Archives of Otorhinolaryngology* 266(1), 1-7. DOI: 10.1007/s00405-008-0749-y

Määttä, J., Majuri, M. L., Luukkonen, R., Lauerma, A., Husgafvel-Pursiainen, K., Alenius, H., and Savolainen, K. (2005). "Characterization of oak and birch dust-induced expression of cytokines and chemokines in mouse macrophage RAW 264.7 cells," *Toxicology* 215(1-2), 25-36. DOI: 10.1016/j.tox.2005.06.021

Määttä, J., Ritva Luukkonen, R., Husgafvel-Pursiainen, K., Alenius, H., and Savolainen, K. (2006). "Comparison of hardwood and softwood dust-induced expression of cytokines and chemokines in mouse macrophage RAW 264.7 cells," *Toxicology* 218(1), 13-21. DOI: 10.1016/j.tox.2005.09.001

Matrat, M., Radoi, L., Fevotte, J., Guida, F., Cenee, S., Cyr, D., Sanchez, M., Menvielle, G., Schmaus, A., and Marrer, E. (2019). "Occupational exposure to wood dust and risk of lung cancer: The ICARE study," *Occupational and Environmental Medicine* 76(12), 901-907. DOI: 10.1136/oemed-2019-105802

Meng, E., Yin, J. Z., Jin, W., Mao, Y. Y., Wu, Q. H., and Qiu, J. (2020). "Wood dust exposure and risks of nasopharyngeal carcinoma: A meta-analysis," *European Journal of Public Health* 30(4), 817-822. DOI: 10.1093/eurpub/ckz239

Ojima, J. (2016). "Generation rate and particle size distribution of wood dust by handheld sanding operation," *Journal of Occupational Health* 58(6), 640-643. DOI: 10.1539/joh.16-0136-BR.

Pałubicki, B., Hlásková, L., and Rogoziński, T. (2020). "Influence of exhaust system setup on working zone pollution by dust during sawing of particleboards," *International Journal of Environmental Research and Public Health* 17(10), 3626; DOI: 10.3390/ijerph17103626

Paraskevaidou, K., Porpodis, K., Kontakiotis, T., Kioumis, I., Spyratos, D., and Papakosta, D. (2021). "Asthma and rhinitis in Greek furniture workers," *Journal of Asthma* 58(2), 170-179 DOI: 10.1080/02770903.2019.1674328

Pérez-Escuredo J., García Martínez, J., Vivanco, B., Álvarez Marcos, C., Suárez, C., Llorente, J. L., and Hermsen, M. A. (2012). "Wood dust-related mutational profile of TP53 in intestinal-type sinonasal adenocarcinoma," *Human Pathology* 43(11), 1894-1901. DOI: 10.1016/j.humpath

Pesch, B., Pierl, C. B., Gebel, M., Gross, I., Becker, D., Johnen, G., Rihs, H. P., Donhuijsen, K., Lepentsiotis, V., Meier, M., *et al*. (2008). "Occupational risks for adenocarcinoma of the nasal cavity and paranasal sinuses in the German wood industry," *Occupational and Environmental Medicine* 65(3), 191-196. DOI: 10.1136/oem.2007.033886

Ramroth, H., Andreas Dietz, A., Ahrens, W., and Becher, H. (2008). "Occupational wood dust exposure and the risk of laryngeal cancer: A population based case-control study in Germany," *American Journal of Industrial Medicine* 51(9), 648-655. DOI: 10.1002/ajim.20605

Ratnasingam, J., Scholz, F., Natthondan, V., and Graham, M. (2011). "Dust-generation characteristics of hardwoods during sanding processes," *European Journal of Wood and Wood Products* 69(1), 127-131. DOI: 10.1007/s00107-009-0409-y

Rogoziński, T., Wilkowski, J., Górski, J., Czarniak, P., Podziewski, P., and Szymanowski, K. (2015). "Dust creation in CNC drilling of wood dust from CNC drilling composites," *BioResources* 10(2), 3657-3665. DOI: 10.15376/biores.10.2.3657-3665

Sabolić Pipinić, I., Varnai, V.M., Beljo Lučić, R., Čavlović, A., Prester, Lj., Orct, T., and Macan, J. (2010). "Endotoxin exposure assessment in wood-processing industry: Airborne *versus* floor levels," *Arhiv za Higijenu Rada i Toksikologiju* 61(2), 161-165. DOI: 10.2478/10004-1254-61-2010-1996

Sauvé, J. F., Davies, H. W., Parent, M. E., Peters, C. E., Sylvestre, M. P., and Lavoué, J. (2019). "Development of quantitative estimates of wood dust exposure in a Canadian general population job-exposure matrix based on past expert assessments," *Annals of Work Exposures and Health* 63(1), 22–33. DOI: 10.1093/annweh/wxy083

Scarabelli, T. M., Corsetti, G., Chen-Scarabelli, C., and Saravolatz, L. D. (2021). "Follicular B-cell lymphoma and particulate matter associated with environmental exposure to wood dust," *American Journal of Case Reports* 22(e929396). DOI: 10.12659/AJCR.929396

Scheeper, B., Kromhout, H., and Boleij, J. S. (1995). "Wood-dust exposure during wood-working processes," *Annals of Occupational Hygiene* 39(2), 141-54. DOI: 10.1016/0003-4878(94)00105-a

Schlünssen, V., Sigsgaard, T., Raulf-Heimsoth, M., and Kespoh, S. (2018). "Workplace exposure to wood dust and the prevalence of wood-specific sensitization," *Allergologie Select* 2(1), 101-110. DOI: 10.5414/ALX01503E

Siew, S. S., Martinsen, J. I., Kjaerheim, K., Sparen, P., Tryggvadottir, L., Weiderpass, E., and Pukkala, E. (2017). "Occupational exposure to wood dust and risk of nasal and nasopharyngeal cancer: A case-control study among men in four Nordic countries-With an emphasis on nasal adenocarcinoma," *International Journal of Cancer* 141(12), 2430-2436. DOI: 10.1002/ijc.31015

Soćko, R. (2021). "A Quantitative risk assessment of sinonasal cancer as a function of time in workers occupationally exposed to wood dust," *International Journal of Occupational Medicine and Environmental Health* 34(4), 541-549. DOI: 10.13075/ijomeh.1896.01673 2021;34(4):541-9

Spee, T., Van de Rijdt-Van Hoof, E., Van Hoof, W., Noy, D., and Kromhout, H. (2006). "Exposure to wood dust among carpenters in the construction industry in The Netherlands," *The Annals of Occupational Hygiene* 51(3), 241-248. DOI: 10.1093/annhyg/mel075

Straumfors, A., Olsen, R., Daae, H. L., Afanou, A., McLean, D., Corbin, M., Manetje, A., Ulvestad, B., Bakke, B., Johnsen, H. L. *et al*. (2018). "Exposure to wood dust, microbial components, and terpenes in the Norwegian sawmill industry," *Annals of Work Exposures and Health* 62(6), 674-688. DOI: 10.1093/annweh/wxy041

Szewczyńska, M., and Pośniak, M. (2017). "Assessment of occupational exposure to wood dust in the polish furniture industry," *Medycyna Pracy* 68(1), 45-60. DOI: 10.13075/mp.5893.00458

Teschke, K., Demers, P. A., Davis, H. W., Kennedy, S. M., Marion, S. A., and Leung, V. (1999). "Determinations of exposure to inhalable particulate, wood dust, resin acid and monoterpenes in a lumber mill environment," *The Annals of Occupational Hygiene* 43(4), 247-255. DOI: 10.1136/oem.57.6.376

Vested, A., Kolstad, H. A., Basinas, I., Burdorf, A., Elholm, G., Heederik, D., Jacobsen, G. H., Kromhout, H., and Omland, O. (2021). "Dust exposure and the impact on hospital readmission of farming and wood industry workers for asthma and chronic obstructive pulmonary disease (COPD)," *Scandinavian Journal of Work, Environment & Health* 47(2), 163-167. DOI: 10.5271/sjweh.3926

Vinzents, P. S., Schlünssen, V., Feveile, H., and Schaumburg, I. (2001). "Variations in exposure to inhalable wood dust in the Danish furniture industry. Within- and between-worker and factory components estimated from passive dust sampling," *The Annals of Occupational Hygiene* 45(7), 603-608. DOI: 10.1016/S0003-4878(01)00033-3

Wiggans, R. E., Evans, G., Fishwick, D., and Barber, C. M. (2016). "Asthma in furniture and wood processing workers: a systematic review," *Occupational Medicine* 66(3), 193-201. DOI: 10.1093/occmed/kqv149

Zhao, C., Ando, K., Hattori, N., and Kitayama, S. (1999). "Effects of sanding conditions on concentration of respirable wood dust under belt sanding," *Mokuzai Gakkaishi* 45(4), 306-312.

ZH 1/120.41(1989). "Verfahren zur Bestimmung von Holzstaub," Zentralstelle für Unfallverhütung und Arbeitsmedezin-Hauptverband der gewerblichen Berufsgenossenschaften, ["A method for the determination of wood dust," Central Office for risk prevention and Occupational Medicine-Confederation of Professional Trade Associations]. Carl Heymans Verlag KG, Köln, Germany.

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