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PRELIMINARY STUDY OF EFFECT OF FURNITURE AND FINISHING MATERIALS ON FORMALDEDYHE CONCENTRATION IN OFFICE ROOMS

For many years formaldehyde has been known as a major eye irritant in indoor environment. It is not only one of the most common indoor air contaminants, but also the most common aldehyde detected in office and residential indoor air. Its concentration in office spaces at the Lublin University of Technology, Poland, was measured. It appeared that formaldehyde was detected in all the samples collected and its concentration ranged from 14.4 to 56 μg/m^3. Concentration of this gas in rooms with carpeting was lower than in those with wood-based panels. Higher aldehyde concentration was found in the rooms painted a few months before the experiment.

1. INTRODUCTION

Nowadays people spend more and more time indoors. The number of hours spent in offices and classrooms often exceed 8 hours per day. Therefore, the air quality in the work environment has a strong impact not only on our health, but also on our comfort and work efficiency. The occurrence of eye irritants, including selected aldehydes, in office environment is of a special concern (WOLKOFF and KJAERGAARD [29]).

Formaldehyde is the most common aldehyde detected in indoor air. It is an important chemical compound widely used in the industry to manufacture building materials and numerous household products. It is also a by-product of combustion and certain other natural processes. Thus, its concentration, both indoors and outdoors, may be substantial; however, indoor levels exceed outdoor ones (WOLKOFF [27]).

The sources of formaldehyde in the indoor air can be itemized as follows: building materials, smoking, household products, and the use of unvented, fuel-burning appliances, like gas stoves or kerosene space heaters. Formaldehyde, alone or in combination with other chemicals, serves a number of purposes in the manufactured products. For

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example, it is used to add permanent-press qualities to clothing and draperies, as a component of glues and adhesives, and as a preservative in some paints and coating products (NIU and BURNETT [20]).

The most significant sources of formaldehyde are likely to be the products made of pressed wood whose production is based on adhesives that contain urea-formaldehyde (UF) resins. Among the pressed wood products made for indoor use there are: particle boards (used as subfloors and shelvs and for cabinet works and furniture); hardwood plywood panels (used for decorative wall covering as well as for floor covering); and medium-density fiberboards (used for drawer fronts, cabinets, and furniture tops) (SALTHAMMER [22], WIGLUSZ et al. [26]).

The low-VOC paints appear to be one of the important and unexpected sources of formaldehyde. Latex paints are typically used by allergists and have become popular as they are considered to be environmentally friendly (Van der WAL et al. [25], CHANG et al. [6]). Formaldehyde has been found to be a major secondary pollutant from cleaning products in the presence of ozone (SINGER et al. [23], WOLKOFF et al. [28]).

Formaldehyde has been known for many years as a major eye and nose irritant in indoor environment. It is probably responsible for many health treats (HODGSON et al. [12]). Some studies have suggested that people exposed to formaldehyde levels ranging from 50 to 100 $\mu g/m^3$ for long periods of time are more likely to experience asthma-related respiratory symptoms, such as coughing and wheezing (WOLKOFF et al. [28]).

Authors agree that formaldehyde is a sensory irritant but vary in the opinion about its cancerogenity (ARTS et al. [1]). Until 2004 it was considered by IARC as genotoxicant. But in 2006, IARC published a new report based on USA data, which clearly indicated that formaldehyde is carcinogenic to humans, and listed HCHO in Group 1 (IARC [15]). Laboratory animals exposed to formaldehyde suffer from nasal cavity cancer, but only in the case of *very high* levels of exposure (thousands of ppb or higher). Exposure to moderate levels of formaldehyde (hundreds of ppb or higher) can cause a number of irritant symptoms, including temporary ophtalmitis or rhinitis, and a sore throat (WOLKOFF and KJAERGAARD [29]). The National Institute for Occupational Safety and Health (NIOSH), USA, has set the recommended exposure limit (REL) for formaldehyde equal to 0.016 ppm, which might be converted to approximately 20 $\mu g/m^3$ [19].

The permitted levels of formaldehyde in non-occupied indoor spaces in Poland are set at 100 $\mu g/m^3$, while in occupied spaces – at 50 $\mu g/m^3$ (Ministry of Health, 1997). The current regulations are under evaluation, and the new standard is proposed to be set at 20 $\mu g/m^3$ for both occupied (residential) and non-occupied (workplace) spaces. The new value is in compliance with exposure limits recommended by NIOSH, whose REL values apply only to workplace hazards.

A lot of data is available on the emission rate and concentration of formaldehyde, including the European Concern Action Report (1990) and data for Japan (SAKAI et al.

[21]), Mexico (BAERZ et al. [2]), and Canada (GILBERT et al. [10], [11]). Summarized literature data are presented in table 1.

Table 1

Concentration of formaldehyde obtained in this study in comparison with other studies in residential and office samples

Site/ country	Formaldehyde ($\mu g/m^3$)	Type of samples	Reference
EC	6–840	residence	ECA report [8]
Rio de Janeiro, Brasil	12.2–99.7	office	BRICKUS et al. [3]
Mexico , Mexico	17.0–36.00	office	BAERZ et al. [2]
Bralisilian University, Brasil	32.2–41.0	office	CALVACANTE et al. [4]
Fortaleza, Brasil	4.64–18.37	office	CALVACANTE et al. [5]
Prince Edward Island, Canada	5.5–87.5	residence	GILBERT et al. [9]
Strasburg, France	7–83	residence	MARCHAND et al. [16]
Lublin, Poland	14.4–56	office	this study

Model measurements (in test chambers) of formaldehyde emissions from different wood and wood-based products as well as from paints, carpeting, etc., are considered to be another important field of research (SALTHAMMER [22], WIGLUSZ et al. [26], Van der WAL et al. [25], CHANG et al. [6]). All types of materials which release formaldehyde are found not only in residential environments, but also in office environments. The impact of formaldehyde on the memory skills has been confirmed by LU et al. [14].

Compared with residential indoor areas, less data is available on formaldehyde levels in office environment and other public spaces (CHUAH et al. [7], WOLKOFF [27], CAVALCANTE et al. [5], HUTTER [13], MIU et al. [18]). The majority of current research were carried out in large-space offices with several dozens of occupants and an air conditioning system (HUTTER [13], MIU et al. [18]).

Despite the fact that model studies in chambers and studies concerning direct emissions from certain materials such as paints and plywoods are carried out, there is no information about the influence of different finishing materials on formaldehyde levels in real indoor spaces. This is mainly due to the fact that a lot of parameters have to be considered, as offices vary in size, equipment, occupant number as well as the type of activities they are designated for, etc.

In Poland, a typical office environment consists of small office rooms (up to 20 m^2) occupied by 1–3 people. Such offices have gravity ventilation and a central heating system operating in the winter. Office windows have not been opened frequently, because most of offices are situated in noisy city centers. Until now there has been no detailed information about pollutant levels, including eye irritants in offices in Poland. Therefore an attempt to measure the concentration of formaldehyde and other VOCs in office spaces has been undertaken together with the estimation of the possible sources of pollutants.

2. MATERIALS AND METHODS

Formaldehyde concentrations were measured in Lublin and its surroundings in winter and spring of 2008 using a passive sampling method. Lublin has 360,000 inhabitants and is located in the eastern part of Poland in rural areas. There are five universities in the city. The samples for measurements summarized in this study were collected in office rooms located at the Lublin University of Technology, building of the Faculty of Environmental Engineering. The building was put into use in 2002. Rooms (identical in the volume of ca. 400 m^3, naturally gravitationally ventilated) were situated at the third and fourth floor in a five-storey building. The building has a central heating system. During measurements, temperature in the rooms examined was kept at a stable level of 20 + 1 °C due to weather conditions (winter – spring) and the heating season.

The rooms were occupied by university employees – teachers and researchers who performed daily activities – prepared materials for students, evaluated research data and wrote reports and proposals. Every room has one window, overlooking north or south, and one door which opens onto the same hall. The rooms were equipped with typical office furniture: two varnished plywood desks, a few shelves (open and closed), two computers, one laser printer. Furniture varies in age. Some rooms were painted within the last 2 months. The other were painted more than one year prior to the research (one room have not been painted for 6 years). The rooms on the third floor were carpeted, while those on the fourth floor had wood-based panels. Carpets were vacuumed daily, whereas panels were cleaned using special liquid products. Smoking was not permitted in the building and the occupants of the rooms under examination were non-smokers. Occasional visits of smokers were reported in only one of the offices.

The samples were collected in triplicate over 7 days of normal occupation (including the weekend). Aldehydes were sorbed by passive sampling method with Radiello dosimeters (RAD165) (exposition time of 168 hours). Adsorbed aldehydes were extracted with acetonitrile (HPLC grade) and analyzed using the RP HPLC method (Waters) in the Restek Allure AK column; acetonitryle/water elution and UV detection set at 365 nm. Each measurement was carried out in triplicate.

The method allowed us to measure the concentration of about 10 different carbonyl compounds, and seven of them were detected in all the samples. However, only formaldehyde was selected for discussion in this study. The calibration of dosimeters was performed in a 5-dm^3 glass chamber under controlled conditions of temperature, air flow and aldehyde concentration. The detection limit of formaldehyde was 0.1 $\mu g/m^3$, and blank concentrations were lower than detection limit.

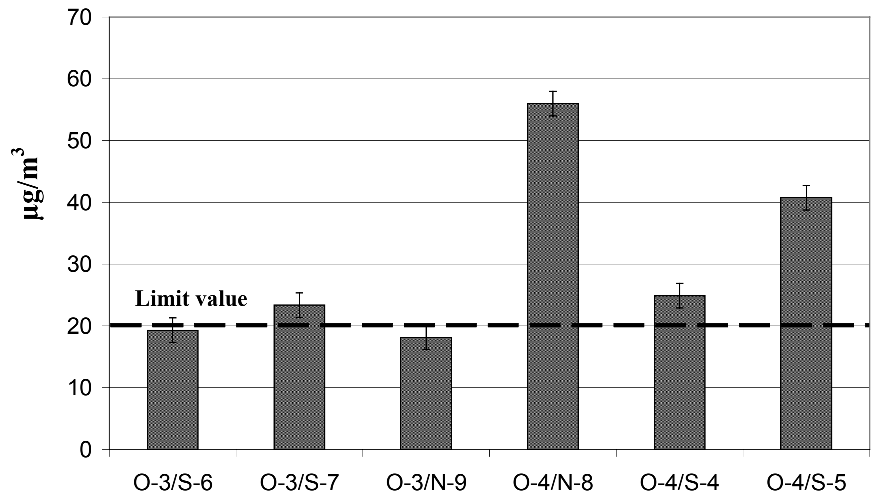
3. RESULTS AND DISCUSSION

Formaldehyde was detected in all the office rooms and its concentration varied from 14.4 to almost 56 μg/m^3 (table 2), while the levels for selected room are presented in the figure.

Table 2

Formaldehyde concentrations (μg/m^3) in office rooms

Office room	Minimum	Maximum	Mean ± SD	Median
With carpeting	14.41	23.35	20.20 ± 3.5	17.93
With panels	23.77	55.98	40.54 ± 13.8	38.12
Window overlooking north	14.41	55.98	37.07 ± 20.2	32.91
Window overlooking south	14.95	40.77	27.0 ± 9.08	25.58
Painting < 3 months	20.75	40.77	32.06 ± 9.65	30.76
Painting > 1 year	14.41	55.98	27.6 + 15.1	18.94



Formaldehyde (metanal) concentration (μg/m^3) in selected office rooms.
Line at 20 μg/m^3 corresponds to proposed Polish standard of formaldehyde level

There were no significant differences between formaldehyde concentration measured in the rooms with windows overlooking north and south. However, some significant differences existed between the rooms on the third floor and on the fourth one. The concentration on the third floor ranged from 14.4 to 23.4 μg/m^3 (median: 17.9 μg/m^3), while on the fourth one – from 23.8 to 56 μg/m^3 (median: 38.1 μg/m^3). This was due to the differences in the floor covering – rooms on the third floor have carpeting and on the fourth floor – wood-based panels. Carpeting was vacuumed daily, while panels were cleaned only occasionally with cleaning fluids. Therefore, higher concentrations on the fourth floor could be caused by the plywood panels themselves, or by secondary products from cleaning fluids. SINGER et al. [23] and WOLKOFF et al. [28] in the model studies provide evidence of this conclusion. The results in table 2 testify to the relationship between the time that elapsed since the room had been painted. Low-emission latex paints are currently commonly used, but they might be responsible for higher emissions of formaldehyde (CHANG et al. [6]). In the case of the offices under examination, higher levels of formaldehyde were detected in the rooms painted within the last 2 months. There were no differences between the rooms painted one or more years before, although more data is needed to support such a statement. Furniture, especially plywood-based, is another typical indoor source of formaldehyde. The concentration of formaldehyde in a freshly refurnished room (O-4/S-5 office in the figure) was higher than an average and approached 40 $\mu g/m^3$. This was not a surprising finding and confirmed the strong influence of the products made of pressed wood whose production is based on adhesives that contain urea-formaldehyde (UF) resins on the emission of formaldehyde. Pressed wood products are used to make furniture as well as plywood panels. However, plywood panels are made from hardwood panels, while the parts of furniture (drawer fronts, cabinets) are made of medium density fiberboard (MDF) whose resin-to-wood ratio is higher than that of other pressed wood products. Medium density fiberboard is recognized as the pressed wood product being the source of the highest formaldehyde emissions which is confirmed by model studies in test chambers (HODGSON et al. [12]).

Unexpectedly, the highest concentration of formaldehyde was measured in the room with the oldest furniture, painted and decorated 6 years prior to the experiment (O-4/N-8 office in the figure). Furniture in this room was even older as it was taken from another building, and was probably purchased in the late 1980s. Studies suggest that emission decreases with time, but this applies to the emission from the panels and fiberboard covering. Other studies show that the coating applied to the furniture surface may reduce formaldehyde emission from wood pressed boards. However, to be effective, such coating must cover all surfaces and edges. The pieces of furniture suffer some damage by exploitation and the edges of the “old” desks and cabinets in this particular room were broken. Taking into consideration that wood pressed products used in this furniture were manufactured 20 years ago, when no such strict production standards were in force, the emission above 50 $\mu g/m^3$ might be explained. Additionally this room is occupied by visiting professors for only 1–2 days per week, therefore natural ventilation rates were lower than in other rooms.

The concentration of formaldehyde in none of the rooms under examination exceeds the current limit (100 $\mu g/m^3$), but in most of the offices, formaldehyde concentration is higher than 20 $\mu g/m^3$ (the intended limit value).

4. CONCLUSIONS

Formaldehyde, popular eye and nose irritant, was detected in the all the samples collected. Formaldehyde concentration in rooms with carpeting was lower than in those with wood based panels. Windows overlooking north or south had no impact on the formaldehyde levels. Its higher concentration was found in the rooms painted a few months before the experiment. However, the highest levels were measured in the room, which was occupied only occassionally and equipped with old plywood furniture (manufactured in the 1980s).

Fresh paintings, insufficient ventilations and wood based floor panels had the highest impact on the formaldehyde levels in the office rooms. The concentration in none of the rooms under examination exceeds the current limit; however, the concentration in most offices was higher than 20 $\mu g/m^3$ (the intended limit value).

The concentration found in real office environment supports the literature findings that MDF boards and latex paints are the main sources of indoor formaldehyde. Despite the efforts to minimize emissions from different materials, an efficient ventilation system is the most effective way to decrease aldehyde concentration in the indoor environment.

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