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The Effect of Application Method of Lacquer Products on Emissions of Volatile Organic Compounds

Učinak metode lakiranja na emisiju hlapljivih organskih spojeva

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 6. 11. 2013.
Accepted – prihvaćeno: 14. 1. 2015.
*UDK: 630*829.3*
doi:10.5552/drind.2015.1358

ABSTRACT • *The aim of the study was to determine the effect of lacquer product application methods used in the furniture industry on emissions of volatile organic compounds (VOCs). The air samples for analyses came from three industrial plants, located in Poland, producing case furniture. In each of these plants, the finishing process was performed using waterborne lacquer products, but using different types of lacquer application machines and devices: automated finishing lines, automated vertical spray machines, a curtain coater and classical pneumatic spray guns. The compounds found in the air collected for analyses were adsorbed on a Tenax TA synthetic sorbent. The volatile compounds were analyzed by gas chromatography combined with mass spectrometry and thermal desorption. The results showed differences in the amounts of identified compounds depending on the type of the used lacquer application machine. It was found out that the use of automated finishing lines for lacquering of furniture elements does not only lead to an increase in the efficiency of the process, but also results in a reduction of pollution in the production halls.*

Keywords: *volatile organic compounds, surface finishing, waterborne products, furniture industry, air analysis, GC/MS/TD*

SAŽETAK • *Cilj istraživanja bio je utvrditi utjecaj primijenjenih metoda lakiranja proizvoda u proizvodnji namještaja na emisiju hlapljivih organskih spojeva (VOCs). Uzorci zraka za analizu prikupljeni su u tri industrijska postrojenja u Poljskoj u kojima se proizvodi namještaj. U svakome od tih postrojenja za proces površinske obrade upotrebljavaju se vodeni lakovi, ali se primjenjuju različiti uređaji i strojevi za nanos laka: automatizirane linije za površinsku obradu, automatizirani vertikalni uređaji za prskanje, uređaji za površinsku obradu sa zavjesom i klasični pneumatski pištolji za prskanje. Spojevi nađeni u analiziranim uzorcima zraka adsorbirani su na Tenax TA sintetičkom sorbentu. Hlapljivi spojevi analizirani su plinskom kromatografijom u kombinaciji s masenom spektrometrijom i toplinskom desorpcijom. Rezultati su pokazali razlike u količinama utvrđenih spojeva ovisno o vrsti uređaja za nanošenje laka. Utvrđeno je da uporaba automatskih linija za lakiranje elemenata namještaja ne samo povećava učinkovitost procesa već i rezultira smanjenjem onečišćenja zraka u proizvodnim halama.*

Ključne riječi: *hlapljivi organski spojevi, površinska završna obrada, proizvodi na bazi vode, proizvodnja namještaja, analiza zraka, GC/MS/TD*

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1 INTRODUCTION
1. UVOD

In the recent years, the interest in indoor air quality has increased considerably. The presence of some substances in indoor air may cause many health problems, e.g. diseases of the respiratory tract, allergies, migraines and overall irritation**.** Many researchers are of an opinion that these health problems are caused by volatile organic compounds (Brinke *et al.,* 1998; Jones, 1999; Pappas *et al.,* 2000; Nielsen *et al.,* 2007). Volatile organic compounds are emitted from many sources, both internal and external.

The problem of air quality has been discussed in terms of indoor air quality in housing buildings (Wallace *et al.,* 1991; Brown *et al.,* 1994; Hodgson *et al.,* 2002; Park and Ikeda, 2004, 2006; Guo *et al.,* 2003, 2009) and public buildings (Lee *et al.,* 1999; Kim *et al.,* 2001; Loh *et al.,* 2006; Eklund *et al.,* 2008)**.** Air quality in educational institution facilities is considered to be of particular importance (Norback, 1995; Lee *et al.,* 1999a; Daisey and Angell, 2003; Godwin and Batterman, 2007).

Increasing interest in indoor air quality in housing buildings, office buildings, schools, hospitals, etc. has resulted in the subject being discussed also in relation to industrial practice. World literature presents studies on VOC emissions and air pollution in industrial practice only to a limited extent, including also different sectors of wood industry. The studies concerning wood industry have discussed mainly VOC emissions from wood, lacquer coatings and finished products (Salthammer, 1997; Risholm-Sundman *et al.,* 1998; Salthammer *et al.,* 1999; Brown, 1999; Baumann *et al.,* 2000; Guo and Murray, 2001; Kim *et al.,* 2006; Roffael, 2006; Ohlmeyer *et al.,* 2008, Kirkeskov *et al.,* 2009).

Such pollution occurs first of all during the process of lacquering of furniture elements.

For this reason the aim of this study was to determine the effect of application methods of lacquer products used in the furniture industry on the microclimate of facilities, in which the finishing operations were performed on surfaces of furniture items.

The scope of the study included quantitative and qualitative analyses of compounds emitted to the air.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Characteristics of wood finishing plants
2.1. Obilježja pogona za površinsku obradu proizvoda

In order to determine the effect of lacquer product application methods on the emission of volatile organic compounds, investigations were conducted in three furniture manufacturing plants located in Poland, producing case furniture.

Production in these plants is based on modern technological solutions, both in rough wood processing and secondary processing as well as surface finishing. All the plants selected for the study in the finishing process use only lacquer systems based on waterborne binders, which were applied on the surface of furniture elements using different lacquer application methods and machines. The parameters of lacquer products used in the production process are presented in Table 1.

In the plant 1, the process of furniture surface finishing was based on:

- An automated finishing line (1) for lacquer application and drying, consisting of a belt sanding machine, a dust suction device and an oscillating spray machine with the electronic control unit for panel dimensions reading, a belt conveyor and the lacquer recovery system and a drying tunnel, composed of the following segments: heating (to a temperature of 30 °C – 40 °C), drying using IR radiators (at a temperature of 60 °C) and conditioning to ambient temperature.

Incoming air by means of the air pressurization unit moves overspray to the filtering system and is then carried to the exhaust fan. Suction system composed of a double set of dry filters.

Table 1 Technical parameters of lacquer products used in plants selected for the study
Tablica 1. Tehnički parametri lakova upotrebljavanih u pogonima odabranim za istraživanje

Parameters / *Parametri*	**Lacquers** / *Lakovi*		
	Plant 1 *Pogon 1.*	**Plant 2** *Pogon 2.*	**Plant 3** *Pogon 3.*
Binding agent / *Vezno sredstvo*	acrylic dispersion / *akrilna disperzija*		
Solvents / *Otapala*	water		
Non-volatile contents / *Sadržaj nehlapljivih tvari*, %	43	33	48
Density / *Gustoća*, g/cm^3	1.18	1.07	1.25
Working viscosity at a temp. of (22±1) °C *Radni viskozitet pri temp. (22±1)°C*, s* Spraying / *Prskanje* Curtain coater / *Uređaj za lakiranje sa zavjesom*	55 -	68 -	23 45
Colour / *Boja*	white / *bijela*	blue / *plava*	white / *bijela*
Other information / *Druge informacije*	multilayer product *višeslojni proizvod*	multilayer product *višeslojni proizvod*	undercoating product *zaštitni proizvod*
Information on ingredients / *Informacija o sastavu*	2-butoxyethanol *2-butoksietanol*	2-butoxyethanol *2-butoksietanol*	2-butoxyethanol 1,2-propanodiol *2-butoksietanol 1,2-propanodiol*

* Value measured using a Ford's cup No. 4 / *Vrijednost izmjerena uporabom Fordova uređaja broj 4*

- An automated vertical spray machine, equipped with two spray guns. The spraying was performed in a spraying booth.

The lacquering booth consisted of two rooms, i.e. a painting room of 4.9 x 3.9 m (*L* x *W*) and a drying room of 7.6 x 4.9 m (*L* x *W*). Pure air was supplied to the booth through the filter ceiling. The air filtration process consisted of preliminary and final filtration stages. Dusted air was discharged through a filtering water curtain.

In turn, in the plant 2, the furniture surface finishing process was performed using:

- An automated finishing line (2) for lacquer application and drying, equipped with a standing belt machine, a reading line with photocells to identify dimensions of processed elements, a drying tunnel with IRM lamps, an automated spray machine with six spray guns, a drying tunnel composed of the following zones: the drying zone using microwave electromagnetic radiation energy (the *Microwaves Operating System* - MOS), the drying zone with hot air injection in a nozzle tunnel with IRM lamps, the conditioning zone adjusting the temperature to ambient temperature.

Air purity in the lacquering chamber was provided by two fans coupled with filters. The unit is supplied with ambient air using an electric fan. Overspray is sucked in by two pipes mounted on an elevator using an exhaust fan and passes through the system of two filters: a prefilter and an after filter.

- Manual pneumatic guns in spray booths with dry filters.

The lacquering unit was equipped with the supply-exhaust ventilation system. The ventilation system was equipped with two filters: a cardboard pleated filter and a Paint-Stop filter mat.

In turn, the plant 3 was equipped with:

- A 1-headed curtain coater.

The curtain coater was located in the hall equipped with a mechanical supply-exhaust ventilation system, meeting requirements of the current technical and legal requirements concerning the operation of the plant. It was confirmed by the positive results of environmental analyses conducted at the plant on a regular basis. The lacquering stand was not equipped with a local exhaust ventilation.

- Lacquer application booths with dry filters with manual pneumatic guns.

Spray booths were equipped with the supply-exhaust ventilation system. Contaminated air was purified in a single stage process: using a cardboard pleated filter.

2.2 Adsorption of volatile organic compounds
2.2. Adsorpcija hlapljivih organskih spojeva

The air for analyses was collected to glass tubes filled with a Tenax TA solid sorbent at 120 mg (35/60 mesh, Alltech). Each time, five parallel air samples were collected using a pump (FLEC Air Pump 1001, Chematec).

The analyses were performed at the lacquer application zone at a distance of approx. 0.5 m from the lacquer application machines. The samples were collected at a height of 1.5 m above floor level.

The volume of 500 ml air was transferred by the sorbent at a rate of 50 ml/min.

2.3 Chromatographic analysis
2.3. Kromatografska analiza

The volatile organic compounds adsorbed on the Tenax TA were released in a thermal desorber and next, they were determined by gas chromatography combined with mass spectrometry following the procedure presented in Table 2.

Table 2 Operating conditions of the TD/GC/MS
Tablica 2. Uvjeti rada uređaja TD/GC/MS

Elements of the system *Elementi sustava*	**Parameters** / *Obilježja*
Thermal desorber *Toplinski desorber*	
Injector / *injektor*	Thermal desorber connected to a sorption microtrap / *toplinski desorber spojen na sorpcijski mikrotrap* Purging gas / *plin za čišćenje*: argon at 20 $m^3 \cdot min^{-1}$ Purge time / *vrijeme čišćenja*: 5 min
Microtrap / *mikrotrap*	Sorbent / *sorbent*: 80 mg Tenax TA/30 mg Carbosieve III Desorption temperature / *vrijeme desorpcije*: 250 °C during 90 s.
Gas chromatograph *Plinska kromatografija*	TRACE GC, Thermo Quest.
Column / *kolona*	RTX – 624 Restek Corporation, 60 m x 0.32 mm ID D_f – 1.8 μm: 6% cyanopropylophenyl, 94% dimethylopolysiloxane
Detector / *detektor*	Mass spectrometer / *maseni spektrometar* (SCAN: 10 – 350)
Injector / *injektor*	Thermal desorber connected with a sorption microtrap / *toplinski desorber spojen na sorpcijski mikrotrap* Rinsing gas / *plin za ispiranje*: argon 20 $m^3 \cdot min^{-1}$ Rinsing time / *vrijeme ispiranja*: 5 min.
Microtrap / *mikrotrap*	Sorbent / *sorbent*: 80 mg Tenax TA/30 mg Carbosieve III; Desorption temperature / *temperature desorpcije*: 250 °C during 90 s.
Carrier gas / *plin*	Helium / *helij*: 100 kPa, ~2 $cm^3 \cdot min^{-1}$.
Temperature setting / *postavka temperature*	40 °C during 2 min, 7 $°C \cdot min^{-1}$ to 200 °C, 10 $°C \cdot min^{-1}$ to 230 °C, 230 °C during 20 min

2.4 Qualitative and quantitative analyses
2.4. Kvalitativna i kvantitativna analiza

The compounds were identified by comparing the recorded mass spectra with the spectra contained in the NIST MS Search library – program ver. 1.7 and confirmed by referring the mass spectra and retention times of identified compounds to the spectra and retention times of appropriate standards.

Quantitative analysis of volatile organic compounds emitted from investigated surfaces was conducted by adding a reference standard 1-bromo-4-fluorobenzene (Supelco).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figures 1 to 4 and Tables 3 to 5 present testing results concerning the effect of different lacquer application technologies on the levels of volatile organic compound emissions. These results make it possible to compare the effect of technologies used to apply products based on waterborne binders, in recent years used with increasing frequency in the furniture industry. These comparisons may be made only within individual plants, since the finishing process in each of these plants was performed using different waterborne lacquer products (Table 1).

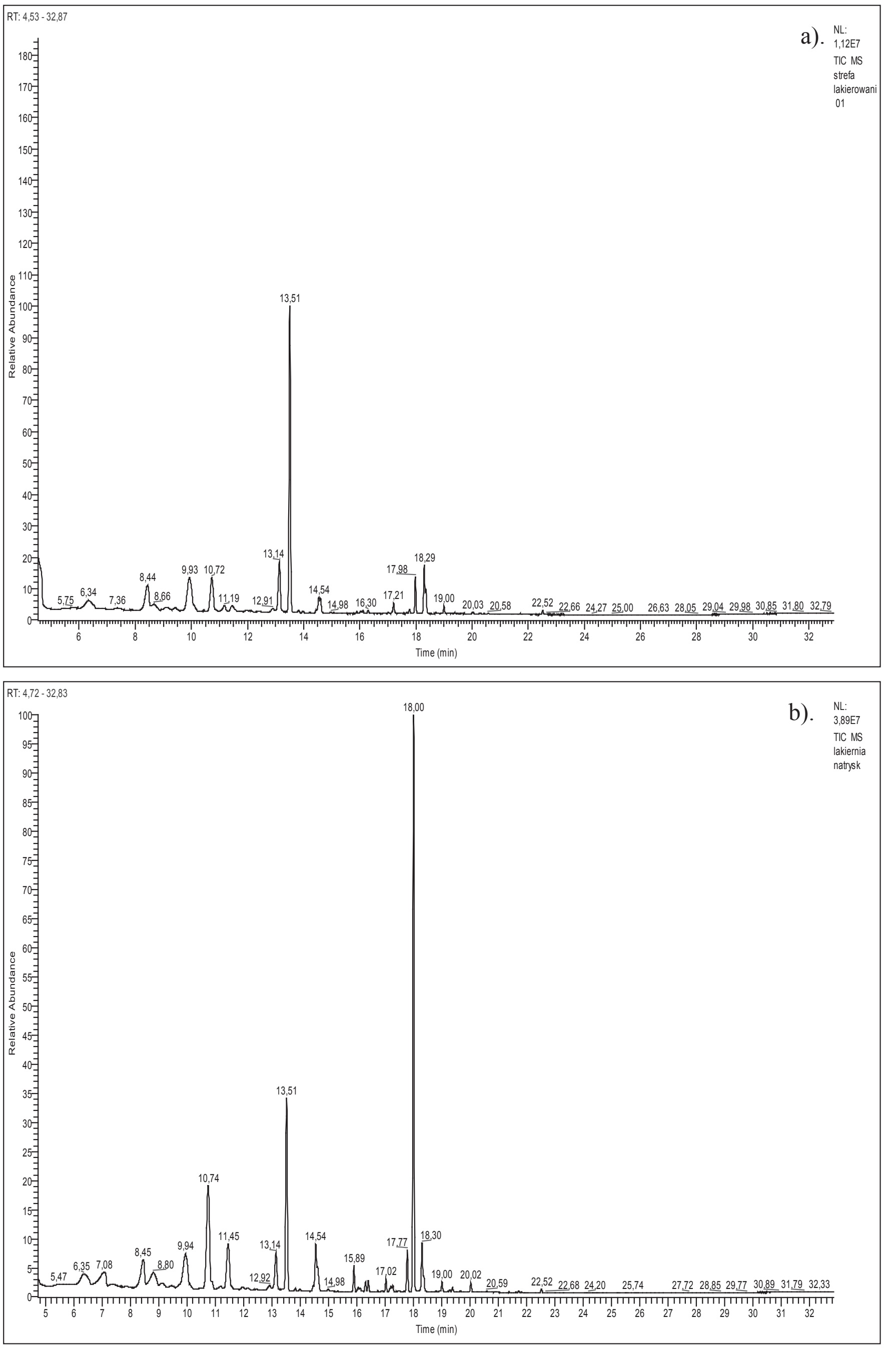

Figure 1 Chromatogram of VOCs emitted during surface lacquering in the plant 1: a) on a finishing line (1), b) using an automated vertical spray machine
Slika 1. Kromatogram hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda u pogonu 1: a) na liniji za površinsku obradu (1), b) primjenom automatskih vertikalnih uređaja za prskanje

Table 3 Concentration of VOCs during surface lacquering on a finishing line (1) and an automated vertical spray machine in the plant 1
Tablica 3. Koncentracije hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda na liniji za površinsku obradu i primjenom automatskih vertikalnih uređaja za prskanje u pogonu 1

Compounds / *Spojevi*	**RT** min	**Concentration, µg·m^{-3}** / *Koncentracija, µg·m^{-3}*	
		finishing line (1) *linija za površinsku obradu (1)*	**automated vertical spray machine** / *automatski vertikalni uređaj za prskanje*
1-butanol / *1-butanol*	10.72-10.74	721.1	2075.8
Toluene / *toluen*	13.14	768.6	547.3
Butyl acetate / *butil acetat* Hexanal / *heksanal*	14.53-14.55	181.9 147.1	501.0 268.1
n-butyl ether / *n-butil eter*	15.89	-	210.8
m.p-xylene / *m.p-ksilen*	16.29	-	81.9
1-methoxy-2-propyl acetate / *1-metoksi-2-propil acetat*	16.40	-	86.9
Propanoic acid. butyl ester / *propanoik acid. butil ester*	17.02	-	100.6
o-xylene / *o-ksilen*	17.21	29.9	-
ά-pinene / *ά-pinen*	17.77	43.3	373.0
2-butoxyethanol / 2-*butoksietanol*	17.98-18.00	293.9	4737.1
3-carene / *3-karen*	20.02	20.7	78.1
Limonen / *limonen*	20.59	-	8.4
Σ unidentified compounds / Σ *nedefinirani spojevi*		80.6	329.0
TVOC		2287	9398

The detailed results concerning the effect of surface finishing technologies applied in the plant 1 are presented in Figures 1 and in Table 3.
In the plant 1 equipped with a modern finishing line (1) and an automated vertical spray machine, the concentration of all volatile organic compounds at the lacquer application zone was in a very broad range of values from 2287 µg/m^3 to 9398 µg/m^3.

In the air, collected from the lacquer application zone on the finishing line (1) the detected compounds included particularly toluene, 1-butanol and 2-butoxyethanol at 768.6 µg·m^{-3}, 721.1 µg·m^{-3} and 293.9 µg·m^{-3}. Moreover, the presence of the following compounds was also detected: n-butyl acetate, hexanal and terpenes, mainly α-pinene and 3-carene.

In the course of lacquer application on furniture elements using an automated vertical spray machine, a broader spectrum of compounds was noted than that recorded at the application by the finishing line (1). When using the automated vertical spray machine, 2-butoxy-

Table 4 Concentration of VOCs during surface lacquering on a finishing line (2) and with the use of manual pneumatic guns in the spray booth in plant 2
Tablica 4. Koncentracije hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda na liniji za površinsku obradu (2) i primjenom ručnoga pneumatskog pištolja u kabini za prskanje u pogonu 2.

Compounds / *Spojevi*	**RT** min	**Concentration, µg·m^{-3}** / *Koncentracija, µg·m^{-3}*	
		finishing line (2) *linija za površinsku obradu (2)*	**manual pneumatic guns** *ručni pneumatski pištolj*
Acetone / *aceton*	6.42	299.0	-
1-butanol / *1-butanol*	10.77-10.79	226.3	944.5
Penatanal / *penatanal*	11.49	142.9	-
Toluene / *toluen*	13.17	401.7	68.7
Tetrachloroethylene / *tetrakloretilen*	14.14	48.1	-
Butyl acetate / *butil acetat*	14.57-14.58	134.1	700.1
Hexanal / *heksanal*	14.64	231.6	258.6
n-butyl ether / *n-butil eter*	15.92-15.93	15.9	110.6
Ethylbenzene / *etilbenzen*	16.08-16.09	54.0	57.1
m.p-xylene / *m.p-ksilen*	16.33-16.34	135.0	102.1
o-xylene / *o-ksilen*	17.19-17.20	43.5	31.9
Styrene / *stiren*	17.25	170.10	-
ά-pinene / *ά-pinen*	17.80-17.81	72.3	26.8
2-butoxyethanol / *2-butoksietanol*	18.04-18.03	1264.9	1970.5
1-butoxy-2-propanol / *1-butoksi-2-propanol*	18.74	23.3	-
3-carene / *3-karen*	20.06	-	10.8
Limonen / *limonen*	20.62	29.7	-
Σ unidentified compounds *Σ nedefinirani spojevi*		448.8	277. 1
TVOC		3741	4559

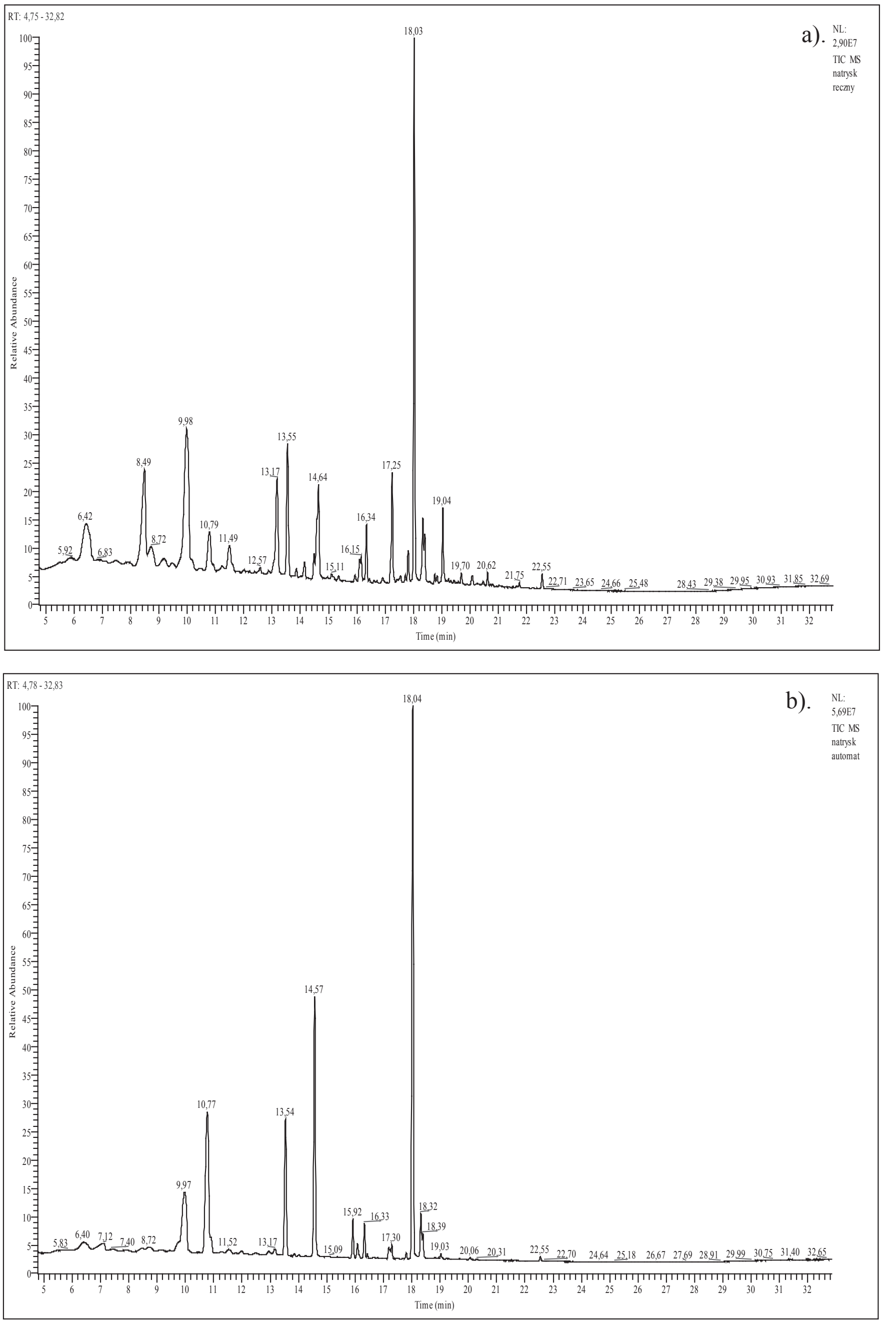

Figure 2 Chromatogram of VOCs emitted during surface lacquering in the plant 2: a) on a finishing line (2), b) with the use of a manual pneumatic gun in the spray booth
Slika 2. Kromatogram hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda u pogonu 2.: a) na liniji za površinsku obradu (2), b) primjenom ručnoga pneumatskog pištolja u kabini za prskanje

ethanol was emitted in the greatest amounts. Concentration of the compound amounted to 4737.1 μg·m^{-3}. i.e. almost 50 % total concentration of all compounds found in the analyzed air. High emissions were also recorded for 1-butanol (2075.8 μg·m^{-3}), toluene (547.3 μg·m^{-3}) and butyl acetate (501.0 μg·m^{-3}).

Large differences in the total amount of all compounds released into the air are primarily the result of the increased concentration of 2-butoxyethanol and 1-butanol in the spray booth. Glycol concentration in the lacquer application zone, when automated vertical spraying was used, was over 16-times higher and that of alcohol was almost 3-fold higher than at the lacquer application zone on the finishing line.

Successive figures (Fig. 2) and Table 4 present results concerning the effect of surface lacquering processes on air quality in the plant 2.

The concentration of the volatile organic compounds at the finishing line (2) amounted on an average to 3741 μg/m^3 and it was lower than when applying coatings with manual spray guns in the lacquer application booth, equipped with dry filters, where it amounted to 4559 μg/m^3.

In the tested air collected near the lacquer application zone on the finishing line (2) considerable amounts were detected for 2-butoxyethanol at 1264.9 μg/m^3, toluene at 401.7 μg/m^3, acetone at 299.0 μg/m^3, 1-butanol at 226,3 μg/m^3 and hexanal at 231.6 μg/m^3. The above mentioned compounds jointly accounted for over 64 % of the total emission. The other substances emitted in smaller amounts included e.g. pentanal, butyl acetate, ethylbenzene, m,p-xylene, as well as terpene compounds. i.e. ά-pinene. It needs to be stressed that in the air collected at the finishing line (2) the presence of styrene was detected at 170.10 μg/m^3. Lacquer application on furniture surface in the finishing line (2) additionally caused by the emission of such compounds as acetone, pentanal, tetrachloroethylene and 1-butoxy-2-propanol, whose presence was not detected in the air collected from the spray booth (2).

In the air samples collected from a spray booth, in which manual spraying was applied, a smaller spectrum of compounds was detected than in the case of the finishing line (2). 2-butoxyethanol was the compound released in the greatest amount, at a concentration of 970.5 μg/m^3. Lacquer application by manual pneumatic guns caused the emission of large amounts of 1-butanol (944.5 μg/m^3) and butyl acetate (700.1 μg/m^3).

Emissions of 2-butoxyethanol, 1-butanol and butyl acetate accounted for over 80 % of all the released compounds.

The measurements taken in the plant 3 made it possible to compare the technology of surface finishing using curtain coater with manual spray pneumatic guns. The results of these measurements are presented in Figures 3 and 5.

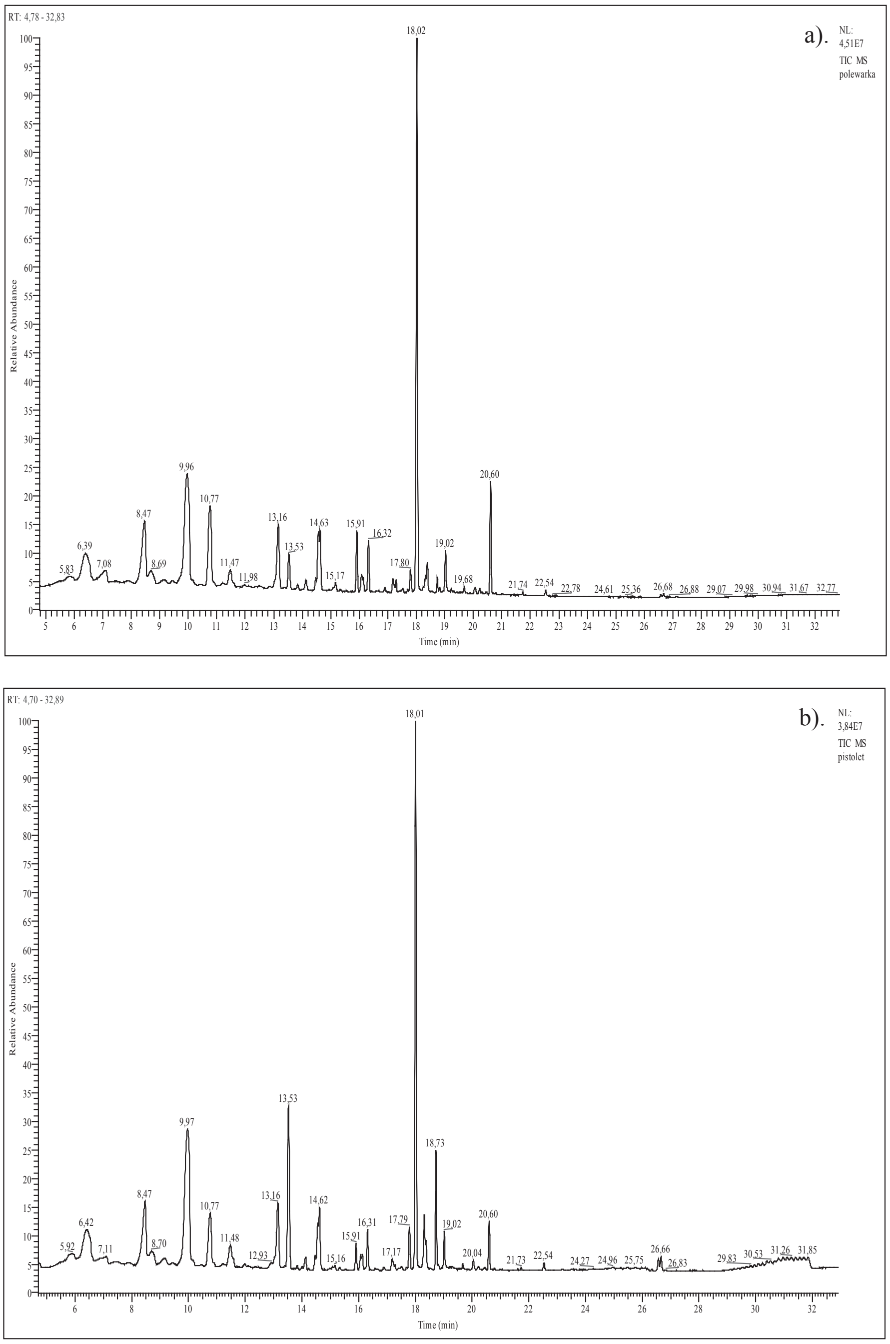

Figure 3 Chromatogram of VOCs emitted during surface lacquering in plant 3: a) with a curtain b coater, b) with the use of a manual pneumatic gun in the spray booth

Slika 3. Kromatogram hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda u pogonu 3.: a) uređajem za nanošenje laka sa zavjesom, b) primjenom ručnoga pneumatskog pištolja u kabini za prskanje

Table 5 Concentration of VOCs during surface lacquering with the use of a curtain coater and of manual pneumatic guns in the spray booth in plant 3
Tablica 5. Koncentracije hlapljivih organskih spojeva emitiranih tijekom lakiranja proizvoda primjenom uređaja sa zavjesom i primjenom ručnoga pneumatskog pištolja u kabini za prskanje u pogonu 3.

Compounds / *Spojevi*	**RT** min	**Concentration, μg·m^{-3}** / *Koncentracija, μg·m^{-3}*	
		curtain coater *uređaj za lakiranje sa zavjesom*	**manual pneumatic guns** *ručni pneumatski pištolj*
Acetone / *aceton*	6.39-6.42	377.1	440.3
1-butanol / *1-butanol*	10.77	1306.5	502.6
Penatanal / *penatanal*	11.47-11.48	146.4	215.3
Toluene / *toluen*	13.16	498.1	447.5
Tetrachloroethylene / *tetrakloretilen*	14.13	51.3	67.4
Butyl acetate / *butil acetat*	14.56	349.9	215.2
Hexanal / *heksanal*	14.63	193.7	274.9
n-butyl ether / *n-butil eter*	15.91	515.9	100.7
Ethylbenzene / *etilbenzen*	16.08	89.2	62.7
m.p-xylene / *m.p-ksilen*	16.32-16.31	262.1	168.9
o-xylene / *o-ksilen*	17.18-17.17	66.9	40.5
ά-pinene / *ά-pinen*	17.80-17.79	75.2	181.6
2-butoxyethanol / *2-butoksietanol*	18.02-18.01	2829.6	2207.3
1-butoxy-2-propanol / *1-butoksi-2-propanol*	18.73	50.9	408.6
3-carene / *3-karen*	20.05-20.04	30.8	47.0
Limonen / *limonen*	20.60	405.5	168.3
Σ unidentified compounds / *Σ nedefinirani spojevi*		357.2	362.5
TVOC		7606	5911

They showed that lower air pollution is caused by manual spray guns in a lacquer application booth than by a curtain coater. The concentration of volatile organic compounds near the lacquer application zone in the curtain coater was 7606 μg/m^3, while at the lacquer application workstation with the use of manual pneumatic guns it was lower amounting on an average to 5911 μg/m^3.

In the plant 3, where during the study, the undercoating product was applied, a spectrum of compounds was found similar to those detected in the two other plants. The compound released in the greatest amount turned out to be 2-butoxyethanol. Finishing of furniture elements by curtain coating caused emission of this compound at 2829.6 μg/m^3, while lacquer application with the use of manual guns resulted in emission at 2207.3 μg/m^3. In the tested air, high concentrations were also detected for acetone, 1-butanol, toluene and 1-butoxy-2-propanol. Lower amounts were recorded for pentanal, n-butyl acetate, hexanal, m,p-xylene as well as terpenes, i.e. ά-pinene, 3-carene and limonene.

Tested air samples collected from the furniture element lacquer application zones contained such compounds as aldehydes, ketones, aromatic hydrocarbons, alcohols, glycols and terpenes. Sources of their emissions included both finished furniture elements and applied lacquer systems. Wood species were sources of emissions of aldehydes, pentanal and hexanal. These compounds are formed through oxidation reactions of unsaturated fatty acids found in wood (Risholm-Sundman *et al*., 1998). Pentanal is formed as a result of oxidation of linoleic acid, while pentanal is the product of oxidation of linolenic acid (Salthammer *et al*., 1999). Terpene compounds (α-pinene, 3-carene, limonene) are also emitted by various wood species, particularly softwood iglaste (Roffael, 2006; Risholm-Sundman *et al.,* 1998; Manninen *et al.,* 2002). Acetone is a compound detected during analyses of emissions of volatile organic compounds from different wood species, wood-based materials and lacquer systems (Brown, 1999; Risholm-Sundman *et al.,* 1998; Kirkeskov *et al.,* 2009).

2-butoxyethanol was an important component released by all lacquer systems applied in the plants. Analyses of water-borne systems conducted by Salthammer (1997) and Stachowiak-Wencek and Prądzyński (2011) showed that 2-butoxyethanol is a characteristic compound emitted by such lacquer systems. Moreover, chamber tests conducted by Stachowiak-Wencek and Prądzyński (2011) also showed that waterborne systems, apart from glycols, may emit to air several other compounds. Air collected from furniture element lacquer application zones in the analyzed plants was found to contain aromatic hydrocarbons (toluene, ethylbenzene, m-, p- and o-xylene, styrene) and esters (butyl acetate, 1-methoxy-2-propyl acetate and propanoic acid butyl ester).

It is rather difficult to explain the presence of styrene in air collected from the lacquer application zone at lacquering line 2. Available literature contains practically no information on emission of styrene from aqueous systems. Moreover, this compound was not detected during the application using spray guns. Emission of styrene is possible from waterborne products cured using UV irradiation. Styrene is used for copolymerization of UPE-systems. A study by Salthammer *et al.* (1999) showed that UV-cured aqueous products based on unsaturated polyester (UPE) may be sources of styrene emission. In the analyzed lacquering line (2) both aqueous products and UV-cured aqueous products may be applied alternately. It may be assumed that sty-

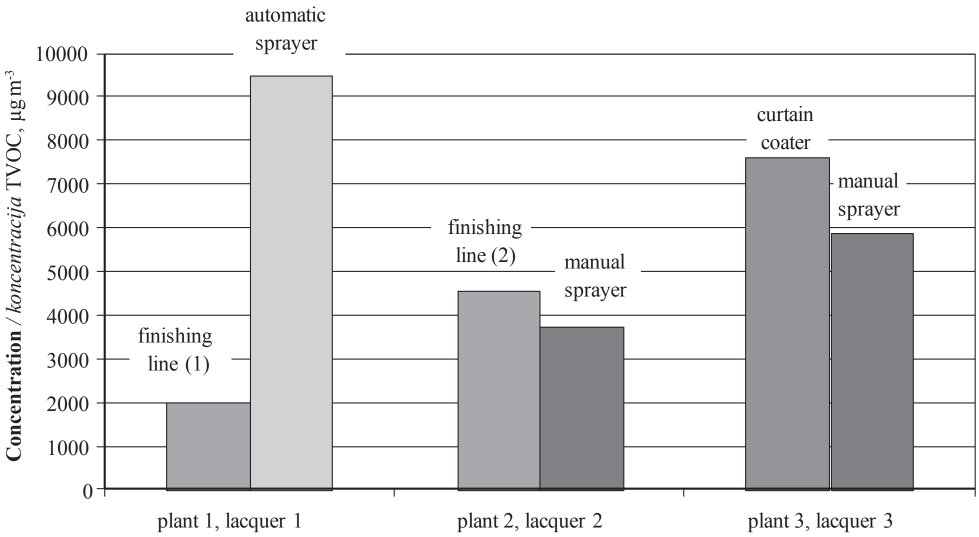

Figure 4 Comparison of TVOC emissions from lacquer application zones using individual lacquer application machines
Slika 4. Usporedba emisije ukupnih hlapljivih organskih spojeva pri primjeni različitih uređaja za lakiranje

rene detected in the lacquer application zone at lacquering line (2) did not originate from the analyzed systems, but rather from the UV-cured aqueous products applied earlier at the same line.

On the basis of the conducted tests, it was found that in the analyzed plants emissions of volatile organic compounds varied and to a considerable extent depended on the type of the used lacquer application machine or device. A comparison of TVOC emissions from the lacquer application zones in individual lacquer application machines is presented in Figure 4.

The highest TVOC content was detected in the air collected from the lacquer application zone with automated spraying amounting to 9398 μg/m^3, while the level for the use of a curtain coater was 7606 μg/m^3. Automated finishing lines proved to be superior in comparison to the other machines. Concentration of VOCs was 2287 and 3741μg/m^3. In the case of manual spraying, the level of emission from the lacquer application zone was varied ranging from 4559 5911 μg/m^3 to 5911 μg/m^3.

When comparing technologies of lacquer product application, in which identical lacquer products were applied, it needs to be stated that VOCs emissions in the plant 1 were 4-fold higher when using automated spraying than in the case of surface finishing of furniture on the finishing line. In turn, in the plants 2 and 3 these differences were less marked. The finishing line installed in the plant 2 in the lacquer application zone caused air pollution with volatile compounds by 20 % higher than the lacquer application with the use of manual pneumatic guns. In turn, in the plant 3, surface finishing with the use of a curtain coater contributed to VOC air contamination higher by 28 %.

4 CONCLUSION
4. ZAKLJUČAK

1. It was found out that surface finishing of furniture with waterborne lacquer products causes air pollution in production halls with volatile organic compounds.
2. A broad spectrum of volatile compounds was found in the air collected from the lacquer application zones. A characteristic component of emissions, irrespective of the type of the applied waterborne product, was 2-butoxyethanol, whose concentration ranged from 293.9 μg/m^3 to 4737.1 μg/m^3 and accounted for 12 % up to 79 % of the total amount of all released volatile compounds.
3. It was determined that not only the type of the applied lacquer product influenced the amount and type of VOCs emitted during the finishing process, but a significant role was also played by the type of the used lacquer application machine.
4. The use of automated finishing lines in surface finishing of furniture elements leads not only to an increase in efficiency of the finishing process, but has a positive effect on the microclimate in the facilities in which these machines are used.

5 REFERENCES
5. LITERATAURA

1. Baumann, M. G. D.; Lorenz, L. F.; Batterman, S. A.; Zhang, G. Z., 2000: Aldehyde Emissions form Particleboard and Medium Density Fiberborad Products. Forest Products Journal, 50(9): 75-82.
2. Brinke, J. T.; Selvin, S.; Hodgson, A. T.; Fisk, W. J.; Mendell, M. J.; Koshland, C. P.; Daisey, J. M., 1998: Development of New Volatile Organic Compound (VOC) Exposure Metrics and their Relationship to "Sick Building Syndrome" Symptoms. Indoor Air, 8: 140-152. http://dx.doi.org/10.1111/j.1600-0668.1998.t01-1-00002.x
3. Brown, S. K., 1999: Chamber Assessment of Formaldehyde and VOC Emissions from Wood-Based Panels. Indoor Air, 9: 209-215. http://dx.doi.org/10.1111/j.1600-0668.1999.t01-1-00008.x
4. Brown, S. K.; Sim, M. R.; Abramson, M. J.; Gray, C. N., 1994: Concentrations of volatile organic compounds in indor air: a review. Indoor Air, 4: 123-134. http://dx.doi.org/10.1111/j.1600-0668.1994.t01-2-00007.x

5. Daisey, J. M.; Angell, W. J., 2003: Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air, 13: 53-64. http://dx.doi.org/10.1034/j.1600-0668.2003.00153.x
6. Eklund, B. M.; Burkes, S.; Morris, P.; Mosconi, L., 2008: Spatial and temporal variability in VOC levels within a commercial retail building. Indoor Air, 18: 365-374. http://dx.doi.org/10.1111/j.1600-0668.2008.00537.x
7. Godwin, C.; Batterman, S., 2007: Indoor air quality in Michigan schools. Indoor Air, 17: 109-121. http://dx.doi.org/10.1111/j.1600-0668.2006.00459.x
8. Guo, H.; Kwok, N. H.; Cheng, H. R.; Lee, S. C.; Hung, W. T.; Li, Y. S., 2009: Formaldehyde and volatile organic compounds in Hong Kong homes: concentrations and impact factors. Indoor Air, 19: 206-217. http://dx.doi.org/10.1111/j.1600-0668.2008.00580.x
9. Guo, H.; Murray, F., 2001: Determination of total volatile organic compounds emissions from furniture polishes. Clean Products and Processes, 3: 42-48. http://dx.doi.org/10.1007/s100980100099
10. Guo, H.; Murray, F.; Lee, S. C., 2003: The development of low volatile organic compounds emission house-a case study. Building and Environment, 38: 1413-1422. http://dx.doi.org/10.1016/S0360-1323(03)00156-2
11. Hodgson, A. T.; Beal, D.; Mcllvaine, J. E. R., 2002: Sources of formaldehyde. other aldehydes and terpenes in a new manufactured house. Indoor Air, 12: 235-242. http://dx.doi.org/10.1034/j.1600-0668.2002.01129.x
12. Jones, A. P., 1999: Indoor air quality and health - formaldehyde and long-term VOC measurements. Atmospheric Environment, 33: 4535-4564. http://dx.doi.org/10.1016/S1352-2310(99)00272-1
13. Kim, S.; Kim, J. A.; Kim, H. J.; Kim, S. D., 2006: Determination of formaldehyde and TVOC emission factor from wood-based composites by small chamber method. Polymer Testing, 25: 605-614. http://dx.doi.org/10.1016/j.polymertesting.2006.04.008
14. Kim, Y. M.; Harrad, S.; Harrison, R. M., 2001: Concentrations and sources of VOCs in urban domestic and public microenvironments. Environmental Science & Tecolohngy, 35: 997-1004. http://dx.doi.org/10.1021/es000192y
15. Kirkeskov, L.; Witterseh, T.; Funch, L.W.; Kirstiansen, E.; Mølhave, L.; Hansen, M. K.; Kundsen, B. B., 2009: Health evaluation of volatile organic compounds (VOC) emission from exotic wood products. Indoor Air, 19: 45-57. http://dx.doi.org/10.1111/j.1600-0668.2008.00560.x
16. Lee, S. C.; Chan L. Y.; Chiu M. Y., 1999: Indoor and outdoor air quality investigation at 14 public places in Hong Kong. Environment International, 25: 443-450. http://dx.doi.org/10.1016/S0160-4120(99)00019-7
17. Lee, S. C.; Chang, M., 1999a. Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere, 41: 109-113. http://dx.doi.org/10.1016/S0045-6535(99)00396-3
18. Loh, M. M.; Houseman, E. A.; Gray, G. M.; Levy, J. I.; Spengler, J. D.; Bennet, D. H., 2006: Measured concentrations of VOCs in several non-residential microenvironments in the United States. Environmental Science & Technology, 40: 6903-6911. http://dx.doi.org/10.1021/es060197g
19. Manninen, A. M.; Pasanen, P.; Holopainen, J. K., 2002. Comparing the VOC emissions between air-dried and heat-treated Scots pine wood. Atmospheric Environment, 36: 1763-1768. http://dx.doi.org/10.1016/S1352-2310(02)00152-8
20. Nielsen, G. D.; Larsen, S. T.; Olsen, O.; Løvik, M.; Poulsen, L. K.; Glue, C.; Wolkoff, P., 2007: Do indoor chemicals promote development of airway allergy? Indoor Air, 17: 236-255. http://dx.doi.org/10.1111/j.1600-0668.2006.00468.x
21. Norback, D., 1995: Subjective indoor air quality in schools – the influence of high room temperature, carpeting, fleecy wall materials and volatile organic compounds. Indoor Air, 5: 237-246. http://dx.doi.org/10.1111/j.1600-0668.1995.00003.x
22. Ohlmeyer, M.; Makowski, M.; Fried, H.; Hasch, J.; Schöler, M., 2008: Influence of panel thickness on the release of volatile organic compounds from OSB made of Pinus *sylvestris* L. Forest Products Journal, 58(1/2): 65-70.
23. Pappas, G. P.; Herbert, R. J.; Henderson, W.; Koenig, J.; Stover, B.; Barnhart, S., 2000: The respiratory effect of volatile organic compounds. International Journal of Occupational Medicine and Environmental Heath, 6: 1-8. http://dx.doi.org/10.1179/oeh.2000.6.1.1
24. Park, J. S.; Ikeda, K., 2004: Exposure to mixtures of organic compounds in homes in Japan. Indoor Air, 14: 413-420. http://dx.doi.org/10.1111/j.1600-0668.2004.00266.x
25. Park, J. S.; Ikeda, K., 2006: Variations of formaldehyde and VOC levels during 3 years in new and older homes. Indoor Air, 16: 129-135. http://dx.doi.org/10.1111/j.1600-0668.2005.00408.x
26. Risholm-Sundman, M.; Lundgren, M.; Vestin, E.; Herder, P., 1998: Emissions of acetic acid and other volatile organic compounds from different species of solid wood. Holz als Roh- und Werkstoff, 56: 125-129. http://dx.doi.org/10.1007/s001070050282
27. Roffael, E., 2006: Volatile organic compounds and formaldehyde in nature, wood and wood based panels. Holz als Roh- und Werkstoff, 64: 144-149. http://dx.doi.org/10.1007/s00107-005-0061-0
28. Salthammer, T. 1997: Emission of Volatile Organic Compounds from Furniture Coatings. Indoor Air, 7:189-197. http://dx.doi.org/10.1111/j.1600-0668.1997.t01-1-00004.x
29. Salthammer, T.; Schwarz, A.; Fuhrmann, F., 1999: Emission of reactive compounds and secondary products from wood-based furniture coatings. Atmospheric Environment, 33: 75-84. http://dx.doi.org/10.1016/S1352-2310(98)00128-9
30. Stachowiak-Wencek, A.; Prądzyński, W., 2011: Emission of volatile organic compounds (VOC) from waterborne lacquers with different content of solids. Drewno 54: 51-63.
31. Wallace, L.; Pellizzari, E.; Wendel, C., 1991. Total Volatile Organic Concentrations in 2700 Personal, Indoor; and Outdoor Air Samples collected in the US EPA Team Studies. Indoor Air, 1: 465-477. http://dx.doi.org/10.1111/j.1600-0668.1991.00011.x

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