

Health evaluation of volatile organic compound (VOC) emission from exotic wood products

Abstract The purpose of this study was to measure and evaluate the impact of the emissions of selected products of exotic wood on health. Ten products were screened for chemical compounds, and five of the most used products which emitted more than 800 µg/kg were selected for further quantitative analyses by climate chamber measurement (iroko, ramin, sheesham, merbau, and rubber tree). Samples of exotic wood (rubber tree and belalu) were further analyzed for emission of chemical compounds by migration into artificial saliva and for content of pesticides and allergenic natural rubber latex (NR latex) (rubber tree). The toxicological effects of all substances identified were evaluated and the lowest concentrations of interest (LCI) assessed. An *R*-value was calculated for each wood product (*R*-value below 1 is considered to be unproblematic as regards health). Emission from the evaluated exotic wood only took place to a very limited extent. None of the selected products, under the chosen rating system, is likely to cause adverse health effects. Products with surface treatment might pose a problem if used as kitchen utensils, as children's toys, or when they are in close contact with the skin for a long time.

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Practical Implications

The authors investigated the chemical emissions from selected products from exotic wood by climate chamber measurement. Quantitative chemical analyses of emissions from the five most used exotic products in Denmark were performed, and all chemical compounds found were evaluated toxicologically. Emission from the evaluated exotic wood was very limited. None of the products is likely, under our exposure conditions, to cause health problems in relation to indoor air.

Introduction

Human personal comfort and health in indoor environment are markedly influenced by the quality of air. Typical symptoms caused by air quality problems vary greatly according to an individual's sensitivity and may include eye irritation, sneezing, coughing, fatigue, skin irritation, breathing difficulties, etc. These symptoms are not necessarily indicative of critical health effects, but they may have an important influence on the overall

human well-being in the indoor environment. Furthermore, it is important to insure that the emissions to indoor air do not lead to chronic health problems. People have different tolerance levels, and hence it is difficult to assign standards or guidelines to set acceptable vs. unacceptable levels of airborne pollutants.

Wood consists mainly of cellulose, hemicellulose, and lignin. In addition to these main components, wood contains numerous other organic and inorganic compounds. The content and composition of these

compounds vary from species to species; in addition, variation within species and within an individual tree can be extensive. Among the compounds found are terpenes and resins, which are primarily composed of abietic, sylvinitic, sapin, and pimaric acid. The odor of the wood is due, among others, to the ethereal oils, which are emitted from the wood during drying. As regards the indoor environment, assessment of the volatile compounds is of utmost interest.

The purpose of the present study was to examine if ordinary indoor use of products of exotic wood causes discomfort or chronic health effects. In a previous paper, we described a method for evaluating emissions to indoor air from wood and wood-based products (Larsen et al., 1999). The method was applied to 23 wood products and included: (i) measurements of volatile organic compounds (VOC) by chamber testing; (ii) calculation of the concentration in a standard room; (iii) toxicological evaluation of individual substances in the VOC emission from selected wood products by defining a lowest concentration of interest (LCI); and (iv) evaluation of the same toxicological effects of total emissions of VOCs from a product (i.e. *R*-value) (Jensen et al., 2001).

The present paper describes the health evaluation of emission of chemical compounds from consumer products made of exotic wood using this method (The Danish Environmental Protection Agency, 2004). In addition, two of the examined wood species were evaluated for

emission of chemical compounds by migration into artificial saliva and one for content of pesticides.

Materials and methods

Emission testing

Ten products made from exotic wood were selected for the emission study. In the present study the term 'exotic wood' is used for wood species imported from far away. The products were selected from a group of 35 of the most common exotic wood species imported to Denmark, and represent the product groups, which have been found in the market in Denmark and the wood species which are widely used for these product groups.

Many of the products had undergone a surface treatment, which can either contribute to the emission of compounds or reduce the emission from the wood by creating a more or less impermeable sealing. The 10 products are listed in Table 1. Initially, all 10 products were screened for emission of chemical compounds by head-space analyses. Based on the results from this qualitative screening, five products were selected for further quantitative analysis of the emission (Table 1).

The following criteria were used for selection:

- products, which are used on large surfaces;
- products, which emit the most;
- products, which are most widely used;
- the type of emission from the product.

Table 1 Products selected for qualitative and quantitative analyses of the emissions and the total amount of emitted compounds by headspace

	Wood species	Botanical name	Product	Potential surface treatment	Total amount ($\mu\text{g/kg}$) of emitted compounds	Products selected for quantitative analysis	Emitted compounds by quantitative analyses
1	Rubber tree	<i>Hevea brasiliensis</i>	Dining table	Lacquer ^b	2938	X	Formaldehyde, acetaldehyde, acrolein, propanal, hexanal, nonanal, decanal, 2-butanone, acetone, 2-methyl-1-propanol, butanol, 3-methylhexane, methylcyclohexane, toluene, butyl acetate, xylenes/ethylbenzene, 2-butoxyethanol
2	Ramin	<i>Gonystylus bankanus</i>	Venetian blind	Stain	929	X	Formaldehyde, acetaldehyde, butanal, hexanal, nonanal, decanal, 2-butanone, acetone, 2-methyl-1-propanol, butanol, 3-methylhexane, 1,2-butandiol
3	Sheesham	<i>Dalbergia latifolia</i>	Bed table	Wax	819	X	Formaldehyde, acetaldehyde, propanal, butanal, hexanal, acetone, 2-methyl-1-propanol, butanol, 1-methoxy-2-butane, 3-methylhexane, toluene, methylcyclohexane, butyl acetate, α -pinene
4	Teak	<i>Tectona grandis</i>	Tray		110		na
5	Jatoba	<i>Hymenaea courbaril</i>	Floor	Oil	959		na
6	Merbau	<i>Intsia bijuga</i>	Floor	Oil	6445	X	Formaldehyde, acetaldehyde, butanol, pentanal, hexanal, benzaldehyde, decanal, butyl acetate, 2-butanone, acetone, 2-methyl-1-propanol, 2-ethyl-1-hexanol, 3-methylhexane, tridecan, propanal
7	Khaya mahogany	<i>Khaya ivorensis</i>	Kitchen table top	Oil ^a	10		na
8	Iroko	<i>Chlorophora excelsa</i>	Kitchen table top	Oil ^a	1739	X	Formaldehyde, acetaldehyde, hexanal, acetone, 2-butanone, 3-methylhexane, α -pinene
9	Cherry, American	<i>Prunus serotina</i>	Kitchen table top	Oil ^a	67		na
10	Belalu	<i>Albizia falcata</i>	Figure	Ink	<15		na

^aProducts which are normally oil treated, but which in this survey, form part as untreated.

^bThe distributor has informed this product to have been wax treated. It has, however, been evaluated to be lacquered na, not analyzed.

The cut-off value for the total amount of emitted compounds was chosen to be 800 µg/kg, as one of the products (Jatoba) with an emission value of 959 µg/kg was deselected because of its limited use.

The quantitative determination was carried out by climate chamber measurements according to ENV 13419-1 (now: EN/ISO 16000-9) (EN/ISO, 2006). The test specimen was placed in a climate chamber at the following test conditions:

Climate chamber	225 litre polished stainless steel
Temperature	23 ± 0.5°C
Relative humidity	45 ± 3% RH
Air change in climate chamber	1 ± 0.05 h ⁻¹
Air velocity	0.15 ± 0.05 m/s

Emissions from the specimen were mixed with chamber air; air samples were taken at fixed intervals, i.e. 3, 10 and 28 days and analyzed by capillary column gas chromatography combined with mass spectrometric detection, GC-MS-SCAN (29-450 amu-screening analysis) according to ISO/DIS 16000-6.2 (ISO/DIS, 2002). Aldehydes were collected on dinitrophenylhydrazine (DNPH) cartridges and subsequently analyzed by high-performance liquid chromatography with UV detection (HPLC-UV).

Quantification was done in relation to the external calibration standards of the detected compound of closely related chemical compounds.

Detection limit for VOC's on Tenax	0.3–1 µg/m ³
Detection limit for aldehydes on DNPH	1.2 µg/m ³
Inaccuracy of analysis results	10–15%

Blind values were analysed for the empty chamber prior to testing, and unexposed tubes were analysed together with test tubes. All measured concentrations were corrected for blind values. The inaccuracy of the analysis results is based on the laboratory's experience with quantification in relation to external standards on the equipment used.

LCI in indoor climate

When evaluating whether a chemical compound or a product consisting of numerous chemical compounds can constitute a health risk, it would be natural to evaluate the result of epidemiological examinations on the reaction of humans to the exposure in question. These examinations are, unfortunately, rare and in many cases impossible to carry out. It is, therefore, necessary to use other methods to be able to carry out a toxicological evaluation of compounds emitted from, e.g. exotic wood. Jensen et al. (2001), examining wood and wood-based materials, furniture, and interior furnishings, described a method for evaluating the

impacts of emission from these materials on health. This method was applied in this study.

The evaluation of the individual compounds found in the emissions by climate chamber measurements have, when possible, included the following: toxicological effects (cancer, allergy, teratogenicity, nervous system effects and other health effects) and sensory irritation and odor. The necessary information was provided by the TOXLINE, RTECS, ECDIN, NIOSHTIC, Medline, and REPROTOX databases, as well as from existing criteria documents that included evaluations made by The Danish Environmental Protection Agency (1996). For all compounds, an assessment for: (i) effects, where no observed effect level (NOEL) is expected; (ii) effects, where no NOEL is present (e.g. carcinogens); and (iii) sensory irritation and odor were carried out (Jensen and Wolkoff, 1996). The principles for this stipulation are the same as those used in the Guidelines for Air Emission Regulation (The Danish Environmental Protection Agency, 1990).

LCI and *R*-value

The LCI is defined as the lowest concentration of a particular volatile compound present in indoor air, which, according to our present knowledge, at continued exposure has no consequences on human health and/or comfort. LCI values are considered as quality criteria of the indoor air and not as fixed limit values (ECA, 1997).

As a result of the limited toxicological information about many of the chemical compounds emitted from the exotic wood products, the determination of the LCI value for some of the emitted compounds is based on a poor knowledge of the toxicological effects. Hence, considerable safety margins were applied when determining the LCI values.

The concentration of all compounds measured in the climate chamber was calculated by means of a conversion factor, so that it became relevant in relation to the indoor environment (DS/INF, 1994). This 'standard room concentration' (*C*) was calculated for days 3, 10 and 28. The standard room concentration for a substance *C_i* was divided by the assessed LCI value (LCI_{*i*}), and a ratio for each substance was calculated. An *R*-value was calculated for each exotic wood product by adding the contribution of *C_i/LCI_i* for all individual compounds in the product:

$$R = \frac{C_i}{LCI_i}$$

The *R*-value appears for the individual products on the basis of a loading factor of 0.4 m²/m³, corresponding to a floor or a table and six chairs (Jensen et al., 2001). The contribution from the individual compounds to the *R*-value might be based on different health effect. Based

on an earlier study (Jensen et al., 2001), it was assumed that the LCI values were based predominantly on the irritative effects of the substances.

The *R*-value can be used for a quick comparison of emission from different wood species. The lower the *R*-value, the more acceptable the emission from the exotic wood product. At *R*-values below 1, no health effects are expected.

Indoor-relevant time values

The indoor-relevant time value for a product or material is an expression of the time, which passes until the concentration of all individual compounds emitted from the products have dropped to 50% of their odor and irritation thresholds. Hence, it is a direct expression of how much time passes from installation of a product until the emission from the product is no longer expected to cause odor or irritation of mucous membranes in upper airways, nose and eyes. As for the LCI value, this value can be used for comparison of emission from different wood species.

In the case of more compounds with irritative effects, we have estimated the effects to be additive:

$$\sum C_i/CL_i$$

where C_i/CL_i is the concentration of the *i*th compound in relation to the acceptable concentration of the *i*th compound CL_i in the indoor climate. CL is calculated as 50% of the odor and irritation threshold for the individual compounds.

Normally, the indoor-relevant time value is based on both chemical determination and sensory evaluation of the emission. Indoor-relevant time values form the basis of Indoor Climate Labeling of building products, furniture and interior furnishing (Danish Society of Indoor Climate, 2003). In the present study, the indoor-relevant time value is based solely on chemical measurements of the emission in the climate chamber.

A major limitation when using threshold values for odor and irritation is that these are available only for a limited number of compounds, and distinct deviations between published threshold values exist. In addition, odors do not signify any potential health effect of the emission, just as absence of odor does not imply that the emission is harmless.

Migration into artificial saliva

To illustrate the possible intake of compounds by children sucking and biting at the products, samples of belalu [*Albiz(z)ia falcata*] and rubber tree (*Hevea brasiliensis*) were analyzed for the emission of chemical compounds by migration into artificial saliva. Because of the budget of the project, only these two wood species were analysed. For the analyses, the surfaces of

test specimens were scraped and pulverized; then 1 g of test material was added internal standard and subsequently 25 ml of simulated saliva (DIN V, 2002). The samples were placed in an incubator at 37°C, and initially shaken for 1 h and then left undisturbed for 1 h. The samples were centrifuged, extracted by 'solid-phase extraction' (SPE; IST Isolute, C18/ENV), dried by nitrogen flow and eluted with dichloromethane. The dichloromethane evaporated to 250 µl and was analyzed by GC-MS (SCAN).

When assessing the intake of chemical compounds in this context, it is appropriate to calculate the tolerable daily intake (TDI) instead of LCI. TDI indicates the amount of a chemical pollutant which a human being can consume every day throughout life, without it constituting a health risk. The value is determined on the basis of available toxicological data. The TDI calculation is based upon the no observed adverse effect level (NOAEL), i.e. the level which does not cause demonstrable harmful effects in the most sensitive animal species, and the use of safety factors (SF). The SF is normally 100, but in cases where no NOAEL but only the LOAEL (the lowest dose, which can cause a demonstrable harmful effect) or TD_{Lo} (lowest toxic dose for a species) is available, the factor has been determined at 1000 or higher.

Organic compounds

In the literature there are innumerable descriptions of allergy towards NR latex extracted from *H. brasiliensis*. No studies have been described, in which the content of NR latex allergens in the wood itself can cause reaction in NR latex-allergic persons. Therefore, samples of rubber tree (*H. brasiliensis*) were analyzed for content of NR latex allergens (results are reported in Knudsen and Witterseh, 2004).

Among the selected wood species, the rubber tree is especially attacked by mold and insects from the time it is felled until it is dried. Hence, the timber is always treated with fungicide/insecticide to prevent these attacks. The treatment takes place shortly after felling and cutting and prior to drying; therefore, it is carried out while the wood is still wet. In some cases, the treatment includes dipping the timber into a container with liquid containing different active ingredients. In other cases, an actual preservative treatment takes place. As the treatment is carried out while the wood is still wet, the penetration of the fungicide takes place only to a limited depth, predominantly on/in the surface. So, samples of rubber tree were analyzed for content of fungicides as well.

Specimens from staves of rubber tree in the table tops of dining tables were sampled by means of a metal drill; the staves were subjected to pulverization in a metal grinder. The samples were analyzed for content of the following pesticides: tebuconazole, propiconazole, tolylfluanide, dichlofluanide, 3-iodo-2-propynyl-

butyl-carbamate (IPBC), and pentachlorophenol. For all analyses, except for pentachlorophenol, a weighed amount of test material was extracted with acetone. For determining pentachlorophenol concentration, the extraction was done with dichloromethane to which a deuterium-marked internal standard of C13-PCP was added by ultrasound. The extracts were analyzed with capillary gas chromatography combined with mass spectrometry (GC-MS).

Results

Emissions

At the initial qualitative screening of the 10 products, 74 different chemical compounds were identified. The total amount of compounds emitted from each individual specimen is listed in Table 1. The five products selected for quantitative climate chamber measurements emitted, in total, 25 different chemical compounds. The emission from the five individual products is stated in Table 1. Actual measured concentrations are given in the original report (The Danish Environmental Protection Agency, 2004).

Evaluation of health effects

The toxicological evaluation of the chemical substances, quantified by emission chamber measurements is

summarized in Table 2. There were a few compounds in the emissions from the examined wood species, which appeared to have a potential for health effects (cancer, allergy, teratogenicity, and nervous system effects) and therefore were relevant for the *R*-summation.

The assessment of the examined exotic wood species and their potential surface treatment are presented in Tables 3 and 4. Table 4 shows a classification of low- or medium-emitting materials in relation to VOCs, depending on the magnitude of the *R*-values.

Organic compounds

No content of allergenic proteins in the rubber tree could be detected (Knudsen and Witterseh, 2004). For none of the pesticides analyzed, i.e. tebuconazole, propiconazole, tolylfluanide, dichlofluanide, IPBC, and pentachlorophenol, could concentrations above the detection limit be demonstrated. Other analyses indicated the presence of boron in the rubber tree, indicating that it was treated with a boron-based fungicide.

Migration into artificial saliva

Results of analysis for migration into artificial saliva from lacquered table top made of rubber tree (*H. brasiliensis*) and ink-treated figurine made of belalu (*A. falcata*) revealed several chemical compounds (data not shown). The three compounds occurring at the

Table 2 Chemical substances determined by quantitative measurements in the 5 exotic wood products by chemical name, CAS no., odor threshold value, LCI value, and LCI specific effect

Chemical group	Chemical name	CAS no.	Odor threshold value (mg/m ³)	LCI value (mg/m ³)	LCI specific effect
Aldehydes	Acetaldehyde	75-07-0	0.34	5.2	Sensory irritation
	Acrolein	107-02-8	0.41	0.003	Sensory irritation
	Benzaldehyde	100-52-7	0.19	1.2	Sensory irritation
	Butanal	123-72-8	0.028	2.8	Sensory irritation
	Decanal	112-31-2	0.006	3.1	Analog to pentanal
	Formaldehyde	50-00-0	1.1	0.1	Irritation
	Hexanal	66-24-1	0.058	3.4	Sensory irritation
	Nonanal	124-19-6	0.014	3.1	Analog to pentanal
	Pentanal	110-62-3	0.022	3.2	Sensory irritation
	Propanal	123-38-6	0.014	4.3	Sensory irritation
	Butanol	71-36-3	0.09	0.2	Irritation
Alcohols	2-Ethyl-1-hexanol	104-76-7	0.5	0.5	Irritation
	2-Methyl-1-propanol	78-83-1	2.6	0.4	Irritation and neurotoxic
	1,2-Butanediol	584-03-2		0.7	Irritation
Glycols, -ethers, -esters	2-Butoxyethanol	111-76-2	0.005	4.9	Irritation
	Butyl acetate (all isomers)	123-86-4	0.047	2.7	Sensory irritation
	1-Methoxy-2-butanol	53778-73-7		1.0	Unknown
	Acetone	67-64-1	14	0.4	Irritation
Ketones	2-Butanone	78-93-3	0.87	2.9	Irritation
	Methylcyclohexane	108-87-2		2.5	Irritation
Aliphatic hydrocarbons	3-Methylhexane	589-34-4		0.25	Neurotoxic
	Tridecane	629-50-5		5.0	Analog to decan
	Ethyl benzene	100-41-4	2-2.6	4.3	Irritation
Aromatic hydrocarbons	Toluene	108-88-3		0.4	Neurotoxic
	α -Pinene	80-56-8	3.9	0.25	Analog to monoterpenes

CAS, chemical abstract service; LCI, lowest concentration of interest.

Table 3 Results from the quantitative analyses and the determination of the *R*-value of the five examined products

Essential individual compounds			Comfort and health assessment					
Type of compound	Name of compound	CAS no.	Critical type of effect	LCI ($\mu\text{g}/\text{m}^3$)	<i>c</i> /LCI (<i>c</i>) 3 days	<i>c</i> /LCI (<i>c</i>) 10 days	<i>c</i> /LCI (<i>c</i>) 28 days	Indoor-relevant time value (days)
Lacquered dining table, rubber tree (<i>Hevea brasiliensis</i>)								
Aldehydes	Formaldehyde	50-00-0	Irritation	100	0.58 (58)	0.42 (42)	0.33 (33)	<3 days on basis of irritation
	Acrolein	107-02-8	Irritation	3	Nd	0.67 (2)	Nd	
Alcohols	2-Methyl-1-propanol	78-83-1	Neurotox	400	0.11 (42)	0.06 (23)	0.04 (14)	<3 days on basis of odor
	Butanol	71-36-3	Irritation	200	0.01 (2.4)	<0.01 (0.8)	<0.01 (0.8)	
Hydrocarbons aromatic	Toluene	108-88-3	Neurotox	400	0.19 (74)	0.12 (48)	0.07 (29)	<3 days on basis of odor
	Xylenes/ethylbenzene		Irritation	500	0.14 (72)	0.07 (37)	0.04 (20)	
Glycols	2-Butoxy ethanol	111-76-2	Irritation	490	0.11 (52)	0.04 (22)	0.03 (14)	>28 days on basis of odor
Ketones	Acetone	67-64-1	Irritation	400	0.03 (13)	0.03 (12)	0.04 (14)	<3 days on basis of odor
Summary: <i>R</i> -values ($\sum c/\text{LCI}$) and indoor-relevant time-value					1.2	1.4	0.6	>28 days on basis of odor
Stained Venetian blind, ramin (<i>Gonystylus bankanus</i>)								
Aldehydes	Formaldehyde	50-00-0	Irritation	100	<0.01 (0.8)	0.03 (3.2)	0.02 (1.6)	<3 days on basis of irritation
Alcohols	2-Methyl-1-propanol	78-83-1	Neurotox	400	0.01 (5)	0.01 (4)	<0.01 (2.4)	<3 days on basis of odor
	Butanol	71-36-3	Irritation	200	0.18 (35)	0.13 (26)	0.09 (18)	<3 days on basis of odor
Hydrocarbons aliphatic	3-Methylhexane	589-34-4	Neurotox	250	<0.01 (1.6)	<0.01 (1.6)	0.02 (5)	<3 days on basis of odor
Ketones	Acetone	67-64-1	Irritation	400	<0.01 (2.4)	0.05 (19)	0.03 (11)	<3 days on basis of odor
Summary: <i>R</i> -values ($\sum c/\text{LCI}$) and indoor-relevant time-value					0.2	0.2	0.2	<3 days on basis of odor
Waxed bed table, sheesham (<i>Dalbergia latifolia</i>)								
Aldehydes	Formaldehyde	50-00-0	Irritation	100	0.05 (5)	0.04 (4)	0.04 (4)	<3 days on basis of irritation
Alcohols	Butanol	71-36-3	Irritation	200	0.08 (15)	0.06 (12)	0.05 (10)	<3 days on basis of odor
Hydrocarbons aliphatic	3-Methylhexane	589-34-4	Neurotox	250	<0.01 (2.4)	0.01 (3.2)	0.02 (6)	<3 days on basis of odor
Hydrocarbons aromatic	Toluene	108-88-3	Neurotox	400	0.01 (4)	0.01 (4)	0.02 (7)	<3 days on basis of odor
Ketones	Acetone	67-64-1	Irritation	400	0.01 (4)	0.03 (11)	0.02 (7)	<3 days on basis of odor
Summary: <i>R</i> -values ($\sum c/\text{LCI}$) and indoor-relevant time-value					0.2	0.2	0.2	<3 days on basis of odor
Oiled floor, merbau (<i>Intsia bijuga</i>)								
Aldehydes	Formaldehyde	50-00-0	Irritation	100	<0.01 (0.8)	<0.01 (0.8)	0.03 (3.2)	<3 days on basis of irritation
Alcohols	2-Methyl-1-propanol	78-83-1	Neurotox	400	0.002 (0.8)	0.002 (0.8)	0.004 (1.6)	<3 days on basis of odor
	Butanol	71-36-3	Irritation	200	<0.01 (<0.8)	<0.01 (<0.8)	0.06 (11)	<3 days on basis of odor
Hydrocarbons aliphatic	3-Methylhexane	589-34-4	Neurotox	250	0.02 (4)	0.02 (5)	0.02 (4)	<3 days on basis of odor
Ketones	Acetone	67-64-1	Irritation	400	0.06 (22)	0.04 (17)	Nd	<3 days on basis of odor
Summary: <i>R</i> -values ($\sum c/\text{LCI}$) and indoor-relevant time value					0.1	0.1	0.1	<3 days on basis of odor
Kitchen table top, iroko (<i>Chlorophora excelsa</i>)								
Aldehydes	Formaldehyde	50-00-0	Irritation	100	0.06 (6)	0.04 (4)	0.04 (4)	<3 days on basis of irritation
Hydrocarbons Aliphatic	3-Methyl-hexane	589-34-4	Neurotox	250	<0.01 (<0.8)	<0.01 (1.6)	0.02 (6)	<3 days on basis of odor
Terpenes	α -Pinene	80-56-8	Irritation	250	<0.01 (1.6)	0.02 (6)	<0.01 (1.6)	<3 days on basis of odor
Ketones	Acetone	67-64-1	Irritation	400	<0.01 (3.2)	0.02 (8)	0.02 (6)	<3 days on basis of odor
Summary: <i>R</i> -values ($\sum c/\text{LCI}$) and indoor-relevant time-value					0.1	0.1	0.1	<3 days on basis of odor

LCI, lowest concentration of interest; Nd, not detected.
c, concentration in standard room at 0.4 m²/m³ ($\mu\text{g}/\text{m}^3$).

Table 4 Breakdown of wood materials examined on basis of *R*-value after 28 days and indoor-relevant time-value

Classification	Product	Wood species	<i>R</i> -value	Indoor-relevant time-value (days)
Medium-emitting material	Lacquered dining table	Rubber tree (<i>Hevea brasiliensis</i>)	0.6	>28 days
Low-emitting material	Stained Venetian blind	Ramin (<i>Gonystylus bankanus</i>)	0.2	<3 days
Low-emitting material	Waxed bed table	Sheesham (<i>Dalbergia latifolia</i>)	0.2	<3 days
Low-emitting material	Oiled floor	Merbau (<i>Intsia bijuga</i>)	0.1	<3 days
Low-emitting material	Kitchen table top	Iroko (<i>Chlorophora excelsa</i>)	0.1	<3 days

highest concentration in the two specimens and compounds known to be allergens are listed in Table 5.

None of the compounds occurs in concentrations exceeding the TDI value. But, in both specimens, phthalates such as phthalic acid monobutyl ester and diethyl phthalate, and compounds which are well-known allergens, such as vanillin and phthalic anhydride, were detected in small quantities.

Discussion

It should be noted that the results presented here solely concern the actual samples of the products examined and that they are based on random samplings. The results obtained are, therefore, not representative of exotic wood in total. Only minor amounts of chemical compounds were found in the emission at the climate

Table 5 Chemical compounds emitted by migration into artificial saliva from exotic wood

Specimen	Compound	CAS no.	Concentration (µg/g)	Remarks
Lacquered table top, rubber tree (<i>Hevea brasiliensis</i>)	2-Butoxy ethanol	111-76-2	171	NOAEL = 30 mg/kg/day, safety factor, SF = 100. TDI = 0.3 mg/kg/day
	Phthalic anhydride	85-44-9	52	Respiratory and contact allergen. LOAEL = 1562 mg/kg/day, SF = 1000. TDI = 1.5 mg/kg/day
	Phthalic acid monobutyl ester	131-70-4	11.3	TDLo = 400 mg/kg/day, SF = 1000. TDI = 0.4 mg/kg/day
	Vanillin (isovanillin)	121-33-5 (621-59-0)	3.0	Contact allergen
Ink treated figurine, belalu (<i>Albiz(z)ia falcata</i>)	2-Butoxy ethanol	111-76-2	5.5	NOAEL = 30 mg/kg/day, safety factor, SF = 100. TDI = 0.3 mg/kg/day
	1-Methyl-2-pyrrolidinone	872-50-4	41	NOAEL = 300 mg/kg/day, SF = 100. TDI = 3 mg/kg/day
	2-Phenoxy ethanol	122-99-6	3.1	TDLo = 3000 mg/kg/day, SF = 1000. TDI = 3 mg/kg/day
	Vanillin (isovanillin)	121-33-5 (621-59-0)	0.7	Contact allergen

chamber measurements of the examined products made of exotic wood (with or without surface treatment). Totally, 25 individual compounds were demonstrated, of which many could be identified in more of the products. There is every probability that a part of these compounds originates from the surface treatments of the products in question. For only very few compounds in the emissions from the wood species examined, the health effects of the compounds (cancer, allergy, teratogenicity, nervous system effects and other effects) became of importance in relation to the determination of the LCI value. For formaldehyde, the target effects were cancer and irritation, both of which were included in the list of the health effects of the emissions. Formaldehyde assessment is based on recommendations from WHO and is less restrictively determined than the other individual compounds. Acetaldehyde has, similar to formaldehyde, two significant effects, cancer and irritation, where the irritative effect occurs at significantly higher concentrations than that for formaldehyde. The risk of cancer is, furthermore, less documented. Acrolein is assessed to have both an irritative and allergen effect. For 2-methyl-1-propanol, 3-methylhexane and toluene, the LCI value is determined on the basis of the neurotoxic effects of the individual compounds in question. For the remaining individual compounds, the LCI values are based on their irritative effects (see Table 3).

The study examining Nordic wood and wood-based materials found emission values which induced irritative symptoms only in case of living in a house made of pine wood, whereas more restricted use did not lead to any irritating or chronic effects (Jensen et al., 2001). The present results show that the examined untreated exotic wood species have the same low emission rates as the untreated wood species, e.g. oak, beech, and ash, examined in a previous study (Jensen et al., 2001). The results of this study contradict those of Chan-Yeung et al. (1973), who found occupational exposure at exotic wood processing to be a health risk, especial in relation to allergy. We did not find any risk for either acute or chronic health problems in the present study.

The emission of chemical compounds from the products is very low. This could be due to several reasons. It is assumed that during drying, a major part of the compounds is emitted. During processing of the wood, further emission takes place and some of the surface treatment will contribute to encapsulating the compounds in the wood, thereby limiting emission. Often, transportation from countries of origin to the consumer is long, which leaves time for further emission of chemical compounds.

The examined products were assessed in relation to health effects by determining the *R*-value on the basis of LCI values and comfort considerations of the indoor-relevant time value (The Danish Environmental Protection Agency, 2004). The *R*-values vary for the 3- and 10-day measurements for the five products (iroko, ramin, sheesham, merbau and rubber tree) between 0.1 and 1.4, where rubber tree has the highest *R*-value. The increase in *R*-value for rubber tree was based on identification of acrolein in the second sample (day 10) and not in the first (day 3). It can, however, not be explained, why acrolein was not demonstrated in the first measurement. Measurements on day 28 indicated that the values had further dropped. At that time the *R*-value for all products – including the rubber tree – was below 1 (an *R*-value below 1 is considered to be unproblematic).

The measurements and toxicological evaluations indicate that emissions of individual compounds from the examined exotic wood species or their surface treatments are not expected to cause adverse health effects. The obtained *R*-values and indoor-relevant time values are based on material loading, which for most of the products would be an absolute 'worst case' and none of the products would at that scenario imply health effects.

One of the limitations of the present study is the possibility of error during the conversion from the measurements in climate chambers to emission in a standard room. A new study comparing measured concentrations in indoor air and measurements from climate chamber is recommended (Qian et al., 2007). Another limitation is that because of limited toxicological information about many of the chemical

compounds emitted from the exotic wood products, the LCI value determination for some of the emitted compounds is not based on a sound knowledge of toxicological effects. Thus, considerable safety margins were applied when determining the LCI values and the values should be regarded as 'worst case'. Additionally, the limited knowledge as regards combinatory effects, which is not only additive as assumed in the present study, is also of importance.

Rubber tree is the only examined product with an *R*-value, which, during the measuring period, exceeds 1. The individual compounds important in relation to the calculated *R*-value are formaldehyde and acrolein. It is less plausible that they are constituents of the rubber tree itself. There is, on the contrary, every probability that they originate from the surface treatment. The problems in question with emission from rubber tree could be solved by changing the surface treatment or by leaving the product unpacked to emit for 1 month, before release to the consumers.

None of the compounds found by migration into artificial saliva occurs in concentrations that exceed the calculated TDI values. The pretreatment of the products (scraping and pulverizing) might have increased the extraction of chemical compounds and hence overestimating the migrated dose. In both specimens, phthalates and compounds were detected. These are well-known allergens. In a worst-case calculation, it is estimated that a child weighing 10 kg consumes the entire amount of saliva being in contact with 1 g of specimen a day. For 2-butoxy-ethanol, 171 µg/g specimen was found corresponding to 171 µg/10 kg body weight/day, which corresponds to 0.017 mg/kg/day. The TDI-value for 2-butoxy-ethanol is 0.3 mg/kg/day. It is inappropriate that, in general, allergenic compounds and, in particular, phthalates are emitted from the products in question. The problem is of utmost importance in case the products are used for storage of food (salad bowls, chopping boards, etc.) or if they are used for purposes, in which they are in close and long contact with the skin, e.g. musical instruments or trinkets. In Denmark, the use of phthalates in toys and articles for small children is limited to a maximum concentration of 0.05% (w/w). This can be used as a restrictive comparison, as infants hardly suck at exotic wooden articles to the same extent as at toys. The demonstrated concentrations of phthalates are significantly below 0.05%. For products which might get into contact with food, the accepted maximum concentration varies depending of the type of phthalate and is between 1 and 60 mg/kg, corresponding to 1–60 µg/g. Hence it is recommended that exotic wooden articles (or other studies), if used for storage or are in contact with food, are not surface-treated with compounds other than those listed by the Ministry of Food, Agriculture and Fisheries (2005). Other analyses indicated the presence of boron in the rubber tree,

indicating that it was treated with a boron-based fungicide. It would therefore be inadvisable to use rubber tree without surface treatment, if this is found to be a general practice.

Studies indicate numerous wood species, which can cause different symptoms in humans. To date most of the cases in which symptoms have been reported have, however, occurred in connection with processing of the wood, e.g. sawing or sanding (Chan-Yeung et al., 1973; The Danish Environmental Protection Agency, 2004). Exposure during processing is often many times larger than during general use of the products. Exposure can, in this connection, take place by inhalation of the compounds emitted, inhalation of dust and by skin contact with wood and wood dust. Allergic reactions to wood is either due to direct contact to intact wood through contact of the finished product, or – almost always – exposure to wood dust, which is produced during processing. Among the five wood species examined, ramin should be considered to be more irritating to the skin and airways than the other four wood species. Allergic reactions in the airways can be result from inhalation of dust from iroko (Azofra and Olaguibel, 1989; DeZotti and Gubian, 1996, Hausen, 1981) and ramin (Hausen, 1981; Honijosa et al., 1986). Allergic contact dermatitis can, especially, result from contact with iroko (Hinnen et al., 1995, Mitchell and Rook, 1979, Stingeni et al., 1998) and sheesham (Gallo et al., 1996; Hausen, 1981; Mitchell and Rook, 1979) and, presumably, to a lesser extent with ramin (Hausen, 1981; Mitchell and Rook, 1979). Some of the contact allergens have been identified, i.e. chlorophorin, *R*- and *S*-4 methoxydalbergione and 1,4-quinone latinone (Hausen, 1981). Allergen proteins are predominant in the sap of rubber tree (*H. brasiliensis*), and is extensively described in the literature in connection with rubber products made of NR latex from this wood species (Turjanmaa et al., 2002), but there are no publications about asthma in persons processing wood or reactions caused by contamination of food by contact with products made of wood from rubber tree. None of these allergenic compounds was detected in the present study. This could either be due to the fact that they are not emitted from the products because of the large molecular weight or they are emitted but escape detection by the applied analytical procedure, or the fact that all products were surface-treated which can encapsulate the wood components. In all probability, surface treatment could be the determining factor for the emission of compounds. Further investigations of wood without surface treatment would be of interest.

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Appendix

Results of quantitative analyses

In this appendix, tables with results in detail of the quantitative analyses of five selected products are stated:

Specimen no. 1: Rubber tree, dining table, lacquered

Specimen no. 2: Ramin, Venetian blind, stained

Specimen no. 3: Sheesham, bed table, wax treated

Specimen no. 6: Merbau, parquet flooring, oiled

Specimen no. 8: Iroko, table top, untreated

The results are stated in separate tables for each product.

Compound	CAS no.	Measure-ment time (days)	Emission rate ($\mu\text{g}/\text{m}^2 \text{ h}$)	Concentration in standard room at $0.4 \text{ m}^2/\text{m}^3$ ($\mu\text{g}/\text{m}^3$)	LCI ($\mu\text{g}/\text{m}^3$)	c/LCI ($\mu\text{g}/\text{m}^3$)	Odour threshold ($\mu\text{g}/\text{m}^3$)
1 Rubber tree (<i>Hevea brasiliensis</i>), dining table							
Formaldehyde	50-00-0	3	72	58	100	0.58	124*
		10	53	42		0.42	
		28	41	33		0.33	
Acetaldehyde	75-07-0	3	12	10	5200	<0.01	340
		10	9	7		<0.01	
		28	54	43		<0.01	
Acrolein	107-02-8	3	Nd	—	3	—	120*
		10	2,5	2.0		0.67	
		28	Nd	—		—	
Propanal	123-38-6	3	3	2.4	4300	<0.01	14
		10	Nd	—		—	
		28	5	4.0		<0.01	
Hexanal	66-25-1	3	4	3.2	3400	<0.01	58
		10	4	3.2		<0.01	
		28	3	2.4		<0.01	
Nonanal	124-19-6	3	<1	<0.8	3100	<0.01	14
		10	<1	<0.8		<0.01	
		28	2	1.6		<0.01	
Decanal	112-31-2	3	<1	<0.8	3100	<0.01	6
		10	<1	<0.8		<0.01	
		28	4	3.2		<0.01	
MEK (2- butanone)	78-93-3	3	Nd	—	2900	<0.01	870
		10	2	1.6		<0.01	
		28	3	2.4		<0.01	
Acetone	67-64-1	3	16	13	400	0.03	14000
		10	15	12		0.03	
		28	18	14		0.04	
2-Methyl-1-propanol	78-83-1	3	53	42	400	0.11	2570
		10	29	23		0.06	
		28	18	14		0.04	
Butanol	71-36-3	3	3	2.4	200	0.01	90
		10	1	0.8		<0.01	
		28	1	0.8		<0.01	
3-Methylhexane	589-34-4	3	Traces	—	250	—	—
		10	Traces	—		—	
		28	7	5.6		0.02	
Methylcyclohexane	108-87-2	3	<1	<0.8	1000	<0.01	>200000
		10	<1	<0.8		<0.01	
		28	2	1.6		<0.01	
Toluene	108-88-3	3	93	74	400	0.19	644
		10	60	48		0.12	
		28	36	29		0.07	
Xylenes/ethylbenzene	—	3	90	72	500	0.14	—
		10	46	37		0.07	
		28	25	20		0.04	
Butylacetate	123-86-4	3	18	14	2700	<0.01	47
		10	10	8		<0.01	
		28	8	6		<0.01	

Appendix (Continued)

Compound	CAS no.	Measure-ment time (days)	Emission rate (μg/m ² h)	Concentration in standard room at 0.4 m ² /m ³ (μg/m ³)	LCI (μg/m ³)	c/LCI (μg/m ³)	Odour threshold (μg/m ³)
Unknown	—	3	4	3.2			—
		10	3	2.4			
		28	1	0.8			
2-Butoxyethanol	111-76-2	3	65	52	490	0.11	5
		10	27	22		0.04	
		28	18	14		0.03	
2 Ramin (<i>Gonystylus bankanus</i>), Venetian blind							
Formaldehyde	50-00-0	3	1	0.8	100	<0.01	124*
		10	4	3.2		0.03	
		28	2	1.6		0.02	
Acetaldehyde	75-07-0	3	1	0.8	5200	<0.01	340
		10	8	6		<0.01	
		28	Nd	—		—	
Butanal	123-72-8	3	Nd	—	2800	—	28
		10	14	11		<0.01	
		28	Nd	—		—	
Hexanal	66-25-1	3	Nd	—	3400	—	58
		10	3	2.4		<0.01	
		28	2	1.6		<0.01	
Nonanal	124-19-6	3	<1	<0.8	3100	<0.01	14
		10	<1	<0.8		<0.01	
		28	2	1.6		<0.01	
Decanal	112-31-2	3	<1	<0.8	3100	<0.01	6
		10	<1	<0.8		<0.01	
		28	4	3.2		<0.01	
MEK (2-butanone)	78-93-3	3	Nd	—	2900	—	870
		10	2	1.6		<0.01	
		28	2	1.6		<0.01	
Acetone	67-64-1	3	3	2.4	400	<0.01	14000
		10	24	19		0.05	
		28	14	11		0.03	
2-Methyl-1-propanol	78-83-1	3	6	5	400	0.01	2570
		10	5	4		0.01	
		28	3	2.4		<0.01	
Butanol	71-36-3	3	44	35	200	0.18	90
		10	32	26		0.13	
		28	23	18		0.09	
3-Methylhexane	589-34-4	3	2	1.6	250	<0.01	—
		10	2	1.6		<0.01	
		28	6	5		0.02	
1,2-butandiol	112-31-2	3	8	6	700	<0.01	—
		10	5	4		<0.01	
		28	4	3.2		<0.01	
3 Sheesham (<i>Dalbergia latifolia</i>), bed table							
Formaldehyde	50-00-0	3	6	5	100	0.05	124*
		10	5	4		0.04	
		28	5	4		0.04	
Acetaldehyde	75-07-0	3	2	1.6	5200	<0.01	340
		10	4	3.2		<0.01	
		28	4	3.2		<0.01	
Propoanal	123-38-6	3	Nd	—	4300	—	14
		10	Nd	—		—	
		28	7	6		<0.01	
Butanal	123-72-8	3	Nd	—	2800	—	28
		10	Nd	—		—	
		28	3	2.4		<0.01	
Hexanal	66-25-1	3	1	0.8	3400	<0.01	58
		10	3	2.4		<0.01	
		28	3	4		<0.01	
Acetone	67-64-1	3	5	4	400	0.01	14000
		10	14	11		0.03	
		28	9	7		0.02	
2-Methyl-1-propanol	78-83-1	3	1	0.8	400	<0.01	2570

Appendix (Continued)

Compound	CAS no.	Measure-ment time (days)	Emission rate ($\mu\text{g}/\text{m}^2 \text{ h}$)	Concentration in standard room at $0.4 \text{ m}^2/\text{m}^3$ ($\mu\text{g}/\text{m}^3$)	LCI ($\mu\text{g}/\text{m}^3$)	c/LCI ($\mu\text{g}/\text{m}^3$)	Odour threshold ($\mu\text{g}/\text{m}^3$)
Butanol	71-36-3	10	0.8		<0.01		
		28	1.6		<0.01		
		3	19	15	200	0.08	90
		10	15	12		0.06	
1-Methoxy-2-butanol	53778-73-8	28	12	10		0.05	
		3	2	1.6	1000	<0.01	—
		10	1	0.8		<0.01	
		28	2	1.6		<0.01	
3-Methylhexane	589-34-4	3	3	2.4	250	<0.01	—
		10	4	3.2		0.01	
		28	7	6		0.02	
		3	1	0.8	1000	<0.01	>200000
Methylcyclohexane	108-87-2	10	1	0.8		<0.01	
		28	2	1.6		<0.01	
		3	5	4	400	0.01	644
		10	5	4		0.01	
Butylacetate	123-86-4	28	8	7		0.02	
		3	2	1.6	2700	<0.01	47
		10	2	1.6		<0.01	
		28	2	1.6		<0.01	
α -pinene	80-56-8	3	2	1.6	250	<0.01	3890
		10	2	1.6		<0.01	
		28	2	1.6		<0.01	
		3	1	0.8	100	<0.01	124*
4 Merbau (<i>Intsia bijuga</i>), parquet flooring Formaldehyde	50-00-0	10	1	0.8		<0.01	
		28	4	3.2		0.03	
		3	3	2.4	5200	<0.01	340
		10	6	5		<0.01	
Propanal	123-38-6	28	Nd	—		—	
		3	5	4	4300	<0.01	14
		10	Nd	—			
		28	Nd	—			
Pentanal	110-62-3	3	2	1.6	3100	<0.01	22
		10	2	1.6		<0.01	
		28	Nd	—		—	
		3	5	4	3400	<0.01	58
Hexanal	66-25-1	10	5	4		<0.01	
		28	Nd	—		—	
		3	4	3.2	1200	<0.01	186
		10	Nd	—		—	
Benzaldehyde	100-52-7	28	Nd	—		—	
		3	3	2.4	3100	<0.01	6
		10	3	2.4		<0.01	
		28	5	4		<0.01	
MEK (2-butanone)	78-93-3	3	7	6	2900	<0.01	870
		10	2	1.6		<0.01	
		28	1	0.8		<0.01	
		3	27	22	400	0.06	14000
Acetone	67-64-1	10	21	17		0.04	
		28	Nd	—		—	
		3	1	0.8	400	0.002	2570
		10	1	0.8		0.002	
2-Methyl-1-propanol	78-83-1	28	2	1.6		0.004	
		3	<1	<0.8	200	<0.01	90
		10	<1	<0.8		<0.01	
		28	14	11		0.06	
2-Ethyl-1-hexanol	104-76-7	3	<1	<0.8	500	<0.01	500
		10	<1	<0.8		<0.01	
		28	3	2.4		<0.01	
		3	5	4	250	0.02	—
3-Methylhexane	589-34-4	10	6	5		0.02	
		28	5	4		0.02	

Appendix (Continued)

Compound	CAS no.	Measure-ment time (days)	Emission rate ($\mu\text{g}/\text{m}^2 \text{ h}$)	Concentration in standard room at 0.4 m^2/m^3 ($\mu\text{g}/\text{m}^3$)	LCI ($\mu\text{g}/\text{m}^3$)	c/LCI ($\mu\text{g}/\text{m}^3$)	Odour threshold ($\mu\text{g}/\text{m}^3$)
Butylacetate	123-86-4	3	<1	<0.8	2700	<0.01	47
		10	<1	<0.8		<0.01	
		28	3	2.4		<0.01	
Tridecane	629-50-5	3	4	3.2	5000	<0.01	16600
		10	4	3.2		<0.01	
		28	3	2.4		<0.01	
5 Iroko (<i>Chlorophora excelsa</i>), table top							
Formaldehyde	50-00-0	3	8	6	100	0.06	124*
		10	5	4		0.04	
		28	5	4		0.04	
Acetaldehyde	75-07-0	3	Nd	—	5200	—	340
		10	2	1.6		<0.01	
		28	2	1.6		<0.01	
Hexanal	66-25-1	3	1	0.8	3400	<0.01	58
		10	3	2.4		<0.01	
		28	2	1.6		<0.01	
MEK (2-butanone)	78-93-3	3	Nd	—	2900	<0.01	870
		10	2	1.6		<0.01	
		28	2	1.6		<0.01	
Acetone	67-64-1	3	4	3.2	400	<0.01	14000
		10	10	8		0.02	
		28	8	6		0.02	
3-Methylhexane	589-34-4	3	<1	<0.8	250	<0.01	—
		10	2	1.6		<0.01	
		28	7	6		0.02	
α -pinene	80-56-8	3	2	1.6	250	<0.01	3890
		10	7	6		0.02	
		28	2	1.6		<0.01	

*: Threshold value for irritation; Nd: Below the detection limit.