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Emission of Volatile Organic Compounds from Wood and Wood-based Materials

Annelise Larsen, Lydia Frost, Lis Winther Funch
Danish Technological Institute. Wood Technology

Miljøstyrelsen
Miljø- og Energiministeriet

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Background

The impact of emissions from wood-based furniture and building products on the indoor environment is gaining more and more attention. In an increasing number of cases the emission to the indoor air has become an essential product selection criterion for both end-users and professional users.

Wood is generally considered as an advantageous material in a wide environmental perspective, even though studies performed only rarely comprise material emissions except for formaldehyde emission.

This project was carried out to extend the limited knowledge on emissions from wood and wood-based materials for interior use and to propose a model for evaluation of emissions from these materials and methods to reduce material emissions. It has not been the intention to evaluate the emission from wood in relation to other material emissions.

Test Programme

This study was based on chemical analysis of emissions from 23 materials representing solid wood and wood-based materials commonly used in furniture, interior furnishings and building products in 1996. The test scheme comprised materials and products in varying degrees of complexity from solid wood to coated veneered panels. The study comprised the solid wood species: ash, beech, spruce and pine; six different wood-based panels: particleboard of pine and spruce with different glues, MDF (medium density fibreboards) and OSB (oriented strand board) of conifer and plywood of birch; beech veneered particleboards with two different glue types for veneer gluing; two floor oils on solid beech on urethane alkyd/linseed oil and natural resin basis respectively; five different lacquered beech veneered particleboards coated with nitrocellulose lacquer, UV-curing lacquer, acid-curing lacquer, water-borne acrylic lacquer and polyurethane lacquer respectively.

The selected 23 wood-based materials and measured emissions are to be considered examples and can neither be considered representative for all wood-based materials for interior use nor be generally representative for emissions from wood and wood-based materials.

The project task, which only comprised emission from wood and wood-based products to the indoor environment, does not lay the foundations of a weighting of the emissions in relation to other material types or weighing the emission in relation to other indoor environment factors.

Emission Testing

Prior to testing and analysis the chemical substances expected to emit from the selected materials were identified, so were the substances included in national or international lists as health hazardous in respect to cancer, allergy, reprotoxicity and neurotoxicity

The selected materials were initially examined by a qualitative screening to identify the above mentioned substances and to determine an analysis programme for the quantitative determinations for each of the wood-based materials.

Of the 144 different chemical substances identified by the screening analyses 42 were aldehydes (saturated or unsaturated) or ketones and 20 hydrocarbons of the terpene types: mono- and sesquiterpenes.

The quantitative determinations were carried out by emission chamber testing under conditions common in building interiors according to a test method for determination of volatile organic compounds especially adjusted to wood-based products.

The analysis programme for the quantitative measurements comprised determination of all individual volatile organic compounds, VOC's, by gas chromatography with mass spectrometric detection, liquid chromatography and photometry by the acetylacetone method.

Results

By the chamber measurements totally 84 individual substances were quantified. The predominant emissions determined from uncoated wood and wood-based materials were aldehydes, mainly acetaldehyde, propanal, butanal, pentanal and hexanal, as well as the ketone: acetone. The aldehydes varied in content in the different materials. Formaldehyde was the predominant single emittant in the case of urea-formaldehyde-glued panels. In the emission from pine also emissions of terpenes, mainly α-pinene, 3-carene and limonene, were detected in larger concentrations. The emissions from the investigated wood-based panels varied as expected considerably dependent on the applied glue systems.

The emissions from surface treated wood-based materials originate mainly from the oils and lacquers, and were mainly alcohols, unsaturated aldehydes, esters, glycol ethers and -esters. The emission of most aldehydes from the treated materials can be traced back to both coating or oil and wood.

A part study of four variations of pine of varying origin (northern Finland and southern Sweden respectively) and content of heartwood and sapwood showed considerable difference in emission rates of especially 3-carene and α-pinene. It should be noted that the growth conditions and place can be of major importance.

From the results there is no documentation that indoor air problems are caused by wood.

Evaluation of Emission In General

Concentrations of the chemical substances quantified by chamber measurements were converted into concentrations to which persons are exposed in the indoor air by means of standard room considerations.

Very limited indoor air concentrations were seen from solid ash, beech and oak calculated at a material-load of 0.4 m^2/m^3 corresponding to, for example, a floor or a table and 6 chairs. Solid pine gave considerably larger emissions than the other tested wood species. Solid ash, beech, oak, wood-based panels and beech veneered particleboards are examples of materials seldom used in practice without surface treatment.

A small cottage covered with α-pinene and 3-carene rich untreated pine on the floor, ceiling and all four walls is an example of a scenario resulting in relatively high indoor air concentrations in consequence of emissions from wood. Worst case occur if the cottage is newly built of fresh wood and if it for some reason is made relatively air tight, hence resulting in a low air exchange rate.

Evaluations of the Comfort and Health Effects

The evaluation of comfort and possible health effects of emissions from wood and wood-based materials was based on experiences from the above mentioned experimental work and general principles for toxicological evaluation and literature data.

Evaluation of single substances included all the 84 substances quantified by the emission chamber measurements.

Concentrations converted from test chamber to concentrations, to which humans are exposed in the indoor air, were compared with the toxicological determined "Lowest Concentration of Interest in the indoor air (LCI)" and odour threshold values.

The influence of materials and products on the indoor environment was evaluated by:

- A sum of concentrations in the indoor air divided by the "lowest concentration of interest in the indoor air" for additive effects of the same type,

$$S = \sum c_i / LCI_i = \frac{c_1}{LCI_1} + \frac{c_2}{LCI_2} + \ldots\ldots + \frac{c_n}{LCI_n} \quad \text{hereafter called S}$$

- An indoor-relevant time-value based on odour and irritation thresholds

LCI- and S-Value

LCI is defined as the lowest concentration of a certain substance, which will not - with our present knowledge - cause risk of hazardous effects on humans. For most of the chemical substances the LCI-values in this investigation were based on irritation. More severe effects occurred for most of the chemical substances at concentrations magnitudes higher than odour and irritation.

Determination of LCI-values was difficult due to lack of toxicological data for most of the emitted substances in the relatively low concentrations, in which the substances are present in the indoor air. In several cases the LCI-values were determined by analogue considerations. In cases, in which the data on the substances lacked, and in which it was evaluated that the most essential effect was irritation, the LCI-values were based on "RD50-values", which are determined based on decrease of the respiratory frequency of mice.

Irritation is thus the most frequent toxicological effect for the examined wood and wood-based materials and gave the basis of the S-value calculations.

Indoor-Relevant Time-Value

The indoor-relevant time-value in days is an expression of the period of time necessary for the decline of the emissions into acceptable concentration levels, where neither irritation of eyes, nose and the upper respiratory tract nor odour may be expected.

Model for Evaluation

The proposed model for assessment based on the S-value and the indoor-relevant time-value differentiates the emissions from the investigated materials and can be used as a common basis for relative evaluations of wood, wood-based materials and products. It should, however, be noted that the absolute S-values as well as LCI-values, odour and irritation threshold va-lues can always be questioned, and the values might change, as new know-
ledge occur.

In the case of materials, which do not cause emissions containing carcinogens, allergens or reproductive toxicants, the procedures and results of the evaluations were basically the same both according to the S-value and to the indoor-relevant time-value based on the addition of the irritative impact.

The time-values based on odour thresholds, resulted, however, in longer time-values than time-values based on irritation thresholds - for all decisive individual substances apart from formaldehyde - and consequently odour became determining for the indoor-relevant time-values in most cases.

If health hazardous effects except from respiratory irritation due to emission could be excluded, the evaluation could solely be based on the concept of indoor-relevant time-value.

Evaluation of Emission - Material

When the indoor air is of high priority, it should be advised to select products made of lower-emitting materials, in order to limit the emission to the indoor air. Thus a larger probability of reducing the discomfort and possible health effects caused by emission from these materials and products is achieved.

Selection of relatively lower-emitting materials and products can be made by selection of materials and products with a relatively low S-value and a relatively low indoor-relevant time-value.

A proposed classification based on 28 days measurement in test chamber divides wood and wood-based materials in three classes: low-emitting, medium-emitting and high-emitting materials. Among the tested coatings the UV-curing lacquer on beech veneered particleboards was low-emitting, the acid-curing lacquer on beech veneered particleboards was high-emitting, while the other investigated lacquers on beech veneered particleboards and investigated oils on solid beech were considered medium-emitting. Among the tested solid wood species ash, beech, oak and spruce were low/medium emitting and pine high-emitting. It should be taken into account that it is different types of chemical substances that are emitted depending on wood species and type of surface treatment.

Reduction of Hazardous Effects

Modification/substitution of materials should be considered when the emission contains toxicologically unknown chemical substances. Materials and products should as far as possible not contain chemical substances with carcinogenic, reprotoxic or immunologic effects. Should this be the case these substances should be replaced by substances or materials, which are less hazardous or the material should at least be modified to minimize the content as much as possible.

Modification of materials and products should be considered for the materials and products with relatively large S-values and high indoor-relevant time-values.

Modification/Substitution Examples

Factors of importance for modification/substitution considerations have been systematized and applied on six examples of wood and wood-based materials and products.

The examples, which have been based on a theme for inspiration for modification/substitution considerations, illustrate primary relations of importance for the impact of materials on the indoor environment. Further environment a.o. working environment, and economics should be involved, where these are of decisive importance for the modification/substitution, and if their consequences are known. Description of a product in relation to a given application as well as general and specific comments elaborates the conside-
rations.

The six examples of substitution/modification considerations for wood furniture, interior furnishings and wood-based building products comprise: A wooden floor treated with different types of lacquer and oil; wardrobe of veneered panel coated with different types of transparent lacquer; coffee table of uncoated solid wood and respectively veneered panel coated with different types of transparent lacquer; bookcase of uncoated solid wood and respectively veneered panel coated with different types of transparent lacquer; office table of veneered particleboard coated with different types of transparent lacquer and a cottage of pine. Finally, a proposal is given for a model for relative description of materials of the similar type exemplified for wooden floor treated with different lacquers and oils.

Introduction and Purpose

The present project: "Emission of volatile organic compounds from wood, wood-based materials, furniture and interior furnishings" has been carried out for the "Rådet vedrørende genanvendelse og mindre forurenende teknologi" in the period June 1995 - September 1997.

In the project an advisory committee was formed consisting of the following members:

Committee

Elisabeth Paludan	Danish Environmental Protection Agency
Lea Frimann Hansen	Danish Environmental Protection Agency
Birgitte Borup	The Association of Danish Designers
Jakob U. Christiansen	Danish Working Environment Service
Frits Hansen	Danish Furniture Retailers Organization
Ove Nielsen	National Housing and Building Agency
Martin Ravnsbæk	Sørvad Møbelfabrik A/S (The Association of Danish Woodworking Industries)
Henrik Skovbo	Novopan Træindustri A/S (The Association of Danish Woodworking Industries)
Kirsten Stær	Akzo Nobel Industrial Coating A/S (The Association of Danish Paint and Varnish Industries)
Lennart Sørensen	The Timber, Industry and Construction Worker's Union in Denmark

Target Group

The target group for the present publication is the wood and furniture industry, manufacturers of building interior furnishings, manufacturers of paint, lacquers & foils, projecting and advisory architects and engineers as well as authorities. The end-users are a secondary target group.

Emission from Wood

The impact of the emission from furniture, interior furnishings and building materials on the indoor air is gaining more and more attention. The emissions from volatile organic compounds have in several cases been decisive for both end-users and professional users' material selection. It is to be expected that low emission of volatile organic compounds becomes an essential competition parameter a.o. for the export of furniture.

Wood and wood-based materials are from nature characterised by containing varying amounts of volatile compounds. This could a.o. be stated by the fact that wood smells. Wood products in use are most frequently a combination of wood and the materials, which have been added, a.o. glues and lacquers.

Seen in a wide environmental perspective wood is a superior material, which is a renewable raw material with low extraction costs and can be disposed by combustion. The impact of the wood products on the environment during use (except for the formaldehyde emission) has only been examined and described to a poor extent, even for products manufactured for use in-doors.

A systematic investigation of emissions from wood and wood-based materials as well as from surface treatments will be essential to avoid that wood and wood-based products will be confronting a new emission problem, which in extent could develop into a similar problem as the formaldehyde emission from former generations of particleboards.

Purpose

The purpose of the project is therefore to clarify VOC (Volatile Organic Compounds) emissions from wood and wood-based products by experimental investigation of selected products within the categories wood, wood-based materials, furniture and interior furnishings. The investigation should provide a detailed knowledge of the exact VOC's, which are emitted during time, and to identify problems with emission of these volatile substances in relation to the end-user. Potential environmental and health problems of the emissions were analysed toxicologically. Methods for reduction of the emission from wood and additives were evaluated and modification/substitution considerations for reduction of the emission were included.

Process

The project was divided into 5 phases:

1. Selection and description of the representative materials
2. Measurement of VOC-emission
3. Evaluation of VOC-emission
4. Evaluation of product modification and substitution respectively
5. Reporting

The project was carried out by a project group consisting of:

Lydia Frost M.Sc. biochemistry and pharmacy,
Centre for Environmental Technology
Danish Technological Institute

Lis Winther Funch Laboratory Technician
Wood Technology, Danish Technological Institute

Mogens Kragh Hansen M.Sc. pharmacy, phD
Danish Painters Occupational Health Service

Lilli Kirkeskov Jensen Chief physician, Department of Occupational and Environmental Medicine, Skive Hospital

Bodil B. Knudsen Medical specialist, Department of Dermatology
Gentofte University Hospital

Annelise Larsen M.Sc. chemical eng., Centre for Wood Technology
Danish Technological Institute

Lars Mølhave, M.Sc., phD, Dr. med. Institute of Environmental and Occupational Medicine, Aarhus University

The work was carried out in close cooperation between the participants of the project group. All participants have been involved in the theoretical parts of the project. The experimental part (phase 2) was carried out by Organic Analyses Laboratories and Wood Technology, Danish Technological Institute.

Reporting

The project is furthermore reported in a separate Danish project report, "Emission af flygtige organiske forbindelser fra træ, træbaserede materialer, møbler og inventar", which gives the main results. The English version differs from the Danish report by containing more details regarding evaluation of emission and by more extensive and detailed appendices.

Wood and Wood-Based Materials

Cellulose, Hemicellulose and Lignin

Wood is composed of a number of different types of cells. In the wood used as material in buildings and interior furnishings, the water of the celllumen and the main part of the water in the cell walls is dried away. The cell walls of wood is primary composed of cellulose, hemicellulose, and lignin.

Cellulose constitutes 40-45% of the cell wall and is composed of linear polymers of glucose hydride units (with a degree of polymerization of 7-15,000).

Hemicellulose is mainly composed of pentosans and hexosans in chains (with a degree of polymerization of 50-250). The hemicellulose amounts to 25-30% of the cell wall.

Ligning amounts 20-30% (25-30% of coniferous wood and 20-25% of deciduous wood). Lignin is amorphous giant molecules predominantly consisting of p-coumaryl-alcohol, coniferyl alcohol and sinapyl-alcohol. Sinapyl-alcohol is mainly found in deciduous wood. Lignin acts as a stiffening substance in the cell wall.

Extractives

In additioned to the three basic polymers: cellulose, hemicellulose, and lignin wood contains a number of other substances, which are often named extractives. The composition and the content of these extractives vary extensively, primary, between wood species, but also between different parts of the wood and from tree to tree. Heartwood contains more extractives than sapwood, some of the extractives are the primary reason for the dark colouring of the heartwood. The extractives of heartwood forms part of the natural defence of the wood against fungi attacks.

Terpenes and resins are among the most important extractives, both composed of isoprene units, polyphenols (such as flavonols, anthocyanines, quinons, lignans and tannins), carbonhydrates, fatty acids and inorganic substances.

The volatile substances from wood are the extractives, which is why these seen from an indoor air point of view are interesting. It is, however, also among the volatile substances that the major variations exist.

• Wood Species

Approx. 12,000 wood species have been identified world-wide, approx. 1,000 are used industrially world-wide. In Denmark approx. 20-30 wood species are used industrially. Some of the most important wood species for interior purposes are: Pine (Scotts Pine), spruce (Norway Spruce), beech, oak, ash, birch, alder (Common Alder) and cherry.

• Wood-Based Materials

Wood materials can be divided into two main groups - solid wood and glued wood materials.

• Solid Wood

By solid wood is understood wood, which has been sawn, dried, planed, etc. in such a way that the original structure of the wood is easily recognised in the material. Solid wood is present in a number of products e.g., windows, panels, rafters, floors and furniture. Solid wood in products can be found in combination with glue and surface treatment. In the case of the glue it is found in significantly smaller amounts than what is the case in the wood-based panels - typically below 1%.

Indoor air-wise solid wood differs from the wood-based panels by not being exposed to so high temperatures during production as the wood-based panels. The amount of volatile extractives in the wood can be reduced by exposing the wood to heat, which will intensify the evaporation of the volatile substances. The solid wood is exposed to heat during the drying. Normally, the drying will take place at temperatures far below 100℃. A possible influence of the emission of volatile substances from the wood can be to optimise the drying in order to emit the volatile substances.

- **Glued Wood Materials**

The glued wood materials mainly consist of wood-based panels. The main part of the wood-based panels sold on the Danish market is used for production of interior furnishings and furniture as well as for structural purposes in buildings, e.g. floorings, walls, and ceilings.

Wood-based panels most commonly used:

Fibre board	Masonite compressed under high temperatures without using glue. Wet process.
HDF	High Density Fibreboard, hard fibreboards manufactured by gluing together wood fibres. Dry process. Density over 900 kg/m³ (prEN 316, 1995)
MDF	Medium Density Fibreboard, manufactured by gluing together wood fibres. Dry or wet process. Density 400-900 kg/m³ (prEN 316, 1995)
Particleboard	Panels manufactured from glued wood chips.
OSB	Oriented Strand Board manufactured by gluing together thin wood chips in a length of 50-70 mm. The chips are oriented so that the fibre direction is the same in all the layers of the panels (the middle layer is perpendicular to the outer layers)
Plywood	Panels manufactured by gluing veneer layers with the fibre direction perpendicular to each other

Other glued wood materials comprise:

Laminates	Wood glued together of several layers of veneer
Glulam	Wood glued together of solid lamellas

The wood-based panels contain in excess of the wood materials, glue. Particleboards and MDF panels contain 8-10% glue, OSB 4-5% glue and plywood, glulam and laminated veneer approx. 5-7% glue. Particleboards, MDF and OSB contain furthermore approx. 1% wax.

- **Adhesives**

Common for the wood-based materials is the use of glue in the production process. For the manufacture of wood panels in Denmark the following glues are used:

UF	Urea-formaldehyde glue
MUF	Melamine-urea-formaldehyde glue
MUPF	Melamine-urea-phenolic-formaldehyde glue

There are, however, imported panels on the market that are manufactured with other types of glue e.g. phenolic glue and polyurethane glue isocyanate glue, PUR-glue, PU glue)

Approx. 90% of the consumption of glue in the Danish wood and furniture industry is used for panel manufacture. The remaining 10% is used in the furniture companies and joineries for gluing of edges, lamination etc. and for the manufacture of glulam.

For gluing of edges and lamination mainly three types of glues are used: Polyvinlyacetate glue (PVAc-glue, PVA-glue), urea-formaldehyde glue (UF-glue) and melting glue.

For manufacture of glulam for structural purposes in buildings two types of glue are used:
Phenol-resorcinol glue and melamine-urea-formaldehyde glue.

• Surface Treatments

In far the most cases both solid wood and panels are surface treated. This could either be a foil, a paint/lacquer film or an oil/wax treatment. Treatments are carried out to increase the lifetime of a product, improve the performance properties during use, make cleaning and maintenance easy, decrease the emission from the underlying material (diffusion tight coatings) and of aesthetic reasons.

At the same time as the emission from the underlying material is often decreased, the treatment itself will contribute to emission of other chemical substances.

Most surfaces made for interior use by the wood and furniture industry are: melamine coating, laminates, oil treatment, wax treatment, acid-curing lacquer, UV-curing lacquer, water-borne lacquer and polyurethane lacquer.

Content of VOC

Type and content of volatile organic compounds in oils, paints and lacquers vary extensively. Content of binders and solvents in the investigated oils and lacquers appear from the table in paragraph 2.6.

In excess of solvents other substances can emit from the different types of coating. Examples are:

- Photo initators from UV-curing lacquer
- Residue monomers (e.g. acrylics) from water-borne lacquer and polyesters
- Acetales and formaldehyde from acid-curing lacquer
- Aldehydes from oxidative curing binders based on linseed oil (e.g. alkyds)

The examples are far from being exhaustive. Actual treatments should be evaluated with regard to potential emitting substances. Regarding the practice of the present project, reference is made to "All Chemicals List", chapter 5 and Appendix 5.

• Factors Influencing the Indoor Air

Wood and wood-based materials and products used in such a way that they influence the indoor air, will appear as a combination of several materials and often including a surface treatment. It will, however, still be interesting to know with which amounts and substances the individual materials contribute to the emission.

The emission of VOC's to the indoor air from individual materials will depend on a number of factors the most important ones being:

Solid wood:

Wood species

Habitat
Drying, hereunder drying temperature
Moisture content in the wood
Heart-/sapwood ratio
Age of the product, storage, packing etc.

Wood-based panels:
Wood species
Type and amount of glue
Pressing time and temperature
Moisture content
Age of the product, storage, packing etc.

Surface treatments:
Type of surface treatment
Application conditions - hereunder applied amount
Curing conditions, hereunder curing time and temperature
Possible interactions between wood and coating
Age of the product, storage, packing etc.
Potential interactions between the wood and the surface treatment

- ## Material Selection

The experimental part comprised investigation of 24 examples of wood and wood-based materials representing solid wood and wood-based materials usually used in furniture, interior furnishings and building products in 1996.
The test programme comprised wood and wood-based materials of different degrees of complexity from solid wood to coated veneered wood-based panels.

Survey of investigated materials:

Solid Wood

1 Ash
2 Oak
3 Beech
4 Spruce, narrow annual rings
5 Spruce, broad annual rings
13 Pine, northern Finland, approx. 84% share of heartwood
14 Pine, northern Finland, approx. 96% share of sapwood (approx. 4% heartwood
15 Pine, southern Sweden, approx. 67% share of heartwood
16 Pine, southern Sweden, approx. 98% share of sapwood (approx. 2% heartwood share

Wood-based panels

6	Particleboard, pine/spruce	MUPF glue
7	Particleboard, pine/spruce	UF glue
8	Particleboard, pine/spruce	PU glue
9	Plywood, birch	Phenolic glue
10	MDF, coniferous wood	UF glue
17	OSB, coniferous wood	Phenolic glue

Veneered Wood-Based Panels

11 Beech veneered particleboard (7), veneered with PVAc-glue
12 Beech veneered particleboard (7), veneered with UF-glue

Surface Treated Materials

18 Flooring oil based on urethane alkyd/linseed oil on solid beech (3)
19 Flooring oil based on natural resin/linseed oil on solid beech (3)
20 Nitrocellulose lacquer on beech veneered particleboard (12)
21 UV-curing acrylic lacquer on beech veneered particleboard (12)
22 Acid-curing lacquer on beech veneered particleboard (12)
23 Water-borne acrylic lacquer on beech veneered particleboard (12)
24 Polyurethane lacquer on beech veneered particleboard (12)

Examples

The selected 24 wood-based materials are to be considered as examples and cannot be considered as being representative for all wood-based materials used indoors.

Investigated Oils and Lacquers

Surface treatments forming part of this investigation, are usually used flooring oils and lacquers for industrial coating of wood furniture and interior furnishings.

The composition information of the investigated oils and lacquers has been taken from the safety data sheets of the materials including content of volatile organic compounds and Code Numbers (in ready for use mixture) according to the Statutory Orders of the Danish Working Environment Service, stated in Table 2.1.

Table 2.1
Investigated Oils and Lacquers

Oil/Lacquer Type	%VOC	Solvents According to safety data sheet	Code no. #
Oil (Natural resin and linseed oil basis)	Approx. 50	Isoaliphatic hydrocarbons	3-1
Oil (Urethanealkyd- and linseed-oil basis)	53	White spirit, aliphatic hydrocarbons	2-1
Nitrocellulose lacquer (Nitrocellulose and alkyd basis)	75	Butylacetate, ethanol, 2-propanol, aliphatic hydrocarbons	2-1
Acid-curing lacquer (Urea and melamine-formaldehyde resin, acrylcopolymer, alkyd- and nitrocel-lulose basis)	50	Xylen, butanol, 2-methyl-1-propanol, butylacetate, 1-methoxy-2-propylacetate	4-3
Polyurethane lacquer 2 component (acrylcopolymer-, poly-ester-, cellulose-acetobutyrate- and alkyd basis	67	Xylen, butylacetate, 1 methoxy-2-propylacetate	3-3
UV-curing lacquer (Acrylic basis)	<1,5	Reactive polyacrylate, tripropylenglycoldiacrylate, diproylenglycoldiacrylate	0-5
Water-borne lacquer (Acrylcopolymer-basis)	Approx. 1.5	1-butoxy-2-propanol, 1-butoxy-2-propylacetate 2-(2-butoxyethoxy)-ethanol	00-1

* The UV-curing lacquer contains furthermore photo initiators

\# The Code Number gives safety & health information on lacquers and oils according to the regulations of the Danish Working Environment Service. The figures before the hyphen informs about the volatile substances, and states the requirement for use of respiratory protective equipment against inhalation of volatile substances.

Coating with nitrocellulose lacquer, acid-curing lacquer, polyurethane lacquer, water-borne lacquer consists all of one primer layer and one top layer of lacquer, which have been applied the beech veneered particleboards by spraying. The UV-curing lacquer was coil coated in three layers.

A close description of the test specimens investigated by emission testing in test chamber appears from Appendix 6. As the spruce variables with narrow and broad annual rings respectively (4 and 5) showed uniform emissions by the initiative screening, only the narrow annual ringed spruce example was examined closer by emission testing in test chamber.

Emission Testing

The emission testing of wood and wood-based materials is based on the determination of all the chemical substances in the emissions to evaluate the emissions from the individual materials by comfort and health evaluation and to be able to make proposals for product modifications/substitutions.

- ### Experimental Investigations

Theoretical Evaluation of Potential Emission

As basis of the planning of the chemical analyses a theoretical evaluation was carried out to presume which substances based on knowledge on the enclosed materials (wood, glue, oils and lacquers) in principle might be expected to be emitted. By this evaluation special weight was laid on substances, which have carcinogenic, reprotoxic, immunologic or neurotoxic effects according to lists from the Danish working environment authorities, chapter 4. Substances, which were selected on this basis, appear from "All chemicals List", cf. chapter 5 and Appendix 5.

Initial Qualitative Screening

The selected wood and wood-based materials according to clause 2.6, were investigated by an initial qualitative screening analysis designed to lay down an analysis programme for the quantitative test chamber measurements for each wood-based material.

The qualitative screening was carried out by headspace analysis, as the material to be examined was placed in a diffusion tight bag with a relatively low amount of clean air and was heated to 120°C for 1 hour. An air sample of 1 ml was sampled with a gas tight syringe without using a collection medium and analysed by headspace by capillary column gas chromatography combined with mass spectrometric detection (GS-MS) cf. Appendix 6.

By the initial headspace analyses it was possible to identify all the substances, which might emit from wood and wood-based materials (according to "All Chemicals List") if they were present except from the substances: Carbendazim and tetramethylthiuramsulfid (fungicide).

Quantitative Emission Chamber Measurement

The quantitative determinations were carried out by emission chamber measurement according to the standard test method for determination of emission of volatile organic compounds especially adjusted to wood-based products, cf. Appendix 3.

The method has been co-ordinated according to prENV 717-1: "Wood-based panels. Determination of formaldehyde release. Part 1: formaldehyde release by the chamber reference method", April 1996 and proposal pre-sently subject to preparation within CEN/TC 264/WG7: "Building products. Determination of Volatile Compounds. Emission Test Chamber Method", October 1995 - March 1997.

The method has furthermore been co-ordinated between the Nordic wood research institutes and the Nordic wood industry (Larsen, A., 1998).

Generally, the test method has aimed at being close to practice and to reflect the use of the materials and products in buildings.

Preparation of Test Specimens

The size of the test specimens has been adjusted according to the chamber volume to obtain the desired material load. A relation of n/L=1 between the air exchange rate (n) and the material load (L) has been applied. By n/L=1 the same value of emission rate [μg/ $m^2 \cdot h$] and of the concentration [μg/ m^3] is obtained.

Test specimens of wood-based panels were edge sealed prior to the testing.

The moisture content was measured in all test specimens before and after testing. Moisture content, dimensions etc. of the individual materials appear from the test specimen description in Appendix 6.

Standard Test Conditions

Test conditions:

Temperature:	23 ± 0.5°C
Relative humidity:	45 ± 5%
Air velocity: middle	0.15 ± 0.05 m/s parallel over the of the test specimen
Air exchange rate and load ratio:	n/L: 1

The test specimens have been stored at standard test conditions during the entire test period.

Measurement Principle and Times

Emission chamber measurements have been carried out in 225 l test chambers made of stainless steel. The general principle of emission measurements in emission chambers is that the test specimen to be examined, are placed in a test chamber under standard conditions. Gases and vapours emitted from the test specimen are then mixed with the chamber air. Air samples are sampled at fixed times and are analysed by chemical analysis techniques.

In this investigation the measurement times were fixed at:

3	± 1 days
10	± 1 days
28	± 1 days

Chemical Analysis

The analysis programme for the quantitative analyses comprised determination of all individual volatile organic compounds, VOC's, of the emissions.

The emissions from all the investigated wood-based materials have been analysed by capillary column gas chromatography combined with mass spectrometric detection (GC-MS) cf. Appendix 6 and by aldehyde analysis by means of dinitrophenylhydrazin tubes, acetonitril extraction and subsequent liquid chromatography on equipment with diode detector, HPLC-DNPH, (Possanzini, M., 1995).

Determination of formaldehyde by photometry by the acetylacetone method according to prENV 717-1 was carried out as part of all tests of wood-based panels.

Quantitative gas chromatographic analyses have been carried out by collecting gases and vapours on adsorption tubes of charcoal and tenax and extracted by solvent desorption with carbondisulfid and diethylether with isotop labelled internal standard. The eluates were thereafter analysed by GC-MS.

By all analyses the quantifications were carried out according to calibration standards of the detected substance or closely related chemical substances. Totally, 39 substances (comprising 9 aldehydes, 1 ketone, 6 alcohols, 5 esters, 5 glycols and glycol esters, 5 hydrocarbons and 8 terpenes and terpene-alcohols) were used for quantification of the emission collected on charcoal and tenax tubes.

Sensory Analysis

Sensory determination of the perception of odour was carried out on 3 of the 23 selected materials: spruce , beech veneered particleboard with polyvinylacetate glue for veneering and UV-curing lacquer on beech veneered par-ticleboard. The sensory determinations have been carried out on materials of different degrees of complexity, as they in this investigation are directory only and primary serve to control the evaluation of the chemical analysis according to odour threshold values.

The sensory determination was carried out by emission chamber testing (Danish Society of Indoor Climate, Standard Test Method, 1994) in a Climpaq chamber with an odour funnel diffuser allowing sensory evaluation of the odour perception. By this method the perception of the air quality of the air that has been into contact with the test material and the air from an empty reference chamber is evaluated by an untrained panel of approx. 20 persons reflecting the composition of the society. The odour perception is evaluated regarding intensity (scale from no odour to overwhelming odour) and acceptability (scale from clearly acceptable to clearly unacceptable). The evaluations are carried out to the time 1 day and by a material load of approx. 0.12 m^2 surface per m^3 room air.

- ## Results

The emission results for the investigated wood and wood-based materials are stated generally for the qualitative screenings in clause 3.2.1 and the quantitative emission chamber measurements including the directory sensory evaluations in clause 3.2.2. Results in detail are tabled in Appendix 6.

With a view to the health and comfort evaluations the concentrations mea-sured in an emission chamber were converted into the concentrations to which people are exposed in the indoor air.

Standard Room

A standard room generally used for calculation of the indoor-relevant concentrations reflects the critical case, as it has a relatively large surface in relation to the volume of the room (Danish Standards Association DS/INF 90, 1994). For example a flooring material makes up 7 m^2 of the standard room of 17.4 m^3, and a material for lining all the surfaces of the room makes up 38 m^2 in the standard room of 17.4 m^3.

A part of a piece of furniture, e.g. edges of a table top constitutes as little as 0.1 m^2 or less.

Material Load

In the result tables cf. Appendix 6, a standard room concentration of the broad area interval of 0.1 - 38 m^2 corresponding to material loadings of 0.06-2.2 m^2/m^3 is stated. For most of the examined wood-based materials the whole of this interval is not relevant.

Solid ash, beech, oak, wood-based panels and beech veneered particleboards are examples of materials that in practice are seldom used without surface treatment. It appears a.o. from material prepared by the Ministry of Housing and Building in connection with the latest revision of the Danish Building Code (regarding the requirements of Danish Control Organization for Wood-Based Panels to formaldehyde content in wood-based panels) that wood-based panels in the smallest room in a house constitute up till 0.42 m^2/m^3. Examples of usual material load for wood and wood-based material appear from Table 3.1. In connection with evaluation according to clause 5.3.2, Table 5.3, a need for measurement in excess of 28 days is seen.

Table 3.1
Examples of Material/Product Load in Buildings

Material/Product Load m^2/m^3	Examples of wood and wood-based materials/products by a given load	Surface area in a standard room of 17.4 m^3 [m^2]
2.2	Ceiling, flooring and wall lining respectively 2 bookcase systems	38
0.4	Ceiling respectively Flooring respectively Table + 6 chairs	7
0.12	Door surface respectively Table top	2

- **Qualitative Screening**

By the initial screenings by head space analysis of the 23 selected materials 144 different chemical substances were identified. The 144 substances were divided as follows:

27 aldehydes (saturated or unsaturated)
15 ketones
11 alcohols
2 acids
28 aliphatic hydrocarbons
10 aromatic hydrocarbons
20 hydrocarbons of the terpene types mono and sesquiterpenes
23 esters
3 ethers
4 glycolethers and esters

1 amine

If the identification of headspace of solid wood and uncoated wood-based panels are considered alone, most of the identified substances were: aldehydes and terpenes, it was likewise these types that formed part of most of the emissions.

- **Quantitative Emission Chamber Measurements**

By the quantitative emission chamber measurements of the emissions from the 23 investigated wood and wood-based materials 84 different chemical substances were quantified cf. the result tables ranked according to chemical type of substance in Appendix 6 and "Project Specific List" in Appendix 5. List of Synonyms, which likewise comprises emissions quantified by emission chamber measurements of the 23 examined wood and wood-based materials, is given in Appendix 10.

The measured emissions can not be considered adequate for the investigated type of material nor as generally representative for emissions from wood and wood-based materials.

The predominant emissions from untreated wood and untreated wood-based panels were aldehydes and terpenes as by the headspace analyses.

In the following the results from the quantitative test chamber measurements are illustrated in bar charts. It should be noted that the scales of the emission rate varies in the different bar charts.

Solid Wood

For the investigated types of solid wood:

Ash, beech and oak
Spruce, narrow growth rings
Pine, northern Finland, approx. 84% of heartwood share
Pine, northern Finland, approx. 96% of sapwood share
Pine, southern Sweden, approx. 67% of heartwood share
Pine, southern Sweden, approx. 98% of sapwood share

the emissions of aldehydes and terpenes (expressed as emission rates at the three measurement times) are shown on page 27.

The predominant emissions from solid wood were aldehydes, above all acetaldehyde, propanal, butanal, pentanal and hexanal, as well as the ketone acetone. The aldehydes varied in amount in the different materials.

Very low indoor-relevant concentrations were found for solid ash, beech and oak when calculating at a material load of 0.4 m^2/m^3 e.g. corresponding to a flooring or a table and six chairs.

Solid pine gave considerably larger emissions than the other tested solid wood species including spruce. In the emission from pine also terpenes primarily α-pinene, 3-carene and limonene were found in large emission rates. The four pine variants (that vary what regards origin (northern Finland and southern Sweden) and content of heart- and sapwood) showed considerable differences in emission rates of especially 3-carene and α-pinene.

The broken line on bars for the terpene emission from solid pine states that over exposure of adsorption tubes has taken place and that the emission rates to the time 4 and 11 days are minimum emission rates.

Wood-Based Panels

For the six investigated wood-based panels:

Particleboard, pine/spruce MUPF-glue

Particleboard, pine/spruce	UF-glue
Particleboard, pine/spruce	PU-glue
Plywood, birch	Phenolic-glue
MDF, coniferous wood	UF-glue
OSB, coniferous wood	Phenolic-glue

the aldehyde emissions (expressed as emission rate at the three measurement times) are shown on page 28.

The predominant emissions from untreated wood-based panels were aldehydes, mainly acetaldehyde, propanal, butanal, pentanal and hexanal, as well as the ketone acetone. The aldehydes varied in amount in the different materials. Formaldehyde was the predominant individual emittant in the urea-formaldehyde glued wood-based panels.

The emissions from the investigated wood-based panels varied as expected dependent on the applied glues.

Veneered Particleboard

For the two investigated examples of beech veneered particleboard:

- Beech veneered particleboard, veneered with PVAc-glue
- Beech veneered particleboard, veneered with UF-glue

and the materials forming part: beech and particleboard.

the predominant emissions of aldehydes and benzylalcohols (expressed as emission rate at the three measurement times) are shown on page 28.

The emissions from the investigated veneered wood-based materials reflected the different glues used by veneering and consisted mainly of aldehydes and benzylalcohol from the polyvinylacetate glue. In the emission from beech veneered particleboard glued with urea-formaldehyde-glue considerable amounts of formaldehyde were seen.

Surface Treated Wood-Based Materials

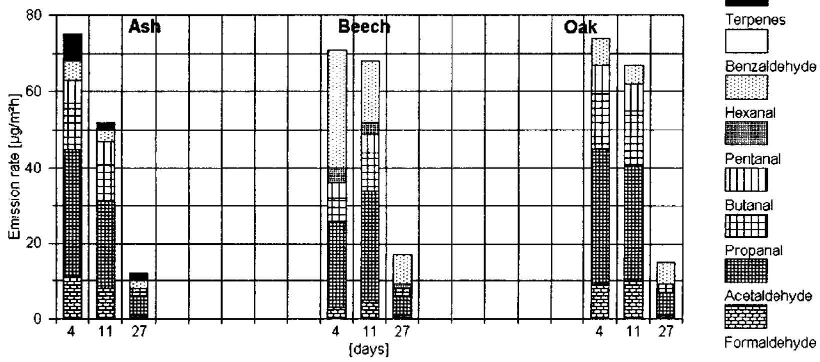
For the two examined flooring oils:

- Flooring oil based on urethanealkyd/linseed oil applied on solid beech
- Flooring oil based on natural resin/linseed oil applied on solid beech

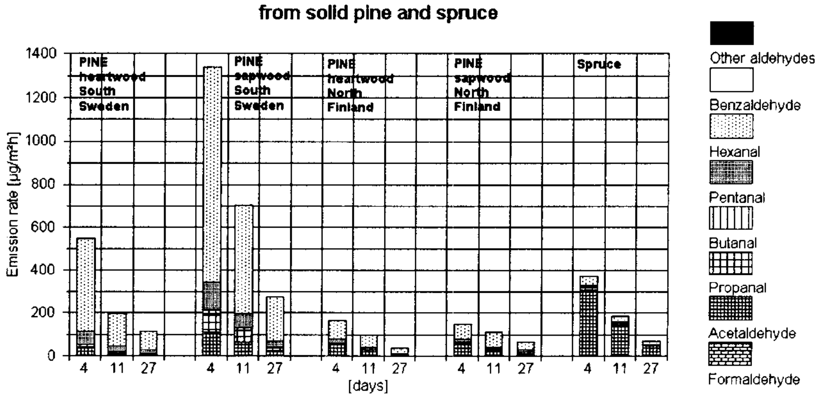
and solid beech

the predominant emissions of aldehydes and hydrocarbons (expressed as emission rate at the three measurement times) are shown on pages 28 and 29.

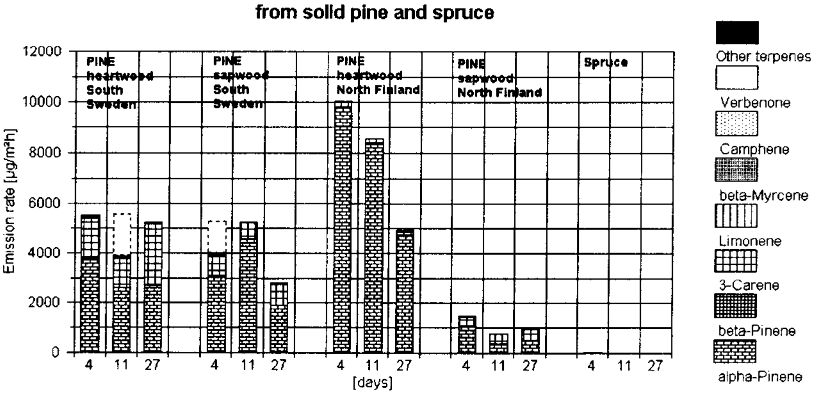
Emission
from solid ash, beech and oak



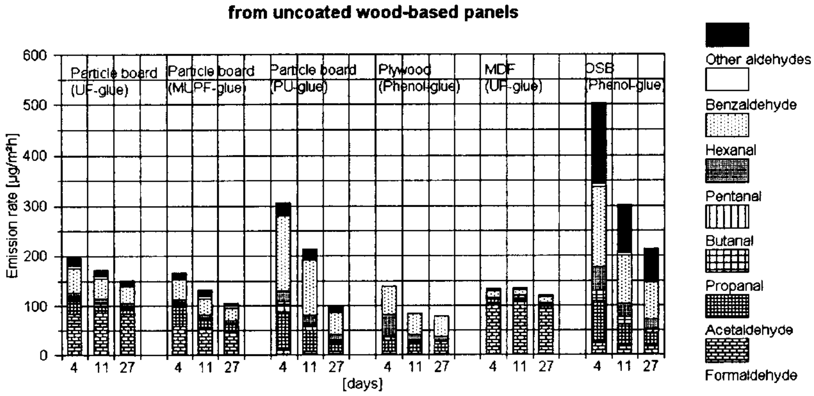
Emission of aldehydes
from solid pine and spruce



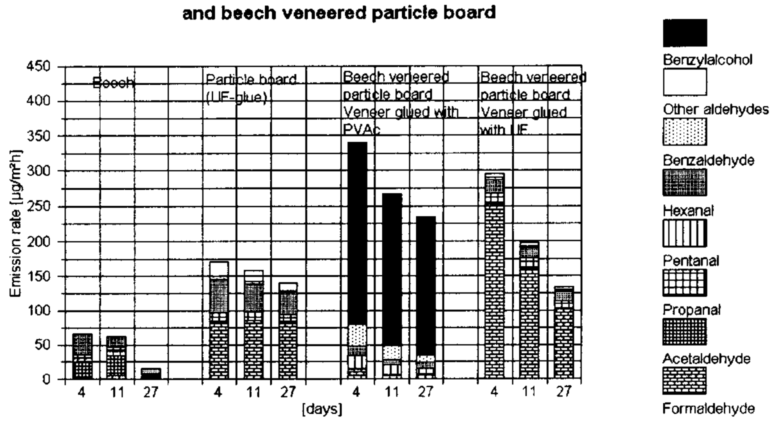
Emission of terpenes
from solid pine and spruce



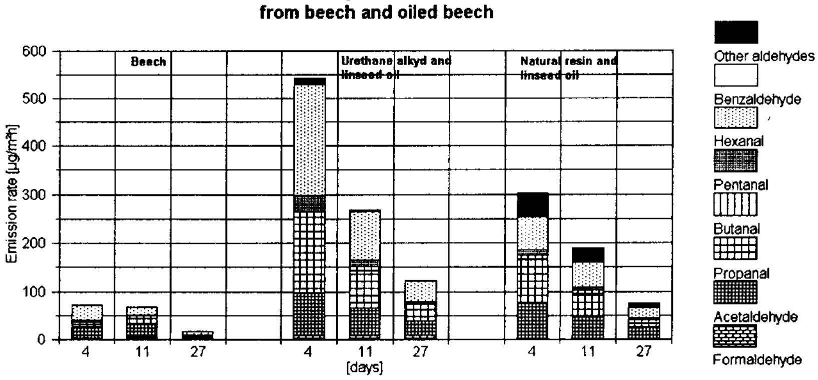
Aldehyde emission from uncoated wood-based panels



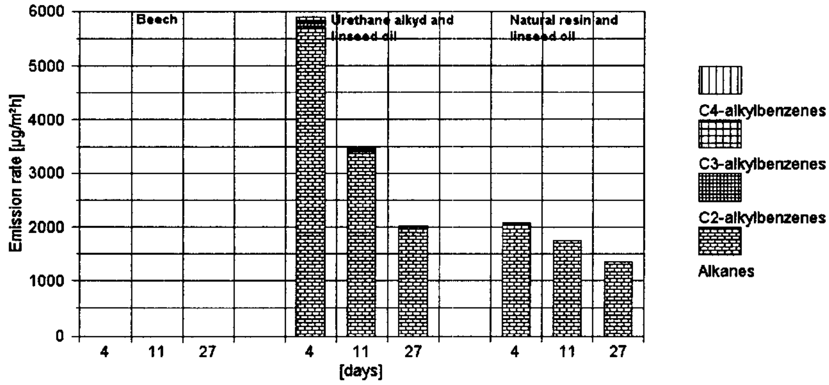
Emission from beech, particle board and beech veneered particle board



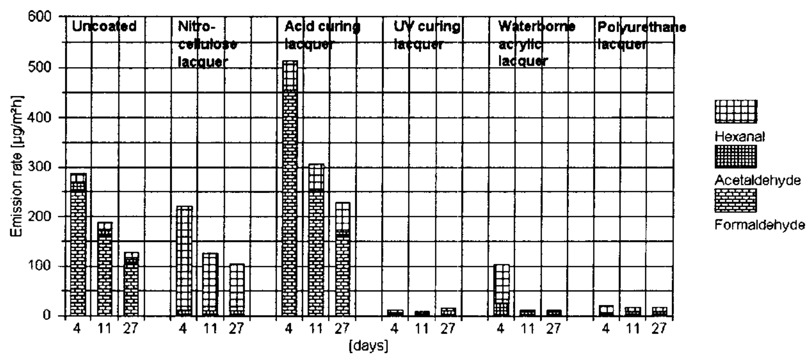
Aldehyde emission from beech and oiled beech



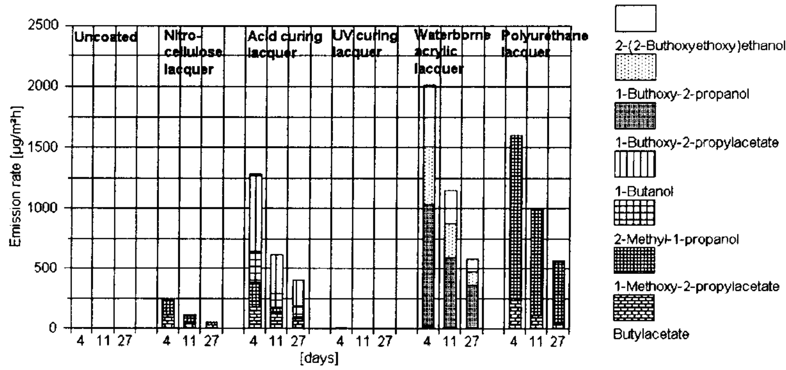
Hydrocarbon emission from beech and oiled beech



Aldehyde emission from laquered beech veneered particle board



Emission of esters, glycolethers and -esters from lacquered beech veneered particle board



For the five investigated lacquers :

- Nitrocellulose lacquer on beech veneered particleboard
- UV-curing lacquer on beech veneered particleboard
- Acid-curing lacquer on beech veneered particleboard
- Waterborne acrylic lacquer on beech veneered particleboard
- Polyurethane lacquer on beech veneered particleboard

as well as the beech veneered particleboard (veneered with urea-formaldehyde glue)

the predominant emissions of aldehydes and esters and glycolethres and esters respectively (expressed as emission rate at the three measurement times) are shown on page 29.

The emissions from the investigated treated wood-based materials originated primarily from the oils and the lacquers and comprised mainly alcohols, unsaturated aldehydes, esters, glycolethers and -esters. The emission of most of the aldehydes from the surface treated materials can be traced back to lacquer or oil and wood.

Results from Sensory Analysis

Results from the directory sensory analysis of the odour perception carried out for spruce, beech veneered particleboard with polyvinylacetate-glue for veneering and UV-curing lacquer on beech veneered particleboard confirm the result from the chemical testing. The acceptability varied for the three investigated materials between 0.3 and 0.7 (0 = acceptable and 1 = clearly acceptable) and the intensity between 1.0-1.7 (0 = no odour and 1 = slight odour and 2 = moderate odour) already when measuring the day one. Regarding the results in detail cf. Appendix 6.

Comparison of time-values determined by emission chamber measurement accompanied by chemical analysis and time-values based on emission chamber measurement with sensory evaluation appears from Table 3.2.

Table 3.2
Comparison of Time-Values

Wood and wood-based materials/ products	Time-Value* based on		Indoor-relevant time-value*
	Chemical testing	Sensory evaluation	
Spruce	<4 days	<1 day	<4 days
Beech veneered particleboard, veneered with PVA-glue	<4 days	<1 day	<4 days
UV-curing lacquer on beech veneered par-ticleboard	<3 days	<1 day	<3 days

*By a material load of 0.12 m² surface per m³ room volume

Principles for Comfort and Health Evaluation of Chemical Substances Emitted from Wood and Wood-Based Materials

In the following section a general procedure for the evaluation of emissions from wood and wood-based materials is outlined.

Quantitative Analyses

The selection of the substances for quantitative analyses was carried out according to the following criteria:

Substances identified by screening analysis
Substances with carcinogenic, reprotoxic, immunologic or neurotoxic effects suspected to be emitted from wood and wood-based mate-rials (See "All Chemicals List")

KRAN-Substances

Substances with carcinogenic, reprotoxic, immunologic or neurotoxic effects follow the "KRAN-lists" from the Danish Working Environment Service and the National Institute of Occupational Health, as K: Carcinogenic effect has been defined according to the list on Threshold Limit Values for chemical substances in the work environment (Danish Working Environment Service, 1994), R: reprotoxic effect has been defined according to the list on Reproductive toxicants in the working environment (Hass. U., Danish Working Environment Service, 1990), A: Immunologic effect has been defined according to the list on Allergens in the working environment (Thomsen, K. G., National Institute of Occupational Health, 1990) and N: neurotoxic effect has been defined according to the list on Neurotoxic substances in the working environment (Danish Working Environment Service, 1990).

Lists

The list of the substances expected to be emitted from wood and wood-based materials and products: "All chemicals list" and a "Project Specific List" of substances quantified by chamber testing in the project are shown in Appendix 5.

Toxicological Evaluation

For all substances quantified in the chamber testing an evaluation of toxicological effects was made according to description in 4.1 - 4.4.

Three Classes

Three classes of toxic effects were considered. The first was adverse effects such as carcinogenic effect, allergy, reproductive toxicity. The second class was other effects such as neurotoxic effects, irritation (inflammatory and sensory irritation) and the third was sensory effects. Substances that may cause cancer and allergy or show reproductive toxicity shall in principle not be accepted and shall generally be replaced by other with less hazardous properties.
For the second group the lowest concentration of interest in the indoor air, LCI, was estimated. Also odour threshold values were included in the assessments and together with sensory irritation thresholds used in calculation of the indoor-relevant time-value described in Appendix 4.
Assessment of substances with little available relevant toxicological information was based on an assumption that their toxicological properties correspond to known and chemically analog substances. If this assessment was impossible, the substance was considered as toxicologically unknown.

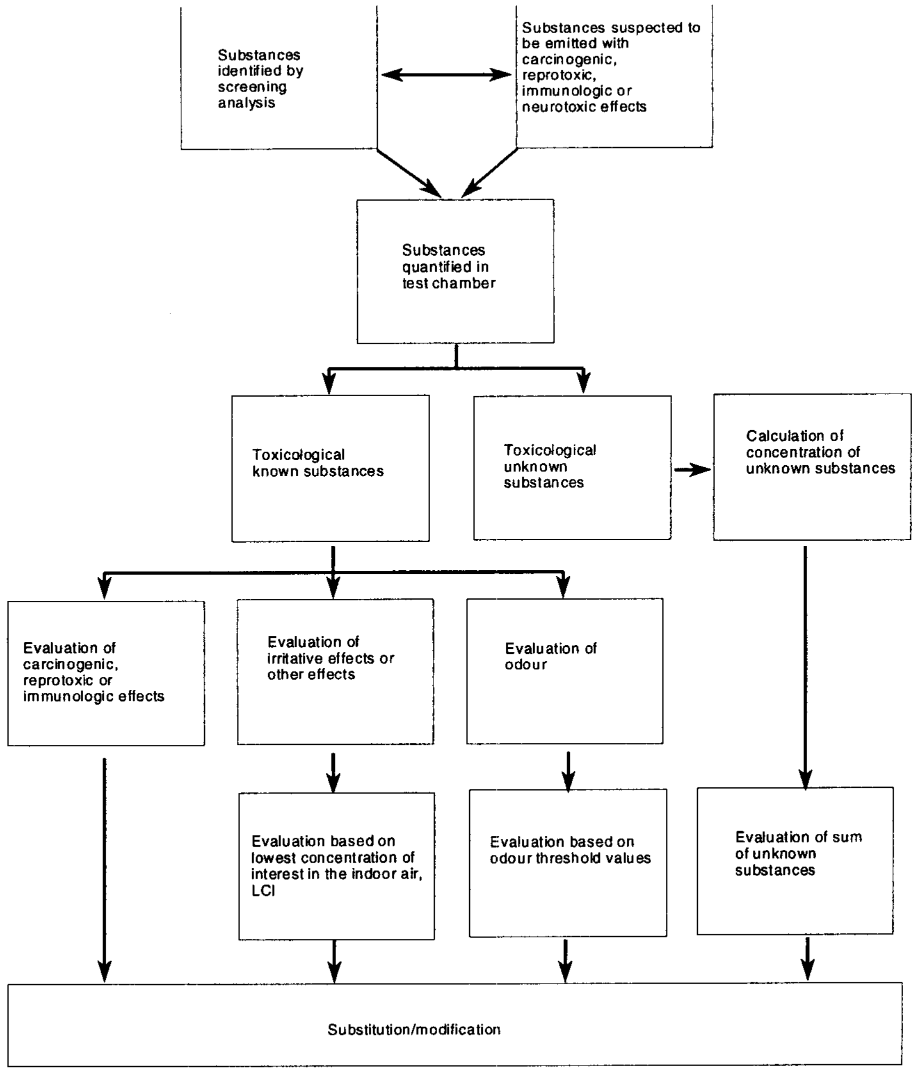


Figure 4.1
Evaluation of emission in principle

The general principles of evaluation of emissions from wood and wood-based materials are shown in Figure 4.1.

Evaluation of individual VOC's is given in Appendix 7 and in brief in "All Chemicals List" and "Project Specific List" in Appendix 5. The lists given in Appendix 5 summerize information on chemical identity and health and comfort effects.

• In General

During the last years approximately 300 different volatile organic compounds have been identified in the indoor climate (Nielsen, P.A., 1994). Some of these substances can be traced back to substances present in wood and wood-based materials and their emission. Some of the emissions are intensive in the initial period of usage.

There are, however, some emissions (certain organic substances), which do not decline or decline very slowly with time. It is difficult to eliminate such emissions of VOC's. It is, however, important to know possible health and sensory effects of VOC's in this period, within which the critical health emission takes place.

Health effects commonly associated with indoor air pollution have non-specific symptomology (Mølhave, L., 1986). Headache, fatigue, reduced attention span, irritability, nasal congestion, difficulties in breathing, nosebleeds, dry skin and nausea are commonly seen in connection with "sick buildings". Exposure to VOC's in the indoor air may also lead to discomfort caused by sensory effects. Although, sensory effects are not related to critical health effects they may have important influence on human well being in the indoor environment.

Epidemiological studies of the toxic effects of the indoor air pollution are difficult to conduct as there are many different sources of pollution and many toxicants. In the indoor air besides VOC's other chemical toxicants occur, e.g. carbon monoxide, nitrogen dioxide and radon, and a variety of toxicants of animal and microbial origin.

There is an international consensus on the general principles for the evaluation of the health effects and for determination of threshold limit values within the environmental area such as pollution of air, drinking water and soil (WHO 1984, WHO Air Quality Guidelines for Europe 1987, Ministry of the Environment 1992, WHO 1994 and ASHRAE 1989). These principles have been applied to the evaluation of the health effects of VOC's emitted from wood and wood-based materials and for determination of Lowest Concentration of Interest, LCI-values, for VOC's (refer to 4.4).

Critical emission of VOC's shall be limited as much as possible. There are two ways (besides increased ventilation) of the limitation of critical emissions, namely to:

- Substitute and modify wood or wood-materials by alternatives
- Assess time necessary for decline of critical emissions

When a substitution has been decided, attention shall be paid to the entire life cycle of the alternatives so that alternatives don't create any new environmental problems, e.g. waste disposal problems.

Critical emissions from a majority of wood and wood-based products decline with time. Careful assessment of this time may be a practical way to ensure safety and comfort in the indoor environment.

Substances with no data available are often emitted in the indoor air. Emission of "toxicological unknown" substances and emission of substances which are difficult to measure shall be limited as much as possible, e.g. substitution/modification.

The following definitions will be used:

Carcinogens: Substances presenting a carcinogenic risk.

Allergens: Substances causing sensitization, immediate hyper sensitivity (e.g. asthma and urticaria) or delayed hypersensitivity (e.g. contact dermatitis).

Reproductive toxicants: Substances causing "teratogenic effects" (defects induced during development between conception and birth) and substances causing "effects on reproduction" (general fertility and reproductive performance".

Neurotoxicants: Substances causing toxic effects on the central or peripheral nervous system.

• Evaluation of Health Effects

Evaluation of health effects includes dose-response assessment, exposure assessment and characterization of uncertainty. Three approaches, namely threshold compounds, non-threshold compounds and sensory thresholds have been proposed for assessment of the dose-response relationship. It is generally recognized that for the majority of toxicological responses, a threshold do exist. It has been assumed in the present work that for irritation, acute, subchronic and chronic toxicity a threshold value (a concentration at which no hazardous effect may be observed) can be determined. For carcinogenic and sensory substances and allergens another procedure has to be adopted.

• Threshold Compounds

Threshold compounds represent substances having other effects than carcinogenic and immunologic effects.

The majority of VOC's exert their hazardous effects only above a certain minimum concentration in the indoor air. They show a distinct dose-response relationship leading to the concept of a threshold, which means a dose (concentration) below which the probability of toxic action is zero.

Determination of a "safe" threshold limit value for human exposure in the indoor air is often based on evaluation of toxicological documentation from animal studies. In addition to animal data other relevant information can be obtained either from epidemiological studies (occupational environment) or from the clinic. However, epidemiological studies are seldom available for individual VOC's.

NOAEL/LOAEL

For toxicologically well known substances a threshold limit value may be based on the no-observed-adverse-effect-level (NOAEL) or lowest-observed-adverse-effect-level (LOAEL) chosen from the most relevant toxicological study.

Having established the NOAEL or LOAEL, safety factors are used to obtain a sufficient margin of safety. Traditionally, the total safety factor is composed of one factor of 10 for extrapolation between species (animal to human) and a second factor of 10 to protect the most sensitive member of the population e.g. children. When the weight of evidence, namely quality and relevance of data are not adequate, a third safety factor may be used and the size of this factor varies. The total safety factor is calculated as a product of all safety factors.

Pollution of the indoor air consists, among others, of a complex mixture of many different VOC's. Considering the complexity of the exposure it is essential to know the possible interactions between different substances. An interaction could result in an increase of effects (synergy) or a decrease of effects (antagonism). Information on possible interaction is rarely available. An interaction most commonly observed when two substances act together. An additive effect occurs when the combined effect of two substances equals the sum of the effects of each substance given alone. Dose additivity is based on the assumption that substances acting together have the same mode of action and elicit the same toxicological effects. When substances elicit a similar effect, e.g. irritancy, the additive model assess the "join action" of toxicological similar substances under the condition that no interaction takes place. This model does not always represent a biologically plausible approach, as the different substances may or may not have the same mode of toxicological action. Several studies, however, have demonstrated that the dose additive model reasonably predicts the toxicity of a mixture composed of a variety of substances (Casarett & Doull, 1995).

The relevant toxicological documentation is very limited for several VOC's identified in the emission from indoor sources. The hazard identification based on the structure-activity relationship may be useful assessing the relative toxicity of chemically related substances.

Physical-chemical data like e.g. solubility, pH, chemical structure and reactivity may provide important information for hazard identification.

TVOC

The concept of Total Volatile Organic Compounds (TVOC) was the first attempt to describe low-level exposure to a mixture of volatile substances in non-industrial environments. This concept assumes that the human health effects may be proportional to the sum of mass-concentrations (mg/m^3) of the VOC's in the air and that the substances are of equal strength and mode of action. No-effect level for TVOC has been suggested to be 0.2 mg/m^3 whereas discomfort at a concentration above 3 mg/ m^3 is to be expected (Mølhave, L. 1991).

The importance of a low concentration of a toxicological potent substance can be underestimated, while that of a low-toxicity substance can be overestimated, if TVOC is estimated as one compound. Scientific literature is inconclusive with respect to TVOC as an expression of risk for health and comfort effects in buildings, despite a very large amount of research in this field. In 1996 it was concluded that TVOC is still an undocumented hypothesis and there is not a scientific basis for establishment of limit values or guidelines for TVOC for emissions from materials and products used indoors (Andersson, K., Consensus meeting 1996).

Sensory and Inflammatory Irritation

For the great majority of VOC's, however, sensory effects and skin irritation are most probably the critical effects at the very low exposure level in the indoor environment.

Skin irritants and fibres in the air may contribute to the skin symptoms described as a part of the "sick building syndrome" (WHO, Criteria for classification of skin- and airway sensitizing substances, 1996).

Irritation includes both sensory and inflammatory irritation. The perception of comfort in the indoor environment is greatly influenced by both sensory irritation and odour.

Sensory irritation is stimulation of the trigeminal nerve endings in the eye cornea and nasal mucosa. Animal experiments showed that such irritations cause reflectory decreases in the respiratory rate. This irritation is characterized by a latency period before the perception of the effect is reached.

Mouse Model

A mouse model is commonly used for assessment of irritating properties of VOC's (Nielsen, G.D., 1995 and Wolkoff, P., 1997). The concentration that induces 50% decrease in the respiratory rate in mice, the RD_{50} value, is used to quantify the irritating potency of a substance. It has been proven that the mouse model has a predictive value for human responses to sensory irritation.

In practice an evaluation of 3% of the RD_{50} concentration is believed to be safe for man in respect to inflammatory irritation and is used as an estimate of a safety level for the occupational environment (Schaper, M., 1993).

In general, the occupational exposure levels are suggested (Nielsen, G.D., 1995) to be used for evaluation of health effects in the indoor air by using an additional safety factor of 40. Furthermore, the lowest acceptable concentration of interest in the indoor air may be calculated by taking exposure 24 hours a day and 7 days a week (8/24 x 5/7 = 1/4) and a safety factor of 10 for the sensitive group into account.

- **Non-Threshold Compounds**

Non-threshold compounds represent substances having particular hazardous effects e.g. carcinogenic effects.

Non-threshold compounds are substances that do not show a distinct dose-response relationship. No observable adverse effects level, NOAEL, can not be obtained directly from the experimental data. Genotoxic carcinogens and sensitizing substances may be considered to be non-threshold compounds.

Genotoxic carcinogens produce DNA damage, and theoretically even one molecule may lead to development of carcinogenicity. Several mathematical models are used to extrapolate from high doses to the region of the dose-response curve for which no experimental data are available. In addition to experimental data determination of a "safe" threshold limit value for genotoxic carcinogens is based on an assumption of a tolerable risk level.

A risk level of about 10^{-6} is regarded as tolerable and a risk level of 10^{-7} is regarded as acceptable for, among others, the Danish society (Ministry of the Environment, 1992 and Dragsted, L., 1990).

Existing mathematical models for low-dose extrapolation may not be appropriate for non-genotoxic carcinogens.

IARC

The International Agency for Research on Cancer (IARC) prepares and publishes critical reviews on the carcinogenicity of a wide range of chemicals to which humans are or may be exposed. The evaluation of the strength of the evidence for carcinogenicity is arising from human and experimental animal data. The total body of evidence leads to categorization of chemicals into one of the following groups: group 1, group 2A, group 2B, group 3 or group 4.

Chemicals that are carcinogenic to humans are categorized to group 1. Group 2A encompasses chemicals that are probably carcinogenic to humans, and group 2B-the chemical is possibly carcinogenic to humans.

Sensitizing Substances

Some of the VOC's are well known skin sensitizers. Most experimental studies are conducted on animals, using much higher doses than those relevant for the indoor air. Dose response studies are extremely sparse and extrapolation from experiments conducted in animals using high doses directly on the skin, to small doses, airborne, in humans, is questionable.
Sensitizing chemicals exposed to the skin by direct contact or indirectly through adherence to particles in the air, may cause allergic contact dermatitis. Several data from experimental studies in animals as well as human clinical data from direct skin contact are available.

Chemicals may in rare cases cause airway hypersensitivity by an immunological mechanism different from that of skin-sensitization. The symptoms evoked are asthma and possible urticarial reactions. Data on airway sensitisation caused by VOC's are extremely sparse and no eligible animal models are available.

Once sensitization has occurred, allergic reactions may result from exposure to relatively low doses. The manifestations of allergy are numerous and may involve various organs and range in severity from minor skin effects to fatal anaphylactic shock.

The main principles of evaluation of these effects is that substances causing these effects should not be present in normal indoor air.

- ## Odour

The olfactory organ is situated in the upper part of the nasal cavity and consists of olfactory receptor cells, the density of which varies among species. To stimulate the receptor cells, contact must be made between the inhaled volatile substances and the epithelial surfaces. There is no known relation between toxic and olfactory properties.

Odour is affected by the degree of volatility of a substance and its solubility in the mucous layer of the epithelium. This explains why some very volatile substances are only slightly odorous and have a very high threshold perception value.

The odours may be described as aromatic, etheric, alcoholic, phenolic etc. or as pleasant and unpleasant. Perception of odour encompasses grades from just perceivable smell to unbearable smell.

Smell adaptation occurs due to prolonged exposure and is caused by several mechanisms one of which is a temporary exhaustion of the receptive mechanism in the mucous membranes of the olfactory region.

Odour properties can be characterized by detection and/or recognition thresholds, the lowest concentration of a volatile substance that e.g. 50%, 20% or 10% of panel members can detect or recognize. These values heavily depend on the method, instruments and the panel used for odour threshold value determination.

Within the indoor environment the perceived odour will often result from exposures to a mixture of several odourants. Such mixture interactions between odourants take place in the form of neutralisation or masking. On this background it is not possible to predict the resulting odour of a mixture of VOC's.

- ## LCI, Lowest Concentration of Interest

To facilitate the assessment of health effects and comparison of wood and wood-based products we propose use of Lowest Concentration of Interest-values, LCI-values. LCI is the lowest concentration of a particular volatile substance presented in the indoor air that just can be accepted. In principle a higher concentration of a pollutant shall not be accepted as it may have consequences on human health and/or comfort. The LCI concept was introduced in a theoretical European R&D-collaboration (ECA, Report No. 18, 1997). The principle behind the LCI-value is well known from occupational and other environmental regulation, but has not been documented or tested in Indoor Air Quality context. Therefore, LCI-values are used as weighing factors indicating the relative hazard of substances and not as criteria for indoor air quality or as fixed threshold limit values.

LCI is defined as the lowest concentration of a certain substance, which according to our present knowledge - at continued exposure in the indoor air will not cause damaging impact on humans.

The advantage is, however, that use of LCI-values enables a quick comparison of sources as wood and wood-based products and therefore promote a more "healthy" indoor environment.

The limitation of LCI-values is that they very often are derived either from limited toxicological documentation, or from structure-activity relationship, or based on odour threshold values. The LCI-values have to be considered as a first indication of health and/or comfort problems with the indoor air, as there is no uniform background for determination of LCI-values.

The LCI-values can typically be changed, when new knowledge is available. In this report LCI-values are only used as weighting factors.

Exposure

The main exposure route of volatile organic compounds present in the indoor air is inhalation, thus contributing to health effects via airways.

This exposure is defined as the concentration of substances in the breathing zone and is usually expressed as an average concentration over a reference period. VOC's may also enter the body (and may cause harm) by passing through the intact skin or by ingestion. Furthermore, VOC's can cause skin effects following dermal exposure. It is difficult to predict which fraction of the inhaled substances may be absorbed. For this reason, health assessments were based on an assumption that the entire quantity of inhaled substances is absorbed via the lungs.

For the great majority of VOC's available toxicological documentation is based on oral studies. Extrapolation of results from such studies to inhalation scenario is extremely difficult and limited by the extent of data. For this reason, toxicological data obtained from oral exposure were anticipated valid for assessment of exposure by inhalation.

Exposure for pollutants in the indoor air encompasses an indefinite period of time and is very complex. To prevent underestimation of exposure, a worst-case scenario is considered, namely a day and night exposure of especially vulnerable groups of people, e.g. children.

Standard Room

Concentrations of substances in the indoor air can be calculated from the concentrations of the substances measured by chamber testing using a standard room approach. A standard room commonly used for general calculations of indoor air concentrations has a relatively large surface area compared to the room volume (DS/INF 90, 1994). E.g. amount a flooring material to 7 m^2 and a material covering all surfaces of a room to 38 m^2 in a room volume of 17.4 m^3, corresponding to calculated standard room concentrations for an area-interval of 7 - 38 m^2. A part of a piece of furniture (e.g. edges of a table) might amount to as little as 0.1 m^2. When the conditions in the test chamber and in a room are similar, the calculated concentration can be used without correction due to climate parameters.

Dose-Response

An important step towards determination of the LCI-value is characterization of a relationship between dose (concentration) and response (toxic effect). Hazard identification is the process of gathering and assessing all available data, which shall reveal the adverse biological effects as a result of inherent properties of a substance. A variety of toxicological effects, e.g. cancer, birth defects or sensitization may be evident.

The necessary information is provided from the databases TOXLINE, RTECS, ECDIN, NIOSHtic and Medline. In connection with dose-response relationship the word dose has a defined meaning: the concentration of a substance in the air inhaled. Concentration-effect relationship is usually very difficult ascertainable from most older toxicological studies. To prevent underlying of on-effect level several safety factors were applied to the toxicological data.

Structure - Activity Relation

When available toxicological data do not give toxicological endpoints, or when only limited data exists, the use of structure - activity relationship may be considered of value indicating a potential hazard. Quantitative structure - activity relationship, particularly useful for determination of threshold limit values for unknown chemicals is still in progress. Consideration of structure - activity relationships have supported determination of some LCI-values.

Irritation and Odour Thresholds

Some of the effects, to which attention at least must be paid in relation to indoor air, are irritation and odour. Determination of sensory effects heavily depends on subjects and method used. A great diversity is also found between the odour threshold values published.

When no relevant toxicological effects were known, LCI-values were based on odour threshold published in the databank VOCBASE, National Institute of Occupational Health, 1996.

C-Values

In connection with industrial air pollution guidelines by the Danish Environmental Protection Agency has assessed several VOC's. For these substances the maximum concentration allowed in the air as emission was defined by the authorities and termed as a contribution value, C-value, (Ministry of the Environment, 1992).

These values are determined on the basis of the Agency's principles for determination of threshold limit values for chemical substances and used for the calculations of the height of chimneys. Although it is stipulated that the C-value does not supply emission values (air quality standards) their establishment follow the common principles for determination threshold limit values and therefore the C-values have been considered and were adopted as LCI-values, where possible.

The Danish Environmental Protection Agency has carried out a toxicological evaluation of the chemical substances in air pollution, in drinking water and in soil pollution. The toxicological principles used by the Danish Environmental Protection Agency were in accordance with the principles used in this investigation in the cases where the Danish Environmental Protection Agency's evaluation was based on the effects of a substance and not based on odour. In the cases, in which the Danish Environmental Protection Agency had a toxicological evaluation of a chemical substance with a fixed C-value based on the effect of the substance, this was used. If the LCI-values differs from this, it has been commented in the individual substance evaluation in Appendix 7.

Sum

For all determined VOC's from a particular wood or wood-based material standard room concentrations are calculated at day 3-4, 9-11 and 27-28 based on test chamber concentrations determined by chemical analyses. The standard room concentration were divided by the determined LCI-values and fractions for each substance were obtained. All the fractions were added for effects of the same kind and a sum (S-value) was obtained for each wood and wood-based material according to the formula:

$$\sum_{i=1}^{x} \frac{C_{si}}{C_{LCI_i}}$$

The sum indicates the severity of health and/or sensory effect of the emission from a particular material. The lower sum value the more acceptable the wood and wood-based material. This sum, however, is expected to be below one, for mixture of VOC's in the working environment and for VOC's emitted from industrial installations to the external environment.

Evaluation of Emissions

Evaluations of health- and comfort effects of emissions from wood and wood-based materials and products are based on toxicological principles and literature data. The toxicological principles used are given in detail in chapter 4.

Evaluation Procedure

The procedure of evaluating the emissions from wood and wood-based materials included:

- Theoretical considerations regarding substances expected to be emitted including health hazardous substances
- Qualitative chemical analysis of the emissions (headspace-analysis)
- Quantitative chemical analysis of all individual substances (test chamber measurements)
- Calculation of concentrations in the indoor environment
- Evaluation of individual substances identified by the quantitative measurements
- Evaluation of the impact from wood and wood-based materials
    - An addition of concentrations in the indoor air divided by the "lowest concentration of interest in the indoor air", S-value
    - An indoor-relevant time-value based on odour and irritation thres-holds

Basis for Calculations

For evaluation of emissions from wood and wood-based materials concentrations are used, which have been converted into indoor air concentrations for individual substances in the emissions by standard room considerations according to clause 3.2.

All Chemicals List/ Project Specific List

A list of substances, which in principle could be expected to be emitted from wood and wood-based materials: "All Chemicals List" and a list of substances quantified by the emission chamber measurements carried out: "Project Specific List" appears from Appendix 5.

Evaluation of Individual Substances

All 84 individual substances quantified by emission chamber measurements were evaluated cf. Appendix 7.

An outline in principle for evaluation of emissions appears from chapter 4, Figure 4.1. By evaluation of the individual substances found in the emissions by chamber measurements, the considerations have, when possible, comprised the following:

- Toxicological effects (carcinogenic, immunologic, reprotoxic or neurotoxic effects)
- Irritation (inflammatory and sensory irritation)
- Other health effects
- Odour
- Amount of unknown substances

Also odour threshold values were included in the considerations. Odour thresholds and irritation thresholds were included in the calculation of the indoor-relevant time-value, cf. clause 5.2 and Appendix 4.

Evaluation of substances without any relevant toxicological information were, when possible, based on the assumption that the toxicological properties corresponded to a known and chemically analogue substance. If there were not sufficient data available for analogue considerations, it was impossible to evaluate the substance, and it was thus considered toxicologically unknown.

• "Lowest Concentration of Interest"

The term Lowest Concentration of Interest in the indoor air, LCI, that first was introduced in a European, theoretical R&D co-operation (ECA, Report No. 18, 1997) is described in detail in clause 4.4.

The LCI-value was laid down on basis of the effect, which was shown of the lowest concentration.

For most of the chemical substances in the emissions from the investigated wood and wood-based materials irritation was the effect, which was decisive for the determination of the LCI-values. More serious effects occurred for most of the substances at concentrations magnitudes higher than irritation.

In more cases the LCI-values have been fixed by analogue considerations. In cases, in which data on substances were missing, and in which it was considered that the most essential effect was irritation, the LCI-values were based on "RD 50-values". "RD 50-values" have been determined based on decrease of the respiratory frequency of mice.

The values have been converted into exposure in the indoor air by introduction of a safety factor of 10 in order to protect sensitive social groups and by taking exposure for 24 hours a day and 7 days a week into consideration (Nielsen, G.D., 1997).

Determination of LCI-values were difficult due to lack of toxicological data for most of the emitted substances in the relatively low concentrations, in which the substances were present in the indoor climate.
The S-value is calculated by adding the contribution of the indoor-relevant concentration divided by the LCI-value for all individual substances of the emissions for effects of the same kind:

$$S = \sum C_i / LCI_i = \frac{C_1}{LCI_1} + \frac{C_2}{LCI_2} + \ldots\ldots + \frac{C_n}{LCI_n}$$, hereafter called S

In principle each effect should be summarised individually, and the addition consideration can only be carried out for additive effects such as irritation.

The advantage of using LCI-values (in the shape of S-values) is that they allow a quick comparison of wood and wood-based materials and thus resulting in identification of more indoor air friendly products.

The most extensive limitation is that LCI-values very often are ascribed to limited toxicological documentation, and that no uniform background for determination of LCI-values exist. LCI-values should therefore only be considered by comparison of materials with a uniform emission profile and as a first indication of health and/or comfort problems in the indoor air.
A non-uniform background for determination of LCI-values may entail that the evaluation of individual substances will be more or less restrictive. In the present report the evaluation of formaldehyde follows the coming WHO-recommendation and is relatively less restrictively determined than the other individual substances cf. clause 5.3.1.

- ## Indoor-Relevant Time-Values

The indoor-relevant time-value for a material or a product is the time, it takes the slowest emitting individual substance of the emission with the lowest odour or irritation threshold to reach down on half of this threshold value. All concentrations and thresholds have been converted into indoor-relevant concentrations by using standard room considerations.

Concerning irritation it is assumed that the impact from more substances is larger than the irritative contribution of the individual substance, accordingly, in case of more substance with irritative effect the requirement to the sum of irritative substances in the emission: $\Sigma C_i/CL_i$ in which CL is the acceptable concentration in the indoor air calculated as half the irritation threshold. Like the sum calculations regarding LCI the sum of irritative substances is determined by adding the contribution of the indoor-relevant concentration divided by the CL-value for all individual substances with irritative effect in the emission.

The indoor-relevant time-value is usually based on both chemical emission measurement as well as sensory determination of the air quality. (In the present project the time-value alone is based on chemical measurement, and sensory evaluation has only been carried out directory for 3 of the 23 investigated materials, cf. clauses 3.1 and 3.1.2).

The indoor-relevant time-value in days is a direct measure of the time it takes from a product is installed till the emissions of individual substances no longer are expected to cause odour or risk of irritation in eyes, nose or upper respiratory passage.

Application of indoor-relevant time-values gives like LCI-values the possibility of an indoor-related comparison of wood and wood-based materials and to identify the most indoor air friendly products.

The most essential limitations are that threshold values for odour and irritation have only been found for a limited number of substances (the database: VOCBASE; National Inst. of Occupational Health, 1996, comprising values for approx. 800 substances), and that there are essential deviations between the published odour threshold values. Besides, the threshold values will typically be changed when new knowledge is obtained.

Odour does not imply that the emission causes health effects, nor does no-odour imply that the emission does not cause health effects.

Presently, the indoor-relevant time-value concept, which was developed by the Danish Building Research Institute and the National Institute of Occupational Health, is based on comparison of indoor-relevant concentrations with odour and irritation threshold values. It is thus based on the effects irritation and odour, which by experience in all circumstances are the relevant effects to take into consideration by evaluation of the indoor air
impacts from materials. The time-value concept could, however, immediately be extended by further effects such as e.g. carcinogenic and immunologic effects, when generally accepted indoor-air related thresholds for these health effects are available.

Indoor-relevant time-values are the basis of the Indoor Climate Labelling of building products and other products when used in buildings (Danish
Society of Indoor Climate, Standard Test Method, 1994), (Wolkoff, P. and Nielsen, P.A., 1996).

- ## Results

Results of the evaluations of emissions are given as individual substance evaluations in clause 5.3.1 and as evaluations of the investigated wood and wood-based materials in clause 5.3.2. Evaluations in detail of the individual substances quantified by emission chamber measurements are stated in Appendix 7.

Individual Emissions

- ### Evaluation of Individual Substance Emissions

By evaluation of the 84 individual substances quantified by emission chamber measurements it was only very few of the substances in the emissions from the investigated wood and wood-based materials, which taken the relatively low indoor-relevant concentrations into consideration, were found to have carcinogenic, reprotoxic, immunologic or neurotoxic effects cf. the following text and Appendix 7.

Formaldehyde

The two effects of formaldehyde: irritation and cancer can have a decisive importance in relation to the total evaluation of the emissions. Evaluation of formaldehyde was in this project based on recommendations from the World Health Organization , WHO's, re-evaluation in 1996, in which it was concluded that the lowest concentration, which have been linked to nose and throat irritation in humans by short term exposure, is 0.1 mg/m³, even though some individual persons would perceive presence of formaldehyde at lower concentrations.

As the "Air quality guideline"-value is more than one magnitude lower than the threshold value, which is expected to cause cytotoxic damages in the nose mucous membrane, this value (0.1 mg/m³) represents an exposure level, at which the risk of cancer in the respiratory passage in humans is negligible.(Mølhave, L., April 1997) and (Larsen, J.C., April 1997).

The international cancer research institute, IARC, has evaluated the carcinogenic effect of formaldehyde and classified it in group 2A due to safe evidence for animals and limited for humans. Cytotoxicity is believed to play an essential role in the carcinogenic effect.

It is therefore probable that the concentration at lifelong exposure should be beneath 0.1 mg/m³ as a yearly average to take the carcinogenic effect adequately into account. Furthermore, it can be expected that especially sensitive persons will react with mucous membrane irritation at concentrations below 0.1 mg/m³.

Acetaldehyde

Acetaldehyde has as is the case for formaldehyde two effects: Irritation and cancer. Mucous membrane irritation occurs at considerably higher concentrations for acetaldehyde than for formaldehyde. Risk of cancer is less documented for acetaldehyde cf. Appendix 7.

Acrolein

The unsaturated aldehyde: acrolein was taken the relatively low concentrations into account evaluated to have irritative and immunologic effect.

2-Ethoxy-Ethyl-Acetate

The glycol ester: 2-ethoxy-ethyl-acetate was evaluated to have reprotoxic effect.

4 Toxicologically Unknown Substances

4 substances: 2,2'azobis(isobutylnitrile); 2.9-decandione; butyrolactone and pentyloxiran had to be described as unknown due to lacking data and lacking possibility of analogue considerations.

- ## Evaluation of Emissions from Wood, Wood-Based Materials and Products

The investigated materials have been evaluated by determination of S-value based on LCI-values and by indoor-relevant time-values based on odour and irritation threshold values. Evaluations of the investigated solid wood species and coated wood-based materials appear from surveys in Table 5.1. and Table 5.2. The stated evaluations comprise determination of S-value as well as indoor-relevant time-value based on odour and irritation threshold values by a material load of 1 m^2 surface per m^3 room air.

A total evaluation of all 23 investigated wood and wood-based materials for a broader interval of material load appears from Appendix 8. The material loads vary from 0.4 m^2/m^3 corresponding to e.g. flooring or table and 6 chairs to 2.2 m^2/m^3 corresponding to e.g. ceiling, flooring, and all 4 walls. It should be noted that the stated wide interval for material surface in relation to room volume for a number of the investigated wood and wood-based materials differs from commonly used loads of these materials.

S-Value in Relation to Time-Values

In case of materials not causing emissions with carcinogenic substances, allergens, neurotoxic or reprotoxic substances, the used procedure and the evaluations and the results of the evaluations were similar both according to the S-value and to the indoor-relevant time-value based on the sum of the irritative impact.

The time-values based on odour thresholds resulted, however, in longer time-values than time-values based on irritation thresholds - for all decisive individual substances apart from formaldehyde - and became therefore in most cases decisive for the indoor-relevant time-value.

By comparison between the different products and their emissions it should be noted that the LCI-value can be determined more or less restrictively. The LCI-value of formaldehyde is in this material e.g. determined less restrictively than the other LCI-values.

From Tables 5.1 and 5.2 it appears that S-values at the 27/28 days measurement vary from 0.08 for solid ash and beech to 43.7 for solid pine of mainly heartwood at a material load of 1 m^2 surface area per m^3 room volume. The indoor-relevant time-value based on odour varies at a material load of 1 m^2 surface area per m^3 room air from <3 days for UV-curing lacquer on beech veneered particleboard to >28 days for the other surface treated wood-based materials, pine and most of the wood-based panels.

A survey of indoor-relevant time-values for all the investigated wood and wood-based materials including information of the decisive individual substance and effect appears from Table 5.3.

Time-values are stated for the two usual material loads for wood and wood-based materials: Material forming part as a door surface or table top (2 m^2) corresponding to a load of 0.12 m^2/m^3 and material forming part as flooring or table and 6 chairs (7 m^2) corresponding to a load of 0.4 m^2/m^3. Lower S-value and time-value state relatively lower emission of substances with given effect.

Proposal for Classification

Tables 5.1 and 5.2 contain additionally a proposal for classification of wood and wood-based materials in 3 classes: Low-emitting, medium-emitting and high-emitting, classifying ash, beech, oak and spruce as low/medium-emitting and pine as high-emitting. Among the investigated coatings the UV-curing lacquer on beech veneered particleboard was considered as low-emitting, the acid-curing lacquer on beech veneered particleboard as high-emitting, while the other tested lacquers on beech veneered particleboard and the investigated oils on solid beech were considered medium-emitting.

Model for Evaluation

As it appears from the survey examples the proposed model for evaluation based on S-value and indoor-relevant time-values differentiate the emissions of the investigated materials. The project results show that the proposed evaluation model can be used as a joint basis for evaluations of the relative health and comfort impact of wood-based materials and products.

The concept for evaluation based on indoor-relevant time-value can be used independently without using LCI or S-values, if emissions containing carcinogenic substances, allergens, neurotoxic or reprotoxic substances is out of the question. This is seen in the light that comfort at present is not included in the evaluation based on S-value. Furthermore, odour and irritation thresholds are available for evaluation of indoor-relevant time-value for approx. 800 chemical substances in a databank.

It should, however, be noted that substances exist which are carcinogenic, immunologic, neurotoxic or reprotoxic at concentration levels below the irritative effect.

Table 5.1
Classification of investigated surface treated wood-based materials - based on S-value after 27/28 days and an indoor-relevant time-value at a material load of 1 m^2/m^3.

Classification of wood-based materials/ products	**Surface treatment on wood**	**S-value [-]**	**Indoor-relevant time-value [days]**
Low-emitting materials/ products	UV-curing lacquer on beech veneered particleboard	0.3	<3
Medium-emitting materials/ products	Urethane alkyd and linseed oil-based oil on solid beech Natural resin and linseed oil-based oil on solid beech Nitrocellulose lacquer on beech veneered particleboard Water-borne lacquer on beech veneered particleboard Polyurethane lacquer on beech veneered particleboard	0.6-4.0	>28
High-emitting materials/ products	Acid-curing lacquer on beech veneered particleboard	9.3	>28

¤ On basis of the indoor-relevant time-value solely the acid-curing lacquer is at level with lacquers in the category medium-emitting

Table 5.2
Classification of investigated solid wood based on S-value after 27/28 days and indoor-relevant time-value at a material load of 1 m^2/m^3.

Classification of wood-based materials/ products	**Solid wood**	**S-value [-]**	**Indoor-relevant time-value [days]**
Low/medium-emitting materials/products	Ash Beech Oak Spruce	0.08-0.3	23-24
High-emitting materials/ products	Pine North Finnish heart- and sapwood South Swedish, carene-rich heart- and sapwood	8.9-43.7	>28

Table 5.3
Indoor-relevant time-value for wood and wood-based materials at a material load of 0.12 m²/m³ and 0.4 m²/m³ respectively

Wood and wood-based materials/products	Decisive effect	Decisive individual substance	Time-value at a material load of 0.12 m²/m³ [days]	Time-value at a material load of 0.4 m²/m³ [days]
Ash	Odour	Propanal	<4	14
Oak	Odour		<4	<4
Beech	Odour	Propanal	<4	14
Spruce	Odour	Propanal	<4	12
Pine, North Finnish heartwood	Odour	α-Pinene	12	>28
Pine, North Finnish sapwood	Odour	Hexanal	<3	>28
Pine, South Swedish heartwood	Odour	Hexanal	18	>28
Pine, South Swedish sapwood	Odour	Hexanal	>28	>28
Particleboard, Pine/Spruce, MUPF-glue	Odour	Octanal	<3	10<t<28
Particleboard, Pine/Spruce, UF-glue	Irritation	Formaldehyde	6	>28 #
Particleboard, Pine/Spruce, PU-glue	Odour	Hexanal	9	>28
Plywood, birch, phenolic-glue	Odour	Hexanal	<4	>27
MDF, coniferous wood UF-glue	Irritation	Formaldehyde	<3	>28
OSB, coniferous wood, phenolic-glue	Odour	Octanal	>28	>28
Beech veneered particleboard, veneering with PVAc-glue	Odour	Pentanal	<4	11
Beech veneered particleboard, veneering with UF-glue	Irritation	Formaldehyde	7	>28
Urethane alkyd and linseed oil based oil on beech	Odour	Propanal	>27	>28
Natural resin and linseed oil based oil on beech	Odour	Octanal and propanal	20	>28
Nitrocellulose lacquer on beech veneered particleboard	Odour	Hexanal	11	>28
UV-curing lacquer on beech veneered particleboard			<3	<3
Acid-curing lacquer on beech veneered particleboard	Odour/ Irritation	1-Butanol, hexanal and formaldehyde	>28	>28
Water-borne lacquer on beech veneered particleboard	Odour	2-(2-Buthoxy-ethoxy-ethanol)	>28	>28
Polyurethane lacquer on beech veneered particleboard	Odour	1-Methoxy-2-propylacetat	6	>28

The concentration is constant during the 28 days

It should, furthermore, be noted that the absolute S-values, LCI-values and odour and irritation thresholds can always be questioned as well as the values could change when new knowledge is available. In consequence of this no exact limits for classification can be given on basis of the present relatively limited experimental basis nor can it be closer laid down where and when modification or substitution could be required.

Reduction of Hazardous Effects Modification/substitution of materials and products should in principle be carried out, when the emission contains toxicologically unknown substances.
Materials and products should as far as possible not contain chemical substances with carcinogenic, reprotoxic nor immunologic properties. Should this be the case these substances should be exchanged by substances or materials, which are less hazardous or at least modify the material, so that the content is minimised as much as possible.

Selection of Material In cases where the indoor air is given a high priority, it should be recommended to choose lower-emitting materials and products in order this way to reduce the emissions from materials and products and to obtain a larger probability of reducing effects and possible health effects in consequence of the emission from these materials and products.

Choosing lower emitting materials and products can be carried out by choosing materials and products with a low S-value and a low indoor-relevant time-value.

Evaluation of Product Modification/Substitution

In cases where the indoor air is given a high priority, it should be recommended to choose lower-emitting materials and products in order to reduce the emissions from materials and products and to obtain a larger probability of reducing effects and possible health effects in consequence of the emission from these materials and products.

If lower-emitting materials and products are aimed at, the modification/sub-stitution of materials and products can be carried out according to the evaluation model shown in principle in Figure 4.1. Modification/substitution is recommended, when the emission contains toxicologically unknown, chemical substances and chemical substances with carcinogenic, reprotoxic or immunologic effects.

The modification of materials and products should be considered for materials and products with a relatively high S-value and a high indoor-relevant time-value.

The following substitution considerations, which only constitutes a minor part of this project, comprise only other effects and aspects (in excess of the significance for the air quality), to the extent that these are generally known.

Examples of potential modifications and substitutions were considered in a broad environmental perspective including the good indoor environment and taking the technical performance hereunder functional class and economical aspects into account. The examples imply usual application of the wood-based materials and products

- ### Wood and Wood-Based Products in a Wide Environmental Perspective

Renewable Resource The afforestation has a major positive environmental effect.

Wood is a renewable resource, as long as continuous transplanting of new trees corresponds to the felling. The duty to preserve the forests implies that the forest after the felling should be re-established by transplanting and tending in order to create sustainable forestry. (Ministry of the Environment and Energy, 1995).

Combustion Waste wood can in excess of being used in wood-based panels a.o. be used as fuel and return approx. 30-50% of the total energy content. Wood treated with chemicals can not in all cases be burned under simple conditions, as it may lead to emissions of environmentally hazardous substances. It could, however, be burned under controlled conditions at a diffuse disposal plant.

During the combustion more energy is released than was used for manufacture of most "simple" wood products e.g. glulam beams. The solid residues, ashes, will contain different minerals and possibly residue of chemicals and possibly heavy metals, which were used by manufacture of the product. Such ashes should be deposited in a controlled way. The ashes from pure wood could be used in the agriculture or the forestry. (Evald, A., 1993).

Deposit By deposit the wood is deteriorating by the presence of adequate oxygen to carbon dioxide and water. The different additives applied to the wood, will be deteriorated at different rates depending on the biological accessibility. (Evald, A., 1993).

Working Environment The largest safety and health problems by processing wood is dust, noise and ergonomics. The extent of a wood dust problem is depending on the size of the particles and wood species. Exposure to wood dust can lead to serious occupational related diseases (Jensen, L.D., 1987). In Denmark there is a threshold limit value for total wood dust in the work environment, according to the threshold limit value list of the Danish Working Environment Service. The dust causes besides mechanical irritation of eyes, mucous membranes or the skin, chemical irritation and sensitizing. Asthma and dermatitis are the most frequent work environmental problem of the wood industry. The workers of the furniture industry bear a larger risk of nasal tumours. Different types of cancer are continuous to be caused by exposure to wood dust. (WHO, 1987). There can be several reasons for this carcinogenic reaction, such as continued mechanical mucous irritation, influence from fungi, wood borne fungi or metabolic products from these or chemical substances used by manufacture of wood (Danish Environmental Protection Agency, 1988).

Indoor Environment Seen in a broad environmental perspective the documentation on materials and products manufactured for interior use generally should include indoor air considerations and other aspects of essential significance for the product in the indoor air hereunder e.g. environmental impact in connection with cleaning and maintenance. For building products and interior furnishings the the actual lifetimes is often essential to determine whether the products are environmentally friendly or not.

• Indoor Environment Aspects

Indoor environment is a combination of all climatic factors influencing the stay and comfort of humans indoors.

The term indoor environment means mainly (SBI, 1995, modified):

- Balance between fresh-air intake and source strength
- Thermal conditions described by room temperature, air velocity, relative humidity, air exchange, draft etc.
- The air quality is described by the content of pollution such as dust, gases and vapours and thereby connected odours
- Microbiological pollution
- Static electricity described by charging of persons
- Light conditions described by light strength, colour, contrasts and reflexes
- Acoustics described by sound intensity and frequency distribution
- Ionizing radiation described by radon concentration

In principle a good indoor environment should be aimed at, as we spend the main part of our lives indoors. Some people spend all their time indoors.

Gases and Vapours Exposure to gases and vapours can lead to a number of symptoms and diseases. The most frequent symptoms are mucous membrane irritation in eyes, nose and throat as well as dermatitis. Furthermore, fatigue , indisposition, headache and sense of heaviness in the head. Such symptoms often do not point at a specific disease, but could be ascribed to bad indoor environment. When a large number of persons show the same symptoms it is described the "sick building syndrome". It should be noted that some persons are more sensitive than other towards e.g. air pollution.

Building materials, furniture and interior furnishings can have a large influence on the indoor air, e.g. because many different organic substances are emitted to the indoor air.

A number of examples exist in which materials hereunder former generations of particleboards and lacquered wood surfaces caused indoor air problems. Emission of formaldehyde from particleboards glued with urea-formaldehyde glue is among the most notorious. Irritation in eyes, headache and pricking odour are symptoms perceived by exposure to formaldehyde over a certain concentration. For UV-lacquers emission of certain photoinitiators and their deterioration products are known to a have an unpleasant odour (Salthammer, T., 1996).

• Evaluation Examples for Wood-Based Building Materials, Furniture and Interior Furnishings

The examples stated below are based on the wood and wood-based materials, which were investigated by emission chamber measurement. As the investigated materials can not be considered as representatives of all variables of the investigated material types, further commonly known material experiences have been included in the modification and substitution proposals.

The considerations concerning modification and substitution have been carried out without regard to concrete conditions and implies ideal conditions as well as "everything else alike" considerations. As a part of more detailed modification and substitution considerations actual conditions should be taken into account, which might influence technical, environmental or economical aspects.

The following examples comprise comparison of variables of typical furniture products, types of interior furnishings and building materials. The product examples, which have been made with a theme for inspiration by modification/substitution considerations, primarily illustrate conditions of importance for the impact of the materials on the indoor environment. Further conditions could be included, where these have a decisive influence on the modification/substitution, and their consequences have been described and generally accepted. Description of a product in relation to a given application as well as general and specific comments elaborate the considerations.

Examples of conditions, which have been considered in connection with modification/substitution are given in the following:

Indoor Environment

- Function
    - Life time
    - Assembly, installation, application
    - Performance properties hereunder, use, cleaning and maintenance
    - Possible limitations in consequence of the modification/substitution

- Indoor Air
    - Comfort hereunder sensory irritation, odour, "good" indoor climate and perceived indoor climate
    - Health

Work Environment

- Health and safety consequences e.g. in connection with application and handling
- Possible limitations in consequence of the modification/substitution

Exterior Environment

- Possible limitations in consequence of the modification/substitution

Economy

- Limitations in consequence of chosen materials e.g. type of glue
- Evaluation of the possibility of adjusting the existing equipment
- Necessary equipment investments
- Adjusting and running-in

The economic considerations have been made primarily in relation to the necessary technical basis for modification/substitution.

It should be stressed that the stated modifications/substitutions are only examples. The evaluation examples are thus not synonymous with necessity of implementation of the modification/substitution.

Model for Evaluation In the efforts to increase the clearness a proposal for a model for evaluation has furthermore been given. The proposed model makes an evaluation of the original product compared with the modification/substitution possible.

The evaluation model in principle is illustrated for the evaluation example "floor - lacquers and oils for treatment of wood floors" what regards indoor environment (function and indoor air).

Evaluation of relevant properties is based on the following classes:

○ Among the best material

∢ Among acceptable materials

● Among the poorest materials/least acceptable materials

Such a schematic version implies in the nature of the case risks of generalization and simplification of the problems in relation to practice.

Product Examples:

Floor Wood floor treated with lacquer and oil.
Theme: "Different materials"

Wood floors treated with water-borne lacquer, polyurethane lacquer, acid-curing lacquer or oil treatment (oil/alkyd basis) or pre-coated floor with UV-curing lacquer

Wardrobe — Wardrobe of veneered particleboard with transparent lacquer
Theme: "formaldehyde emission"
Wardrobes of veneered urea-formaldehyde glued particleboards coated with acid-curing lacquer or of veneered polyurethane glued particleboards with UV-curing lacquer. Wardrobes in a bedroom can e.g. have a wardrobe front area of 0.2 m^2/m^3 and a surface area of other surfaces in contact with the indoor air of approx. 0.8 m^2/m^3.

Coffee Table — Coffee table of uncoated solid wood and veneered particleboard with transparent lacquer respectively.
Theme: "Low material load"
Coffee tables of solid ash, beech, oak or pine or veneered ureaformaldehyde glued particleboard coated with water-borne lacquer, acid-curing lacquer or polyurethane lacquer. The surface of the coffee table constitutes usually a relatively small part of the surface area in the standard room, e.g. 0.12 m^2/m^3.

Bookcase system — Bookcase system of uncoated solid wood and veneered particleboard coated with transparent lacquer.
Theme: "High material load"
Bookcase system of solid beech, oak or pine and veneered particleboard coated with water-borne lacquer, nitrocellulose lacquer or UV-curing lacquer. The surface of the bookcase system constitutes usually a relatively large part of the surface area of the standard room often more than 2.2 m^2/m^3.

Office Table — Office table of veneered particleboard with different types of transparent lacquer.
Theme: "Material combinations"
Office tables of urea-formaldehyde-glued particleboard coated with polyurethane lacquer, acid-curing lacquer, water-borne lacquer or UV-curing lacquer.

Cottage — Cottage of pine.
Theme: "Deviation from common use"
A cottage covered with uncoated pine on floor, ceiling and all 4 walls.

- **Floor Example**

Wood floor coated with lacquer and oil.

Theme

Different materials.

Product Description

Wood floors coated with water-borne lacquer, polyurethane lacquer, acid-curing lacquer or oil treatment (oil/alkyd basis) or pre-coated floor with UV-curing lacquer.

Indoor Environment

Function — When choosing a flooring it is essential to include the application and thereby the performance class, as the choice should be adjusted to the need hereunder the technical properties, cleaning and maintenance.

Performance wise water-borne lacquer, 2-component polyurethane lacquer and 1- or 2-component acid-curing lacquer as well as pre-coated UV-curing lacquer are at the same level. Polyurethane, acid-curing or pre-coated UV-curing lacquer with an extra coat is usually recommended when a larger resistance to wear is required.

For the oil treatments the performance properties vary dependent on type of oil (and "generation" of oil). In practice the term "oils" is used for products spanning from wax treatments (with non-drying binder) to oils and alkyds to traditional lacquer treatments. Division of products with drying binders in oils and alkyds are used, as these can have very different film formation resulting in different properties.

Generally, oil treatments give a poorer pore density, poorer resistance towards liquids and poorer resistance to wear than alkyds. Oil consumption depends furthermore on type of oil, on e.g. walking load on the floor (and the resulting need for maintenance and renovation of the oil treatment) and on the oil penetration of the wood floor, which again depends on e.g. wood species, moisture content and age.

The maintenance frequency is larger for oils and lacquers. A maintenance interval between the oil treatments varies typically between 2-12 months, while re-coating typically is performed with intervals of 3-15 years. Aesthetic regards are often significant for choice of oil treatments in stead of lacquers.

Indoor Air For the oil treatments the indoor air properties vary dependent on oil type (and "generation" of oil) etc. Oils and alkyds with drying binder contain usually aliphatic or aromatic hydrocarbons, which can be more or less volatile. Heavily evaporating solvents influence everything else alike the indoor air in a relatively larger time perspective than the more volatile.

From the oils emission is primary seen, which can be traced back to volatile organic compounds in the oils and alkyds, which are formed during drying. From the investigated acid-curing lacquer, especially, a considerable formaldehyde emission is seen. In the emission from the investigated UV-curing lacquer and polyurethane lacquer no monomers nor unreacted nor partly reacted pre-polymers have been identified. Isocyanates react fast with the humidity of the air. From UV-lacquers certain photo initiators and their deterioration products are known to have an unpleasant odour.

Other conditions of essential importance for the emission comprise: Oil absorption in the wood floor and need for re-treatment. The higher oil absorption and higher interval between re-treatment (maintenance and renovation) the higher emission.

Nothing suggests that it is essential whether the oil treatments are of a natural origin or synthetically produced. Allergic reactions have been seen in connection with odour substances added to the oils. The odour substances have otherwise no special effect on the product.

Other Matters

Work Environment Safety and health information on lacquers and oils is available in the code number according to the regulations of the Danish Working Environment Service. The digit before the hyphen informs which precautionary measures to take against inhalation of volatile substances. (00-is the lowest and 5- the highest). The digit after the hyphen informs which personal protective equipment to be used to protect against:

- Contact with skin and eyes
- Inhalation of dust
- Consumption of the product

The investigated oils and lacquers have the following code number in a ready-to-use mixture and the following content of organic solvents (%VOC) respectively.

Table 6.1
Lacquers and oils, floors

Type of oil/lacquer	**Code number**	**Percent organic solvents**
Oil on natural resin and linseed-oil basis	0-1/3-1	0/approx. 50
Oil on urethanealkyd and linseed-oil basis	2-1	Approx. 50
Acid-curing lacquer	3-1/5-3	Approx. 60
Polyurethane lacquer	3-3	Approx. 60

UV-curing lacquer	0-5	Approx. 1.5
Water-borne lacquer	00-1/1-3	Approx. 1.5

Special training is required in connection with use of polyurethane lacquers.

By application and handling of UV-curing lacquers there is a risk of immunologic reaction from not totally cured specimens and also a risk of exposure to UV-radiation.

Possible wood or grinding dust is a problem when handling all these materials. Grinding dust from grinding of UV-curing lacquer and especially from the inter-grinding of UV-primer can contain unreacted monomers and other reactive substances.

Exterior Environment Solvents in oils and lacquers are emitted to the environment, in case they have not been regained or burned.

The investigated polyurethane lacquer and acid-curing lacquer contain approx. 60% VOC, oil on urethanealkyd- and linseed-oil basis contains approx. 50% VOC, and the water-borne lacquer and the UV-curing lacquer approx. 1.5% VOC.

Economy Pre-coated floor with UV-curing lacquer has larger requirements to application facilities than the physical-chemical drying lacquers and oils.

If a change to UV-curing lacquer is considered, the costs in connection with change of the coating process and investment in new facilities as well as mea-sures to protect the work environment what regards the safety & health should be taken into account.

Comments

Modification/Substitution The stated oils and lacquers will usually be able to substitute each other.

From material emissions alone the acid-curing lacquer could advantageously be substituted by the far less emitting UV-curing lacquer.

Specific Comments In case additives or accessories have been used for assembly of the floor, which might cause emission e.g. glue for joint of groove and tongue, these should be included in the emission measurement and evaluation.

The investigated acid-curing lacquer is not representative for all acid-curing lacquers, according to experience today acid-curing lacquers are available which cause considerably less emission of formaldehyde.

Renovation of pre-coated floors with UV-curing lacquer requires grinding of the UV-curing lacquer and re-treatment with a new type of lacquer, as UV-curing can not be carried out in buildings. Coating with UV-curing lacquer will usually be limited to 2-dimensional specimens.

Oil treatment with some types of oil a.o. types containing heavy volatile paraffins require use of machines for polishing the wood surface after application of the oil.

In connection with re-coating with polyurethane lacquers it is a prohibited to spray apply outside spray booths and cabins.

Water-borne lacquers are often inapplicable on dark (and dark stained) wood species, as the lacquer changes appearance and appear as a film on the surface.

- **Wardrobe Example**

Wardrobe of veneered particleboard with transparent lacquer.

Theme

Formaldehyde emission.

Product Description

Wardrobes of veneered urea-formaldehyde glued particleboards coated with acid-curing lacquer or of veneered polyurethane glued particleboards coated with UV-curing lacquer.

Indoor Environment

Function When selecting materials it is essential to consider the performance requirements, hereunder how high requirement should be placed to the strength of surface and panel. The materials should furthermore be adjusted to application indoors.

Performance wise wardrobes are made of veneered urea-formaldehyde glued particleboards with acid-curing lacquer and wardrobes of veneered polyurethane glued particleboards with UV-curing lacquer at the same level.

The maintenance frequency and the technical lifetime of the wardrobes are likewise expected at the same level. The technical lifetime of the surfaces typically exceeds the actual lifetimes of the wardrobes.

Indoor Air A wardrobe made of particleboards glued with urea-formaldehyde glue and with front and maybe body coated with acid-curing lacquer is an example of a product which might cause a considerable emission of primary formaldehyde (above threshold value for the indoor air).

From wardrobes coated with UV-curing lacquers volatile substances are seen reflecting the substances in the materials and the deterioration products from these. The emission can vary considerably from one UV-curing system to another. The emission from the UV-curing lacquer investigated in this project is very limited.

Emissions from uncoated wood-based panels are predominantly aldehydes and vary dependent on applied type of glue.

Other conditions of significance for the emission comprise: area of unsealed panel edges and number of open shelf bracket holes in the wood panels. The more open edges and holes the larger emission.

By sealing of the edges, minor structural changes of the wardrobe design e.g. by use of lists and by use of plugs to close the excessive shelf bracket holes, the emission can be reduced considerably.

Larger emissions are to be expected from wardrobes delivered directly from the production and only a few days after coating without total curing of the surface than from wardrobes stored unpacked or in perforated packing in a period before installation at the end-user.

Other Matters

Work Environment Health & safety information on lacquers is available in the code number according to the regulations of the Danish Working Environment Service. The digit before the hyphen informs which precautionary measures to take against inhalation of volatile substances. (00-is the lowest and 5- the highest). The digit after the hyphen informs which personal protective equipment to be used to protect against:

- Contact with skin and eyes
- Inhalation of dust
- Consumption of the product

The investigated lacquers have the following code number in a ready-to-use mixture and the following content of organic solvents (%VOC) respectively.

Table 6.2
Lacquers, wardrobes

Type of lacquer	Code number	Percent organic solvents
Acid-curing lacquer	3-1/5-3	Approx. 60
UV-curing lacquer	0-5	Approx. 1.5

For manufacture of polyurethane glued panels closed production systems are used. (At the moment none such panels are produced in Denmark). In Denmark special training is required in connection with use of polyurethane products. Working environmentally it is not favourable to substitute urea-formaldehyde-glue with polyurethane glue.

By application and handling of UV-curing lacquers there is a risk of immunologic reaction from not totally cured specimens and also a risk of exposure to UV-radiation.

Possible wood or grinding dust is a problem when handling all these materials. Grinding dust of UV-curing lacquer and especially from the grinding of UV-primer may contain unreacted monomers and other reactive substances.

Exterior Environment Solvents in glues and lacquers are emitted to the environment in case they have not been regained or burned.

The investigated acid-curing lacquer contains approx. 60% VOC and the UV-curing lacquer approx. 1.5% VOC.

Economy The polyurethane glued particleboards are more expensive to produce than urea-formaldehyde glued particleboards.

If a change to UV-curing lacquer is considered, the costs in connection with the change of the coating process and investment in new facilities as well as mea-sures to protect the work environment should be taken into account.

Comments

Modification/substitution The stated lacquers and wood-based panels can usually substitute each other, even though polyurethane glued particleboards are more expensive than urea-formaldehyde glued particleboards.

Less hazardous glue types will have less impact on the working environment on the indoor air. At present, however, there are no alternative glues to gluing of wood-based panels keeping the same, good technical properties as urea-formaldehyde glue and polyurethane glue respectively. Notoriously, e.g. polyvinyl acetate-glue, which primary is used for edge gluing and veneering, has a poorer strength and "cracks" in the surface layer due to low creep resistance. Existing wood-based panels have been optimised according to technical pro-
perties. An indoor air adjustment by reduction of emissions from the wood-based panels will result in panels with a relatively lower strength.

From material emissions alone the acid-curing lacquer could advantageously be substituted with the far less emitting UV-curing lacquer.

Specific Comments Wood-based panels are rarely used without surface coating. The investigated acid-curing lacquer is not representative for all acid-curing lacquers, noto-riously, today there are acid-curing lacquers giving cause to essentially lower formaldehyde emission.

Emission of photo initiators and their deterioration products are known to have an unpleasant odour. Non-reacted or partly reacted pre-polymers are known to cause allergy.

Coating with UV-curing lacquer will usually be limited to 2-dimensional specimens.

- **Coffee Table Example**

Coffee table of uncoated solid wood and veneered particleboard with transparent lacquer respectively.

Theme

Low material load.

Product Description

Coffee tables of solid ash, beech, oak or pine or veneered unreacted formaldehyde glued particleboard coated with water-borne lacquer, acid-curing lacquer or polyurethane lacquer respectively.

The surface of a coffee table constitutes a relatively small share of the surface area in the standard room e.g. 0.12 m^2 surface/m^3 room air. Regarding a larger material load please refer to the bookcase system example below.

Indoor Environment

Function When choosing materials it is essential to consider performance requirements corresponding to e.g. the requirements to furniture from Danish Varefakta, The Danish Institute for Informative Labelling, including e.g. the resistance of the surface towards liquids etc. and thereby the cleanability of the surface.

Tables coated with acid-curing lacquer and polyurethane lacquer have gene-rally more resistance towards liquids and heat and are more resistant to dirt than uncoated wood surfaces and tables coated with a water-borne lacquer. Often solid table tops are treated with soap or oil. For applications with a relatively large wear requirements, lacquered surfaces with acid-curing lacquer or polyurethane lacquer are usually recommended.

The technical lifetime of the tables is typically expected to be more than 10 years. Maintenance interval between soap and oil treatments vary typically between 1-4 times yearly, while re-coating with water-borne lacquer is carried out after 1-5 years and re-coating with acid-curing or polyurethane lacquer after 5-15 years.

Aesthetic regards are often of significance for choice of untreated, oil treated or surface leach/soap treatment in stead of lacquer.

Indoor Air Seen from an emission point of view untreated, solid ash, beech, oak and surfaces with UV-curing lacquer are at the same level, while the emissions from uncoated, solid pine are considerably larger, mainly of terpenes.

From the tested veneered particleboard with water-borne acrylic lacquer an emission of alcohols and acetates is seen. From the surface coated with poly-urethane lacquer an emission of hydrocarbons and acetates is seen.

The emission from a coffee table constituting a relatively small surface (0.12 m^2/m^3) and composed of the above materials will usually result in a minor and negligible impact on the indoor air.

Other Matters

Work Environment Health & safety information on lacquers is available in the code number according to the regulations of the Danish Working Environment Service. The digit before the hyphen informs which precautionary measures to take against inhalation of volatile substances. (00-is the lowest and 5- the highest). The digit after the hyphen informs which personal protective equipment to be used to protect against:

- Contact with skin and eyes
- Inhalation of dust
- Consumption of the product

The investigated lacquers have the following code number in a ready-to-use mixture and the following content of organic solvents (%VOC) respectively.

Table 6.3
Lacquers, coffee table

Type of lacquer	Code number	Percent organic solvents
Acid-curing lacquer	3-1/5-3	Approx. 60
Polyurethane lacquer	3-3	Approx. 60
Water-borne lacquer	00-1/1-3	Approx. 1.5

Special training is required in connection with use of polyurethane lacquers.

Possible wood or grinding dust is a problem when handling all these materials.

Exterior Environment Solvents in lacquers are emitted to the environment in case they have not been regained or burned.

The investigated polyurethane and acid-curing lacquer contain approx. 60% VOC and the water-borne lacquer approx. 1.5% VOC.

Economy Tables made of solid wood are relatively more expensive than tables of veneered particleboard, in return solid tables are more durable in consequence of the possibility of re-treatment by means of grinding.

Comments

Modification/Substitution The stated treatments will apart from the water-borne lacquer usually substitute each other.

Specific Comments Furniture of solid wood is traditionally considered more genuine than veneered products.

Notoriously, untreated surfaces and surfaces treated with wax, oil, or soap are performance wise good alternatives to lacquered surfaces under the condition that they only are used on the most exposed surfaces (e.g. upperside of the table top) when these table parts are made of solid wood and that they are maintained properly. Surface leach/soap treatments were not included in this project.
Regarding type of oil and composition reference is made to the previous floor example.

The investigated acid-curing lacquer is not representative for all acid-curing lacquers, today acid-curing lacquers are available, which causes considerably less emission of formaldehyde.

The investigated water-borne lacquer is not representative for all water-borne lacquers, it should be expected that other water-borne lacquers are available emitting less.

Water-borne lacquers are often inapplicable on dark (and dark stained) wood species, as the lacquer changes appearance and appear as a film on the surface.

- **Bookcase System Example**

Bookcase systems made of untreated, solid wood and veneered particleboard coated with transparent lacquer respectively.

Theme

High material load.

Product Description

Bookcase systems of solid beech, oak or pine or veneered urea-formaldehyde glued particleboard coated with nitrocellulose lacquer, water-borne lacquer or UV-curing lacquer respectively

The surface of a bookcase system has a relatively large share of the surface area in the standard room e.g. 2.2 m^2 surface/m^3 room air. (The coffee table example comprises application of materials with a smaller material load).

Indoor Environment

Function When selecting materials it is essential to consider performance requirements corresponding to e.g. the requirements to furniture from Danish Varefakta, Danish Institute for Informative Labelling, including e.g. the resistance of the surface.

Performance wise bookcase systems coated with UV-curing lacquer are gene-rally more resistant and are more resistant to wear and dirt than water-borne lacquer, nitrocellulose lacquer and uncoated wood surfaces. For applications with a relatively large requirements to wear lacquered surfaces are usually recommended.

Curing of the water-borne lacquer takes longer time than curing of lacquers with a larger solvent content.

Indoor Air Seen from an emission point of view untreated, solid beech, oak and veneered particleboard coated with UV-curing lacquer are at the same level, while the emissions from uncoated, solid pine are considerably larger, mainly of terpenes. From the tested veneered particleboard with nitrocellulose lacquer and water-borne acrylic lacquer respectively an emission of alcohols and acetates is seen.

The water-borne lacquer results in an emission relatively longer, as the solvents evaporate slower than the solvents in the nitrocellulose lacquer.

The emissions from a bookcase system constituting a relatively large surface area (2.2 m^2/m^3) could influence the indoor air considerably.

Other Matters

Work Environment Health & safety information on lacquers is available in the code number according to the regulations of the Danish Working Environment Service. The digit before the hyphen informs which precautionary measures to take against inhalation of volatile substances. (00-is the lowest and 5- the highest) statement. The digit after the hyphen informs which personal protective equipment to be used to protect against:

- Contact with skin and eyes
- Inhalation of dust
- Consumption of the product

The investigated lacquers have the following code number in a ready-to-use mixture and the following content of organic solvents (%VOC) respectively.

Table 6.4
Lacquers, Bookcase System

Type of lacquer	Code number	Percent organic solvent
Nitrocellulose lacquer	2-1	Approx. 80
UV-curing lacquer	0-5	Approx. 1.5
Water-borne lacquer	00-1/1-3	Approx. 1.5

Regarding UV-curing lacquers there is risk of allergy by application and handling of not totally cured specimens as well as risk of exposure to UV-radiation.

Possible wood or grinding dust is a problem when handling all these materials. Grinding dust from UV-curing lacquer and especially the grinding of UV-primer may contain unreacted monomers and other reactive substances.

Exterior Environment Solvents in lacquers are emitted to the environment in case they have not been regained or burned.

The investigated nitrocellulose lacquer contains approx. 80% VOC. Both the water-borne and the UV-curing lacquer have a low content of organic solvents (approx. 1.5%).

Economy Furniture made of solid wood is relatively more expensive than furniture made of veneered particleboard.

Application of UV-curing lacquer has more extensive requirements to paint equipment than physical drying lacquers.

If a change to UV-curing lacquer is considered, the costs in connection with change of the coating process and investment in new facilities as well as measures to protect the work environment should be taken into account.

Comments

Modification/Substitution The stated treatments will usually substitute each other, even though the environmental impact is considerably larger from nitrocellulose lacquer with a high content of highly volatile solvents.

On basis of material emissions alone untreated pine could advantageously be substituted by less emitting solid beech and oak or veneered particleboard with UV-curing lacquer or water-borne lacquer.

Specific Comments Furniture of solid wood is traditionally considered more genuine than veneered products.

Nitrocellulose lacquer has in the 1990s again found use within the furniture industry as a result of some large-scale purchasers giving "formaldehyde-free" furniture a high priority and thereby departing from acid-curing lacquer. The acid-curing lacquer was substituted by nitrocellulose, when it was chosen not to change the classification according to some technical criterions.

The investigated water-borne lacquer is not representative for all water-borne lacquers, it should be expected that other water-borne lacquers are available emitting less.

Water-borne lacquers are often inapplicable on dark (and dark stained) wood species, as the lacquer changes appearance and appear as a film on the surface.

- **Office Table Example**

Office table made of veneered particleboard coated with different types of transparent lacquer.

Theme

Material combinations

Product Description

Office tables of urea-formaldehyde glued particleboard coated with polyurethane lacquer, acid-curing lacquer, water-borne lacquer or UV-curing lacquer respectively.

Indoor Environment

Function When selecting materials it is essential to consider performance requirements corresponding to e.g. the requirements to furniture from Danish Varefakta, Danish Institute for informative Labelling, including e.g. the resistance of the surface.

Performance wise polyurethane lacquers, acid-curing lacquers and UV-curing lacquer are at the same level. Generally, surfaces coated with water-borne lacquer are not so resistant as other types of lacquered surfaces. For applications with a relatively large requirements to resistance to wear, coating of the above types is recommended, but with an extra coat.

The technical life times and actual life times are generally larger than approx. 10 years.

Indoor Air Emissions from veneered particleboard with UV-curing lacquer is considerably smaller than the emissions from veneered particleboard coated with polyurethane lacquer, acid-curing lacquer and water-borne lacquer respectively.

From the tested veneered particleboard coated with water-borne acrylic lacquer an emission of alcohols and acetates is seen - from the specimen coated with polyurethane lacquer an emission of hydrocarbons and acetates is seen and from the specimen coated with acid-curing lacquer a considerable formaldehyde emission is seen.

Other Matters

Work Environment Health & safety information on lacquers is available in the code number according to the regulations of the Danish Working Environment Service. The digit before the hyphen informs which precautionary measures to take against inhalation of volatile substances. (00-is the lowest and 5- the highest). The digit after the hyphen informs which personal protective equipment to be used to protect against:

- Contact with skin and eyes
- Inhalation of dust
- Consumption of the product

The investigated lacquers have the following code number in a ready-to-use mixture and the following content of organic solvents (%VOC) respectively.

Table 6.5
Lacquers, Office Table

Type of lacquer	Code number	Percent organic solvents
Polyurethane lacquer	3-3	Approx. 60
Acid-curing lacquer	3-1/5-3	Approx. 60
UV-curing lacquer	0-5	Approx. 1.5
Water-borne lacquer	00-1/1-3	Approx. 1.5

Regarding UV-curing lacquers there is risk of allergy by application and handling of not totally cured specimens as well as risk of exposure to UV-radiation.

Possible wood or grinding dust is a problem when handling all these materials. Grinding dust from UV-curing lacquer and especially the grinding of UV-primer may contain unreacted monomers and other reactive substances.

Exterior Environment Solvents in lacquers are emitted to the environment in case they have not been regained or burned.
The investigated polyurethane lacquer and the acid-curing lacquer contain approx. 60% VOC, the water-borne and UV-curing lacquer approx. 1.5% VOC.

Coating of table legs and other parts is generally applied with a low utilisation of the lacquer. For such parts lacquers with a relatively low solvent content should be preferred.

Economy Use of UV-curing lacquer has more extensive requirements to paint equipment than physical drying lacquers.

If a change to UV-curing lacquer is considered, the costs in connection with change of the coating process and investment in new facilities as well as measures to protect the work environment should be taken into account.

Comments

Modification/Substitution The stated lacquers apart from the water-borne lacquer will usually substitute each other.

By application of polyurethane lacquer, acid-curing lacquer or UV-curing lacquer on the table top and water-borne lacquer on the legs (and maybe on other surfaces with less impact on the environment with low lacquer utilisation by application), a technically as well as environmentally appropriate product is obtained.

On basis of material emissions alone the relatively low emitting UV-curing lacquer is preferred.

Specific Comments From UV-lacquers emission of certain photo initiators and their deterioration products are known to have an unpleasant odour. Coating with UV-curing lacquer will generally be limited to 2-dimensional specimens.

The investigated acid-curing lacquer is not representative for all acid-curing lacquers, today acid-curing lacquers are available, which causes considerably less emission of formaldehyde.

The investigated water-borne lacquer is not representative for all water-borne lacquers. It should be expected that other water-borne lacquers are available emitting less.

Water-borne lacquers are often inapplicable on dark (and dark stained) wood species, as the lacquer changes appearance and appear as a film on the surface.

- **Cottage Example**

Cottage of pine.

Theme

Deviation from common use.

Product Description

A cottage with terpene-rich uncoated pine on floors, ceiling and all 4 walls.

Indoor Environment

Function The wall, ceiling and floor surfaces should be treated depending on the use of the cottage.

Indoor Air Emissions from untreated solid pine contain considerable amounts of terpenes, primary α-pinene and 3 carene. The terpenes are the substances to give pine the characteristic odour.

Other properties of essential importance for the emissions comprise a.o. the age, drying and storage conditions of the wood. Fresher wood, shorter time of storage and lower drying temperature will everything else alike result in a larger emission.

In a relatively small cottage with a relatively large wood surface to a minor room air volume the indoor-relevant concentration could be considerable. The concentrations in the indoor air will be further extended, if the cottage for some reason was made relatively airtight resulting in a low air change.

Other Matters

Work Environment Wood and grinding dust is a problem when handling pine.

Exterior Environment The pine has a positive environmental impact cf. clause 6.1.

Economy Isolation of the cottage to save energy could be a nuisance to the indoor air.

Comments

Modification/Substitution In principle it will be possible to limit the emission considerably by choosing a pine variable with a relatively low content of terpenes. The possibility of selecting such a pine quality will, however, in practice require increased attention and efforts at all levels in the chain from sawmill to end-user. This effort could desirably also include process and storage conditions to get the potential emissions emitted that can be a nuisance to the indoor air, but not a problem as emission to the working environment or the exterior environment before the products reach the end-users.

From material emissions alone the extra-ordinarily isolated cottage of uncoated pine for all-year use e.g. permanent habitation or forest kindergartens could advantageously be modified. Modification could consist of coating of the walls, floor, and ceilings with a relatively low emitting lacquer or paint, and/or measures securing a relatively large air exchange.

Specific Comments The pine odour is often considered a pleasant odour.

- **Evaluation Model in Principle**

An evaluation model for relative description of materials of same type has been illustrated in Table 6.6 for the evaluation example "wood floor - coated with different lacquers and oils" what regards indoor environment (performance and indoor air).

Table 6.6
Evaluation Examples in Principles, Wood Floor

Product	Coating	Indoor Environment		Other aspects to be considered
		Function	Indoor Air	
Floor	Wood with water-borne lacquer	∢ / O	∢ / O	
	Wood with 2-comp. polyurethane lacquer	O	∢	Special work environment legislation High VOC-content
	Wood with 2-comp. acid-curing lacquer	O	● / ∢	High VOC-content
	Wood with oil/alkyd	∢	∢	High VOC-content
	Wood pre-coated with UV-lacquer	O	O	

O Among the best materials
∢ Among the acceptable materials
● Among the poorest/least acceptable materials

It should be stressed that the classification is only a general starting point, as it should always be complemented by considerations in relation to actual conditions.

Suggestion for Further Investigations

In the present work a model for evaluation of emission from wood and wood-based materials has been proposed.

There is, however, a need for further theoretical work and to prove the proposed model in practice.

The theoretical work should include an investigation clarify a.o. the assumption concerning the addition of health hazardous effects and limitations of the LCI-values and threshold values used.

Investigations of wood-based materials in a longer time perspective than 28 days and investigations in real scenarios should serve as documentation of the potential impacts on humans and should be carried out as field tests and by emission chamber tests.

Literature

A brief literature list on references used in this report appears from the following.

A literature list comprising a broad section of project related literature primary concerning emissions from materials and products and emissions in buildings appear from Literature List in Appendix 9.

References used by toxicological evaluations appear from Appendix 7.
References concerning indoor-relevant time-values appear from Appendix 4.

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Subject Index