EUROPEAN CONCERTED ACTION

INDOOR AIR QUALITY & ITS IMPACT ON MAN

COST Project 613

Environment and Quality of Life

Report No. 7

Indoor Air Pollution by Formaldehyde in European Countries

Commission of the European Communities
Directorate General for Science, Research and Development
Joint Research Centre - Environment Institute

EUR 13216 EN

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prepared by the

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Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General
Information Market and Innovation
Batiment Jean Monnet
LUXEMBOURG

Cataloguing data can be found at the end of this publication.

In this series the following reports have already been published.

- Report No. 1: Radon in indoor air.
- Report No. 2: Formaldehyde emissions from wood based materials: guideline for the establishment of steady state concentrations in test chambers.
- Report No. 3: Indoor Pollution by NO_2 in European countries.
- Report No. 4: Sick building syndrome - a pratical guide.
- Report No. 5: Project inventory.
- Report No. 6: Strategy for sampling chemical substances in indoor air.

Luxembourg: Office for Publications of the European Communities, 1990

Printed in Italy

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1. INTRODUCTION

Formaldehyde (HCHO) is the simplest and most common aldehyde. At normal ambient temperatures it is a colourless gas with a pungent odour. It boils at - 21°C and melts at - 92°C. Formaldehyde occurs naturally and is an important industrial chemical. In the indoor environment it is introduced mostly as urea-formaldehyde resin and as a component of tobacco smoke. Indoor air pollution by formaldehyde is at the origin of today's scientific interest in the indoor air quality issue.

This summary report is part of the activity of COST project 613 "Indoor Air Quality and its Impact on Man". COST project 613 results from the association of several Non-member countries to a concerted action of the European Communities (EC) in the frame of the COST (=CO-opération européenne dans le domaine de la recherche Scientifique et Technique) agreement. In this report, the Community-COST Concertation Committee (CCCC) has reviewed the present knowledge about formaldehyde as an air pollutant in the non-industrial indoor environment.

The summary aims at collating information made available by national delegates on differences and similarities with respect to sources of and exposures to formaldehyde, as well as to national preventive policies in the European countries participating in COST project 613. Emphasis has been put on the exposure situation and on policies developed to improve this situation. This report does not deal with occupational exposures or with mitigation of air quality problems in existing buildings.

In this report, formaldehyde concentrations in air are reported preferably as weight per volume (mg/m^3 or $\mu g/m^3$; $1\ mg/m^3 = 1{,}000\ \mu g/m^3$). Occasionally, concentrations are also reported in terms of volume per volume (ppm, $1ppm = 1.2\ mg/m^3$).

2. HEALTH EFFECTS

The health effects of formaldehyde have been evaluated by several working groups and panels (1-9). The main acute effects, which have been reported after exposure to gaseous formaldehyde are odour perception and irritation of the eyes, nose and throat. In addition, depending on the concentration, discomfort, lacrimation, sneezing, coughing, nausea and dyspnea have been observed. Generally, symptoms are subject to adaptation.

There is no definite proof that normally occurring formaldehyde concentrations in the air cause respiratory tract sensitization, though aqueous formaldehyde solutions can induce skin sensitization.

Formaldehyde is mutagenic in a multitude of in vitro test systems; however, clear mutagenic effects could not be demonstrated in intact organisms.

There is sufficient evidence of the carcinogenicity of formaldehyde in experimental animals; the evidence of carcinogenicity in humans is inadequate (7). Formaldehyde was classified in Group 2B by the International Agency for Research on Cancer (5). A recent international ad-hoc panel on health effects of formaldehyde concluded that "if a relationship does exist, the excess risk, in absolute terms, must be small" (6).

In 1985, a working group convened by the World Health Organization (WHO) reviewed the literature on the relation between formaldehyde exposure and health effects (7). Based on this work WHO published an air quality guideline for formaldehyde (10). The following conclusions are quoted from this publication.

"HEALTH RISK EVALUATION

Available clinical and epidemiological data indicate that substantial variations in individual responses to formaldehyde exist. ***Table 1*** *lists the ranges of the effects of short-term exposure to formaldehyde.*

Table 1. *Effects of formaldehyde in humans after short-term exposure*

Effect	*Formaldehyde concentration (in mg/m³)*	
	Estimated median	*Reported range*
Odour detection threshold (including repeated exposure)	*0.1*	*0.06-1.2*
Eye irritation threshold	*0.5*	*0.01-1.9*
Throat irritation threshold	*0.6*	*0.1-3.1*
Biting sensation in nose, eye	*3.1*	*2.5-3.7*
Tolerable for 30 minutes (lachrymation)	*5.6*	*5-6.2*
Strong lachrymation, lasting for 1 hour	*17.8*	*12-25*
Danger to life, oedema, inflammation, pneumonia	*37.5*	*37-60*
Death	*125*	*60-125*

The threshold of irritation is reported to be as low as 0.1 mg/m³, but significant increases in symptoms of irritation occur at levels between 0.3 and 1.0 mg/m³ in healthy subjects. At concentrations above 1.2 mg/m³ a progression of symptoms and effects occurs.

Estimating the human carcinogenic risk from formaldehyde on the basis of animal data is a matter of great uncertainty, since the dose-response curve is nonlinear at the higher exposure levels and the situation is even more complex if such nonlinearity continues throughout the entire dose-response curve.

The nonlinear relationship between administered and delivered formaldehyde doses has a substantial impact on quantitative estimates of risk associated with low-level exposures. This was illustrated by comparing estimates of risk obtained using administered dose (airborne formaldehyde concentration) as the measure of exposure with corresponding estimates obtained using delivered dose (the concentration of covalently bound formaldehyde in target tissue DNA). The risk estimates based on delivered dose were approximately 53 times smaller when expressed as the maximum likelihood estimates ***(Table 2)****.*

In spite of the relatively large amount of information gathered on formaldehyde in terms of its genotoxicity, pharmacokinetics and carcinogenicity, differences in assumption can lead to risk estimate differences running into orders of magnitude. Therefore, no risk estimate calculation is indicated because available animal data do not allow a reasonable use of existing models".

Table 2 *) *Multistage model estimates of risk of squamous-cell carcinoma in rats, based on administered dose and delivered dose at selected airborne formaldehyde concentrations*

Airborne concentration (ppm)	*Dose measure*	*Maximum likelihood risk estimate*	*Upper 95% confidence limit*
1.0	*Administered*	251×10^{-6}	16.0×10^{-4}
	Delivered	4.7×10^{-6}	6.2×10^{-4}
0.5	*Administered*	314×10^{-7}	8.1×10^{-4}
	Delivered	5.9×10^{-7}	3.1×10^{-4}
0.1	*Administered*	251×10^{-9}	15.6×10^{-5}
	Delivered	4.7×10^{-9}	6.2×10^{-5}

*) Table 3 in the original WHO text (10)

3. INDOOR AIR QUALITY GUIDELINES

Guideline or threshold values indicate concentrations at or below which, for given exposure durations, a specified population is protected from unacceptable direct or indirect adverse health effects. Guidelines are intended to provide background information and guidance to governments, administrations or the public in making risk management decisions or in setting standards.

Guideline values for formaldehyde established or discussed in European countries are summarized in **Table 3.**

Table 3. Guideline values for formaldehyde established or discussed in European countries and in the U.S.A (as available by February 1990)

Country	Level [mg/m³]	Remarks
Denmark	0.15	guideline value for the general population based on irritation
Federal Republic of Germany	0.12	guideline value for the general population based on irritation
Finland	0.15 0.30	guideline value for buildings constructed after 1981 guideline value for older buildings
France		no general guideline value or standard
Italy	0.12	tentative guideline value

Table 3. (continued) Guideline values established or discussed in European countries and in the U.S.A (as available by February 1990)

Country	Level [mg/m^3]	Remarks
The Netherlands	0.12	standard value, general population and sensitised subjects; irritation & carcinogenicity
Norway	0.06	Recommended guideline value, not yet adopted
Spain	0.48	only for the initial period after installation of UF-foam
Sweden	0.13 0.2	guideline value, wood based panels, 50% rel. humidity guideline value, remedial action level
Switzerland	0.24	guideline value
United Kingdom		no general guideline values or standards
WHO (1987)	< 0.1	30 min average guideline value, general population (10)
USA	0.486	Federal target ambient level

4. SOURCES

Formaldehyde is present in outdoor air due to photooxidation of the abundant naturally occurring constituent methane and of other natural and anthropogenic organic compounds and as a metabolic product from plants. Further anthropogenic contributions to formaldehyde levels in ambient air include automobile exhaust, combustion processes and industrial activities such as the production of resins.

Formaldehyde in the non-industrial indoor environment originates, however, only to a limited extent from outdoor air. Rather, it is released directly into indoor air from various types of sources. Formaldehyde is a constituent of tobacco smoke and of combustion gases from heating stoves and gas appliances. It is used as an additive to water-based paints, as a disinfectant and as a preservative in biological laboratories and in mortuaries. It is also used in the fabric and clothing industry. The bulk of the industrially produced formaldehyde is, however, used for resins and as such also introduced in the indoor environment. The resins are contained in various products, in particular in wood products of which particleboard is the most important. It is an essential feature of these sources that the emission of formaldehyde depends strongly on air temperature and humidity.

A detailed description of formaldehyde and its industrial production is found in reference (4). Data on the industrial production of formaldehyde in Western Europe during the years 1985 and 1987 are summarized in **Table 4.** To give an indication of the possible development of the formaldehyde production, **Table 4** includes also data on the production capacity in 1987 and 1990 and a projection for 1995. These data suggest a rather stable level of production.

Table 4. Production, actual and projected production capacity of formaldehyde (37 %) in European Countries in 1000 tons/year (courtesy BASF AG, 1989)

Country	Production		Production Capacity		
	1985	1987	1987	1990	1995
Austria	160	155	231	231	231
Belgium	45	50	80	80	80
Denmark	40	40	70	70	70
Finland	95	95	169	169	169
France	250	220	525	525	425
FR Germany	1 550	1 650	2 323	2 323	2 323
Greece	20	15	22	22	22
Italy	375	370	836	836	836
Netherlands	240	210	313	313	313
Norway	85	90	185	185	185
Portugal	75	90	102	102	102
Spain	215	200	450	450	468
Sweden	225	220	335	335	335
Switzerland	25	25	40	40	40
United Kingdom	270	305	488	452	452
Western Europe	3 670	3 735	6 169	6 133	6 051

Table 5 reports the amounts of particleboard produced, exported and imported in European countries during 1987 and the consumption calculated from these data. The total production of various wood based panel types in Western Europe in 1983 and in 1987 is given in **Table 6.**

Except for smoking, sources such as particleboard, furniture, urea formaldehyde (UF) lacquers and UF foam used for insulation may completely dominate the emission from other indoor sources, such as textiles, adhesives or cosmetics.

Table 5. Production, export, import and apparent consumption of particleboard in European countries during 1987 [in 1000 m^3], (adapted from FESYP Annual Report 1987/1988 ***)

Country	Production	Export	Import	Calculated Consumption
Austria	1 308	794	91	605
Belgium	1 875	1 003	134	1 006
Denmark	292	34	234	492
Finland	610	224	4	390
France	1 838	303	671	2 206
FR Germany	6 000	1 106	1 114	6 008
Greece	270 e	16	22	276
Ireland	**	20	44	**
Italy	1 600 e	112*	335*	1 823
Netherlands	200 e	55*	564*	709
Norway	401	65	84	420
Portugal	650 e	400	4	254
Spain	1 346	95	146	1 397
Sweden	844	188	115	771
Switzerland	541	243	120	418
United Kingdom	1 098	41	1 716	2 473

e estimate
* source: Eurostat (Statistical Office of the European Communities)
** not available
*** European Federation of Associations of Particleboard Manufacturers, Giessen, 1988

Table 6. Production of wood based panels by product type in Western Europe (same countries as in Table 5) (adapted from FESYP Annual Report 1987/1988 *)

Type of product	1983 [1000 m^3]	1987 [1000 m^3]
Particleboard	16 848	18 672
Fibreboard	2 232	2 574
Plywood	2 200	2 192

* European Federation of Associations of Particleboard Manufacturers, Giessen, 1988

5. CONCENTRATIONS AND EXPOSURES

The natural background concentration of formaldehyde in outdoor air is of the order of 1 µg/m³. In urban air the annual average concentration is about 5-10 µg/m³. Short term peak concentrations, about an order of magnitude higher, may occur in particular situations such as during peak traffic times or periods of smog. Higher concentrations can also be found in the vicinity of industrial processes.

The observed concentrations of formaldehyde in non-industrial indoor environments are generally below the levels known to cause health or comfort effects to the general population (excluding the hypersusceptible part). The exposure is caused by emissions from several sources, of which products containing urea-formaldehyde resins are the most common. Exposure caused by active or passive smoking may be comparable to the exposures caused by emissions from building materials. Measurements in several European countries (see below) show a tendency for indoor formaldehyde concentrations to be higher during summer than during winter, i.e. when temperature and humidity tend to be higher. This tendency supports the finding that urea-formaldehyde resins are a major indoor source of formaldehyde.

In some cases, elevated concentrations of formaldehyde are observed. These high concentrations can in most cases be explained by deficient products (e.g. due to irregular production), erratic or inadequate uses of materials or accidental flooding or wetting of materials containing urea-formaldehyde resins like insulation materials and carpet glues. Such materials will normally have to be removed from a building to decrease the exposure.

The average exposure of humans to formaldehyde is the result of contributions from various atmospheric compartments and from ingestion. In a recent WHO publication (10) the contribution of

Table 7. Contribution of various atmospheric compartments to average exposure to formaldehyde [a]; adapted from WHO (10)

Source	estimated concentration [mg/m³]	daily intake[c] [mg]
Air		
Ambient air (10% of time)	0.01	0.02
Indoor air		
Home (65% of time)		
- conventional	0.04–0.15	0.5–2
- prefabricated (chipboard)	0.08–0.80	1–10
Workplace (25% of time)		
- without occupational exposure [b]	0.04–0.16	0.2–0.8
- with 1 mg/m³ occupational exposure	1	5
Environmental tobacco smoke (ETS)	0.02–0.20	0.1–1
Smoking (20 cigarettes/day)		1

a The contribution of food and water is ignored here
b Assuming the normal formaldehyde concentration in conventional buildings
c Assuming a respiratory volume of 20 m³/day

ingestion has been estimated to amount to about 1–14 mg/day, most of it in a bound and unavailable form (7). Estimated average contributions of various atmospheric compartments to the total intake of formaldehyde are summarized in **Table 7** which has been adapted from (10).

During the past 10 -15 years in several countries (see below) decreasing indoor concentrations of formaldehyde have been observed as a result of decreasing emission from materials used indoors. A competing factor is, however, the tendency to tighten building envelopes in order to save energy or improve insulation against external noise thereby reducing the ventilation rate. The dependency of the indoor concentration level on both the emission rate of the sources and the ventilation rate makes it difficult to predict the effect of any measure to reduce the concentration levels acting on emission rates alone (see p. 18).

In the following, indoor concentrations of formaldehyde measured in various European countries are reported.

5.1 Denmark

In three small scale scientific investigations (11-13) performed between 1975 and 1982 formaldehyde concentrations ranging from 0.072 to 2.24 mg/m^3 (25 rooms of 23 homes containing particleboard) and average concentrations of 0.64 mg/m^3 (7 houses containing particleboard) and 0.43 mg/m^3 (range 0.24 to 0.55 mg/m^3, in seven mobile day care centers) have been detected. In a larger survey of more recently (post 1982) constructed dwellings (14) substantially lower formaldehyde concentrations have been detected (see **Table 8**). However, all these dwellings had mechanical exhaust ventilation systems.

Table 8. Formaldehyde concentrations detected in newer danish dwellings with mechanical ventilation

type of dwelling	number	average formaldehyde concentration [μg/m^3]	standard deviation [μg/m^3]
detached houses	34	9.0	3.3
apartments	68	9.9	4.4

5.2 Federal Republic of Germany

In the Federal Republic of Germany, many formaldehyde measurements have been carried out since 1977 when the guideline value of 0.12 mg/m^3 (0.1 ppm) was introduced. However, many of these measurements have been made by local institutions and the data have usually not been compiled and published. The Institute for Water, Soil and Air Hygiene of the Federal Health Office undertook to analyse formaldehyde in a larger number of indoor environments in the Federal Republic of Germany using passive samplers (15). Three programmes with different goals were carried out between 1984 and 1986.

In Programme I and II, measurements were made following complaints of dwellers, whereas homes of persons chosen at random were included in Programme III. Samples were taken under normal living conditions without recording the temperature and the relative humidity. The homes visited in Programmes I and II were located in Berlin and in the remainder of the Federal Republic of Germany, respectively. Programme III included homes in every parts of the country. In all programmes, samples were taken as duplicates using passive samplers and formaldehyde was analysed using the pararosaniline method. **Table 9** gives an overview of the number of distributed samplers and their fate. In some cases, the two samplers had not been placed side-by-side as requested; these samplers are characterised as "singles" in the table.

Table 9. Overview of three larger measuring programmes to determine formaldehyde in indoor environments in the Federal Republic of Germany

	Programme		
	I	II	III
Distributed samplers	188	1388	740
Lost samplers	-	8	80
Unused samplers	-	2	-
Samplers as duplicates	154	1158	656
Samplers as "singles"	34	147	4

Table 10 gives a summary of the results of the three programmes. As can be seen, the guideline value of 0.12 mg/m^3 (0.1 ppm) is generally respected, with averages being around 0.06 mg/m^3 (0.05 ppm). In the complaint cases (Programmes I and II), the number of homes exhibiting a concentration level higher than the guideline value was about 8%, whereas in the randomised study (Programme III), exceeding values accounted for only 2%. In all programmes, the 50 percentile was lower than 50 µg/m^3.

Table 10. Results of formaldehyde measuring programmes in the Federal Republic of Germany (for details see Table 9); all concentrations in µg/m^3

	Programme		
	I	II	III
Arithmetic mean of concentrations	60	63	56
Standard deviation	±43	±68	±28
Minimum concentration	n.d.	n.d.	n.d.
Maximum concentration	229	1240	279
Fraction of values [%] exceeding 120 µg/m^3	8	8	2

n.d. = not detected (<30 µg/m^3)

Since the passive samplers were exposed over periods of 48 hours, the results in Table 10 are averages over this period of time. Short-term sampling in the same homes, e.g. over periods of 30 minutes, may have led to higher (or lower) concentrations than those reported here. It should also be mentioned that results obtained by a passive sampling procedure are generally less reproducible than those of active sampling procedures. For the samplers used in the studies described above, the relative standard deviation under field conditions, as calculated from the duplicates, was of the order of 20 to 30 %, at concentration levels between 50 and 100 µg/m^3.

5.3 France

No representative survey of formaldehyde concentrations has been carried out in French homes or other indoor spaces. Existing data result either from small scale surveys or from measurements following complaints on inadequate indoor air quality.

Small scale surveys have been performed in the class room of a nursery school and a university lecture hall in Marseille and in 9 dwellings (5 appartments and 4 detached houses) in and around Paris. In all cases measurements were performed during and outside the heating season. Results are summarized in **Table 11**. The table shows that mean concentrations are below 30 µg/m^3.

Table 11. Formaldehyde concentrations measured in various indoor environments in France

Measurement sites	Number of values with (without) heating	Averaging time of single value	Mean concentration [µg/m^3]	
			Within heating season	Outside heating season
nursery school	10 (10)	30 min	19	29
university. lecture hall	10 (10)	30 min	7	5
dwellings	44 (31)	24 hours	16	22

Maximum values did not exceed 70 µg/m^3. Simultaneously measured outdoor values ranged between 5 and 27 µg/m^3 and were always lower than the indoor values with the exception of the lecture hall, which was near to a parking area and a road with heavy traffic.

Thirteen investigations have been carried out between 1984 and 1989 at the request of people complaining about bad indoor air quality in homes or collective sites. In six detached houses only values up to 90 µg/m^3 have been measured (average 60 µg/m^3), whereas in 4 apartments and at three collective sites concentrations up to 2800 µg/m^3 (average 600 µg/m^3) and up to 3000 µg/m^3 respectively have been detected. The high concentrations of formaldehyde at the collective sites were due to urea formaldehyde foam insulation (UFFI), while those at the other sites resulted from shelves made of particleboard or from glues for wall coverings.

Some further investigations in office buildings carried out in Lyon and Paris showed average concentrations of the order of 50 µg/m^3 with a maximum concentration of 200 µg/m^3.

5.4 Greece

On behalf of the Ministry of Health a survey of formaldehyde concentrations was carried out in 12 new (age$<$1 year) and 31 old houses (age 1-20 years) and in 7 schools, all situated in Thessaloniki. In all cases 30 minute samples were taken and analysed using the chromotropic acid technique. The measurements yielded very low concentrations of formaldehyde, all within the range of outdoor concentrations: the highest detected concentration was 22 µg/m^3 and mean values for various groups of houses ranged between 6.2 and 9 µg/m^3. No significant difference was found between the formaldehyde concentrations detected in the above mentioned new and old houses.

5.5 The Netherlands

In the Netherlands many formaldehyde measurements have been carried out, but most of them have been made by local institutions and the data have usually not been compiled and published.

For the period between November 1978 and January 1981, the Dutch Health and Environment Inspectorates have gathered all measurement data known to them. These measurements have been carried out in homes and schools where there were complaints which might have been caused by formaldehyde. **Table 12** gives a summary of these data. As can be seen, on average, in about 50% of the cases where complaints occurred, the formaldehyde concentration was above 120 µg/m^3. In schools, however, this percentage was markedly higher (66%) and concentrations up to 2.5 mg/m^3 have been measured. In homes the highest concentrations were between 0.75 and 1 mg/m^3. In the cases where the formaldehyde concentration was far below 120 µg/m^3 the complaints have probably been caused by other factors.

Table 12. Measured concentrations of formaldehyde in homes and schools, where there were complaints which might have been caused by high formaldehyde concentrations.

Formaldehyde Concentrations [µg/m^3]	Number of Sampled Spaces					
	Living Rooms	Sleeping Rooms	Attic Rooms	Homes (total)	Schools	Total
0 - 60	61	137	25	223	61	284
61 - 120	56	95	17	168	63	231
Subtotal up to 120 µg/m^3	117	232	42	391	124	515
121 - 200	32	57	14	103	81	184
201 - 500	25	48	10	83	107	190
501 - 2,500	4	7	0	11	50	61
Subtotal above 120 µg /m^3	61	112	24	197	238	435
Total	178	344	66	588	362	950

5.6 Norway

No national survey or systematic measurements of the formaldehyde concentration in residential or other non-industrial buildings has been performed in Norway. Usually in Norway, the highest concentrations of formaldehyde are found in residential homes where particle-board is used. The formaldehyde concentrations tend to be markedly lower now than 10 to 15 years ago. In a recent investigation, formaldehyde concentrations in the air of 15 randomly chosen residences have been measured. In each of them one sample was taken in winter and one in summer. The majority of the samples contained less than 60 µg/m^3. Only two samples from the summer period exceeded 60 µg/m^3. The highest detected concentration was 110 µg/m^3.

From measurements in residences where the inhabitants for some reason suspect high formaldehyde levels, very seldom concentrations higher than 240 µg/m³ are measured, whereas in the majority of such cases concentrations are around 120 µg/m³.

5.7 Sweden

No national surveys of formaldehyde concentrations have been performed in residential buildings. However, the formaldehyde levels tend to be lower than a decade ago as a result of the reduced formaldehyde content in UF-bonded products.

5.8 Switzerland

Formaldehyde concentrations in indoor air above the guideline value of 0.24 mg/m³ issued by the Swiss Federal Health Office (8) are still found in a number of residences, schools and offices.

The most important sources are particleboard and, with decreasing importance, UF foam insulation, plywood and sealing-wax on parquet floor. Carpets and curtains are usually minor formaldehyde emitters, even though the latter were in one case responsible for an increased level (0.8 mg/m³) in a private residence (Rothweiler, unpublished results). Most particleboard on the market corresponds to the 'CH-10' standard which is identical to the 'E 1' standard in the Federal Republic of Germany (see **Table 14**, p. 15).

In several new buildings (8 single family houses, 38 apartments, 11 offices, 16 classrooms) formaldehyde concentrations have been measured. During springtime, levels were between 0.24 - 0.84 mg/m³ and in summer levels increased by about 0.1 mg/m³. One year later levels were roughly half as high as initially. The main identified sources consisted of particleboard (16).

In 43 houses insulated with UF foam formaldehyde concentrations ranged from 0.05 to 2.76 mg/m³ (average 0.48 mg/m³, 9% of values >1.2 mg/m³). Only 23% of the measured concentrations were below 0.12 mg/m³ and 53% below the national guideline value of 0.24 mg/m³ (17).

5.9 United Kingdom

Results of three surveys of formaldehyde concentrations in homes and other buildings in the UK are summarized in **Table 13**. In all studies comparison was made between homes with and without urea

Table 13. Mean indoor formaldehyde concentrations and standard deviations measured in three surveys in the United Kingdom; adapted from reference (18)

Building sample	Mean indoor formaldehyde concentration [µg/m³]	Standard deviation
Survey of 10 houses		
winter	34	15
summer	57	29
Survey of 178 buildings		
without UF foam insulation	57	51
with UF foam insulation	114	121
Survey of 21 houses		
without UF foam insulation	23	–
with UF foam insulation	60	–

formaldehyde cavity wall insulation. While concentrations of formaldehyde were relatively high in the few weeks following installation of the foam, the concentrations declined steadily and were indistinguishable from those in homes without foam after a few weeks, as e.g. for the survey of 10 houses in Table 13, five of which with and five without UF foam insulation. However, in this survey a tendency of summer levels to be higher than winter levels was observed but was not statistically significant.

Apart from cases of newly installed UF foam wall insulation, the detected indoor concentrations rarely exceeded 100 $\mu g/m^3$ but were always significantly higher than outdoor concentrations.

6. PREVENTIVE MEASURES

For the design of preventive measures aimed at limiting the health effects caused by the exposure to formaldehyde in the indoor environment four basic facts have to be taken in consideration.

1. The emission depends on the specific source strength (emission rate per surface unit), the physical size of the source respectively the emitting surface area and the environmental conditions (e.g. temperature and humidity).
2. Air concentrations do not only vary with the emission rate, but also with the ventilation rate.
3. Human exposure depends on both the air concentration and the exposure time.
4. The human reaction depends on the exposure and the individual sensitivity.

Each of these relations may play a role in the reduction of the number of reacting persons and the intensity of reactions to formaldehyde exposure. It is generally agreed that source control is the most desirable way of reducing exposure. A working group of the World Health Organization (7) concludes:

"*In new buildings, the use of proper materials is the best way to prevent problems. The administrative background for these control measures can be produced by regulations which can take three shapes:*

1. *Air quality guidelines should provide a measure against which the quality of the air can be measured.*
2. *Product and process standards can give maximum permitted values for the quantity of formaldehyde released per unit surface area per unit time by the product.*
3. *Building regulations can deal with the use of formaldehyde releasing materials, such as particleboard, foam insulation, paint and glue in the building industry. Also the ventilation capacity and rates in buildings can be prescribed.*

It is important to inform the public about sources of formaldehyde in indoor air and measures to avoid or prevent exposure, especially in homes or other buildings occupied by hypersensitive persons. It is also important to note that the total formaldehyde exposure of an individual can be reduced very effectively by limitation or cessation of tobacco smoking."

7. NATIONAL AND COMMUNITY POLICIES

Policies regarding the protection of the population from inappropriate indoor exposure to formaldehyde have been developed in European countries to a very varied extent. However, existing efforts to reduce indoor exposure to formaldehyde have all moved along the following lines.

- Guideline values have been established which in the majority of cases are between 0.12 and 0.15 mg/m^3, with a few up to 0.48 mg/m^3. A generally applicable legally enforceable standard has not been issuedin any case. Also, no explicit information as to the boundary conditions of guideline values has been given (e.g., room type, group of population concerned, temperature, relative humidity, ventilation rate).
- Existing regulations regard those sources which most often cause indoor concentrations to exceed guideline values. These sources are all containing or based on urea-formaldehyde resins. Reduction of formaldehyde concentrations was not the primary aim in regulations concerning tobacco smoke.
- No specific ventilation requirements have been defined to reduce population exposure to indoor formaldehyde. Steady-state concentrations depend on the air exchange rate. Therefore, ventilation is implicitly part of source regulations which specify maximum admissible emissions. In fact, ventilation rates between 0.5 and 1.0 air exchanges per hour have been prescribed in emission test procedures such as the one given in Report No.2 of this series (19). Therefore, building regulations specifying lower minimum ventilation rates may lead to formaldehyde concentrations exceeding the guideline value.

7.1 Denmark

The most important single source of formaldehyde in indoor air in Denmark is urea-formaldehyde resin used for particleboard and for other building materials. The source strength of particleboard has been regulated in the building code (20) and the use of formaldehyde containing materials has been limited (21). A regulation for furniture was established by the Ministry of the Environment (22). The regulation of particleboard specifies the amount of particleboard which can be used under given environmental conditions (ventilation, humidity, temperature, etc.) according to a classification of these boards with respect to their content of free formaldehyde and to additional surface treatment (e.g. with formaldehyde retaining paint).

The guideline value for formaldehyde in the non-industrial indoor environment is 0.15 mg/m^3 (23). This guideline is intended to protect the general population (excluding the hypersusceptible) from sensory irritation caused by formaldehyde. The limit value for occupational environments is 1 ppm (1.2 mg/m^3) for old productions and 0,3 ppm (0.36 mg/m^3) for new ones. From 1992 on all productions will have to comply with 0.36 mg/m^3 (24).

7.2 Federal Republic of Germany

In 1977, an ad-hoc commission convened by the Federal Health Office proposed a guideline value of 0.1 ppm (25) based on toxicological knowlegde and scientific literature. As a consequence of this proposal, a guideline was issued by the Committee on Harmonised Technical Prescriptions for Construction in 1980 (Ausschuss für Einheitliche Technische Baubestimmungen [ETB]) (26). In this guideline, particleboard was classified into three categories according to its formaldehyde emission. The Institute for Building Technology, an institution created by the Federal States (Länder), which have the responsibility for building codes in the Federal Republic of Germany, recommended the application of the guideline to the Länder. **Table 14** defines the three classes of particleboard established in the guideline.

Although the equilibrium concentration in a large test chamber as determined under the conditions given in **Table 15** was defined to be the reference, a more simple, derived test method, namely the "perforator" method, layed down in the German standard DIN EN 120 (27), was developed to permit a more practicable and rapid classification. In addition, the so-called "gas analysis" method (28) was developed as specified in German standard DIN 52 368.

Table 14. Classification of particle board according to its formaldehyde emission

Class	Equilibrium concentration in a 40 m^3 test chamber	"Perforator value" [mg HCHO/100 g dry material]
E1	≤ 0.1 ppm	≤ 10
E2	> 0.1 -1.0 ppm	>10-30
E3	> 1.0 -2.3 ppm	>30-60

Table 15. Conditions for the reference method to test particle board for formaldehyde emissions (1980)

Size of test chamber	40 m^3
Temperature	23 ± 1°C
Relative humidity	45 ± 3%
Loading	1 m^2 / m^3
Air exchange	1 h^{-1}

According to the ETB guideline (26), only particleboard of class E1 was allowed to be used for construction purposes, but it was not excluded to use E2 and E3 quality particleboard, provided it had been given an appropriate coating to lower the formaldehyde emission to the E1 level.

In 1985, a guideline was also issued with regard to the formaldehyde emission of urea-formaldehyde foam insulation (UFFI) (29). In this guideline, three classes of UFFI were defined, as well as the conditions under which the respective foam quality could be used. To guarantee a formaldehyde concentration of or below 0.12 mg/m^3 (0.1 ppm) in the air of a room adjacent to a wall cavity foam insulation, it was prescribed which materials had to be used to separate the foam from the atmosphere of the room.

The classification of particleboard proved to be very useful as a tool for lowering formaldehyde concentrations in indoor air. However, there were some shortcomings. Since only particleboard for construction purposes had been regulated, low quality particleboard was increasingly used in the manufacturing of other products not subject to regulation.

In October 1986, the Ordinance on Hazardous Substances (30) came into force under the Chemicals Act (31). In this ordinance, a number of paragraps also addressed the question of formaldehyde. At present, the ordinance is under revision, but the prescription concerning formaldehyde emissions from wood-based materials will remain unchanged:

- Coated and uncoated wood-based products (particleboard, blockboard, veneer plywood, fiberboard) must not be circulated if they lead to an equilibrium concentration of formaldehyde of more than 0.1 ppm (0.12 mg/m^3). The equilibrium concentration is to be determined in a large test chamber using a test method which corresponds to the scientific and technical state-of-the-art. For practical purposes, the use of derived methods, such as the perforator method (27) is permitted. The specifications of such methods are to be published by the German Federal Institute for Materials Research and Testing (BAM).

- Furniture can only be circulated if the wood-based materials used for its construction meet the above-mentioned specifications or the whole piece of furniture passes the chamber test successfully, not giving rise to more than 0.12 mg/m^3 (0.1 ppm) formaldehyde in the air.

7.3 France

Urea formaldehyde foam insulation (UFFI), as a source of elevated concentrations of formaldehyde in the air of living spaces which are permanently or semi-permanently occupied, has been subject to decree n° 88683 of May 6, 1988. It offers a framework within which the formaldehyde concentration in living spaces deriving from UFFI was limited to 0.2 ppm by volume (0.24 mg/m^3) and sampling and analytical methods were defined for the measurement of formaldehyde concentrations.

7.4 The Netherlands

There are regulations for particleboard and urea-formaldehyde (UF)-foam. For particleboard the limit value is 100 mg formaldehyde per kg of particleboard and for UF-foam the limit value is 7,000 mg formaldehyde per kg of dry UF-foam. At the same time, use more than 0.75 m^2 particleboard per m^3 of living space is not allowed.

There are standardised methods for the measurement of formaldehyde emissions and concentrations.

7.5 Norway

No national regulation of formaldehyde emissions and of the use of formaldehyde-emitting products currently exists. Some factories have joined a voluntary particleboard control system. It requires that the amount of free formaldehyde shall be lower than 30 mg/100 g of particleboard. A few factories also produce particleboard meeting the requirement of the German E1 standard (see Table 14).

A recently recommended indoor air quality guideline for formaldehyde of 0.06 mg/m^3 will be reflected in Norwegian regulation of formaldehyde emission which is scheduled to be issued in 1991.

7.6 Sweden

In 1989 a threshold limit value for formaldehyde in indoor air of 0,2 ppm was introduced as a remedial action level.

From 1991 on, the emission of formaldehyde from wood-based panels is regulated by the National Chemicals Inspectorate. The regulation says that emissions from chipboard, plywood, fibreboard, blockboard and similar wood based panels containing formaldehyde based resins should not lead to concentrations exceeding 0.13 mg/m^3 according to Swedish Standard 27 02 36, based on testing in a 1 m^3 chamber.

Reported measurements of various UF-bonded products manufactured in Sweden (32) and a critical review of the international literature of formaldehyde emissions from furniture (33) support these regulations.

7.7 Switzerland

In March 1987, the Federal Health Office issued recommendations on how to determine formaldehyde in indoor and workplace air and on measures to be taken in case the detected concentrations exceed certain action levels. Action levels for indoor spaces and recommended remedial measures are summarized in **Table 16**.

Table 16. Levels of concern for indoor air concentrations of formaldehyde and recommended remedial measures

Formaldehyde concentration	Remedial measures
0 – 0.24 mg/m^3	as a rule no measures are required
0.24 – 0.36 mg/m^3	• remove mobile sources • as an immediate temporary measure increase ventilation of the space • start measures with stationary sources (respect proportionality)
> 0.36 mg/m^3	spaces must not be used as sleeping, living or common rooms (e.g. office or class room)

7.8 United Kingdom

The use of materials in buildings is controlled in the United Kingdom by Building Regulations, and Regulation 7 requires controlled materials and components to be fit for purpose. One of the means of showing compliance with this requirement is by observing an appropriate British Standard.

Woodbased panels are the subject of various British Standards in each of which the maximum level of extractable formaldehyde is specified.

Urea formaldehyde foam cavity fill resin, the raw material supplied by the manufacturer, is required to satisfy the requirements of BS 56-7 which specifies inter alia the maximum free formaldehyde content and also gives tests for other properties of the made foam which might affect the evolution of formaldehyde.

Building regulations also limit the walls which may be insulated, to reduce the ingress of formaldehyde and water penetration, to those with bricks or block leaves; in addition the building must be suitable in other respects, and the work carried out in accordance with the recommendations of BS 5618 (British Standards Code of Practice for Thermal Insulation of Cavity Walls [with masonary or concrete inner and outer leaves] by Filling with Urea-Formaldehyde [UF] Foam Systems) by a person of assessed capability.

7.9 European Community

Building products are subject to the Council directive 89/106 on the "approximation of laws, regulations and administrative provisions of the Member States relating to construction products". The directive requires that such products "must be suitable for construction works which (as a whole and in their separate parts)......satisfy the...essential requirements". One of these requirements regards "hygiene, health and environment" and specifies: "The construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours, in particular as a result of any of the following:

- the giving off of toxic gas;
- the presence of dangerous particles or gases in the air;
- the emission of dangerous radiation."

Setting this basic rule, the directive committs to "interpretative documents the creation of the necessary links between the essential requirements" and standards, guidelines or other technical specifications.

Limiting the emission of formaldehyde from wood-based materials is presently under consideration as a first case to safegard the above mentioned essential requirement. For this scope CEN (Comité Européen de Normalisation), the organism recognized as the competent body for the adoption of harmonized standards, has been charged to validate a method for the determination of formaldehyde emissions from wood based panels. This method has been specified in a guideline prepared by a Working Group of COST project 613 and published in this series (19). The guideline recommends the test conditions given in **Table 17** .

Table 17. Conditions for the reference method to test particle board for formaldeyde emission (1989)

Size of test chamber	$\geq$ 12 m^3
Temperature	23 $\pm$ 1 °C
Relative humidity	45 $\pm$ 5 %
Air exchange	1 $\pm$ 0.1 h^{-1}
Air velocity	0.3 $\pm$ 0.1 m/s
Loading factor	1 m^2 / m^3

8. DISCUSSION AND CONCLUSIONS

In Europe, occupants of non-industrial spaces are exposed to formaldehyde emissions from several sources of which products containing urea-formaldehyde resins are the most common. Active or passive smoking is another important source. Generally the observed concentrations of formaldehyde are below the levels known to cause health or comfort effects.

In some cases, however, concentrations of formaldehyde exceeding national guideline values are observed. Elevated concentrations can oftèn be explained by the simultaneous presence of several sources or by such factors as deficient products (e.g. due to irregular production), inappropriate use of materials, or accidental flooding or wetting of materials containing urea-formaldehyde resins.

The trend over the last 10 -15 years indicates a decreasing exposure to formaldehyde in non-industrial spaces due to decreasing source strength of the materials used. A competing factor is, however, the decreasing ventilation of buildings resulting from energy saving modifications or improved insulation against traffic noise. The dependency of concentration levels both on the emission strenght of the sources and the ventilation rate makes it difficult to predict future trends.

In conclusion, several problems remain to be solved:

- There is no common guideline value for formaldehyde concentrations in indoor air in the European countries; such a guideline value, however, would be most desirable, especially in view of the establishment of closer (economic) connections among these countries.
- Measures to reduce formaldehyde emissions and thereby indoor concentrations of formaldehyde may not produce the desired effect if ventilation rates are independently decreased. Therefore some link should be established between regulations concerning formaldehyde emissions/concentrations and those establishing minimum ventilation rates.
- The cumulative effect of emissions from various sources has not sufficiently been taken into account since sources are being tested individually for compliance with the guideline value.
- There may be sensitive people who complain at a concentration level of 0.12 mg/m^3 (0.1ppm) or perhaps even below.

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European Communities - Commission

EUR 13216 – European concerted action
"Indoor Air Quality and Its Impact on Man"
COST Project 613:
Indoor Air Pollution by Formaldehyde in European Countries.

The Community-COST Concertation Committee

Luxembourg. Office for Official Publications of the European Communities

1990 – I-VI, 25 pp. – 21.0x29.7 cm

Series: Environment and quality of life

EN

The report summarizes information on indoor pollution by formaldehyde (HCHO) in European countries participating in the concerted action "Indoor Air Quality and Its Impact on Man" (COST project 613). Major scope of the report is to give a concise information to people involved in research planning, policy making and regulatory activities and to identify a European view of the issue.
The summary includes a short review of health effects of formaldehyde, of existing air quality guidelines and standards and of indoor sources of formaldehyde. For those countries for which information has been made available occuring indoor concentrations and national policies have been collated. Preventive measures are briefly discussed unresolved problems are identified.