SURVEY OF PCB IN MATERIALS AND INDOOR AIR

CONSOLIDATED REPORT

10 DECEMBER 2013

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Foreword

This report presents the consolidated results of the project entitled "Survey of PCB in materials and indoor air". The results of the survey of PCB in materials have previously been published in a phase 2 report. The surveys of PCB in sealed glazing units and fluorescent lamp capacitors and the assessment of PCB in building materials with secondary PCB contamination have been presented in an unpublished phase 3 report. The results of the survey of PCB in materials formed the basis for the selection of buildings for further investigations into PCB in indoor air in phase 4 of the project, which are published in this consolidated report.

The results in this report are presented in a way which ensures that it is impossible to link individual results to particular buildings or building owners which have contributed to the survey.

This survey is referred to below as the "ENS survey".

The ENS survey has been monitored by an interministerial group consisting of representatives of the following:

- Danish Energy Agency
- Danish Environmental Protection Agency
- Danish Working Environment Authority
- Ministry of Housing, Urban and Rural Affairs
- Danish Health and Medicines Authority.

For the sake of clarity, it is implicit throughout the report that, unless stated otherwise, mg/kg and ng/m^3 refer to the concentration of PCB_{total} in materials and indoor air respectively.

The survey was conducted by a consortium consisting of Grontmij A/S and COWI A/S, with IMM Statistical Consulting Center, DTU Dataanalyse acting as sub-consultant as regards statistical analysis.

1 Summary and conclusion

A survey of materials containing PCB has been carried out in 352 buildings, split between three building types: detached and semi-detached houses, blocks of flats and office buildings and public institutions (collectively referred to as "the ENS survey"). The results were compared with the results of surveys of PCB in materials in 669 public institutions and office buildings from surveys conducted by municipal authorities across the country, as well as results of other surveys.

Based on a structural review and concentration levels in the building materials, a total of 67 buildings were selected within the three building categories in which PCB measurements were taken in indoor air. This part of the survey was supplemented by a summary of results of surveys concerning PCB in indoor air in 507 public institutions and office buildings from surveys conducted by municipal authorities across the country.

1.1 PCB in materials

1.1.1 Survey of PCB in materials

Sealants, paint and flooring

The survey of materials in the 352 buildings focused on the primary presence of PCB in sealants, certain types of paint and flooring. Two other sources, sealed glazing units and capacitors, were surveyed separately.

Materials containing PCB at a concentration ≥0.1 mg/kg, which means that they must be destroyed upon disposal in accordance with the recommended thresholds, were found in more than 75% of the buildings surveyed. This result is consistent with the outcome of the survey of Danish Defence's buildings and data collected concerning refurbishments and demolitions reported by the Danish Environmental Protection Agency in 2012. Paint containing PCB occurs in a higher than expected proportion of the buildings and is responsible for the very widespread presence of materials containing PCB at relatively low concentrations.

Even at the low concentrations involved, the PCB in the paint appears to originate from the paint manufacturing process, as over 50% of the analysed outdoor paints, which are not expected to be contaminated by other sources, contained ≥0.1 mg/kg PCB.

Detached and semi-detached houses

PCB was found to be widespread in detached and semi-detached houses, with materials containing ≥50 mg/kg being found in 18% (13–24%, 90% confidence interval) of the buildings. However, concentrations were statistically significantly less than in the other two types of building. This is particularly marked in the case of materials containing concentrations ≥5,000 mg/kg, which were found in 6% (4–11%) of the buildings. Most of the materials containing PCB were paints used either indoors or outdoors. Indoors, paint was for example found on water pipes in toilets and on floors in larders, laundry rooms, offices and storage rooms, while paint outdoors had been applied to stairs. Sealant joints with high concentrations (≥100,000 mg/kg) were found in two buildings around windows and doors, one outdoors and one indoors. No cases were found of sealant between concrete elements or sanitary sealant in bathrooms with high PCB concentrations. The most frequently occurring PCB sources in institutional buildings with high concentrations of PCB in indoor air thus occur with a markedly lower frequency in detached and semi-detached houses.

Blocks of flats

In blocks of flats, materials containing ≥50 mg/kg were found in 31% (24–40%) of the buildings, while materials containing ≥5,000 mg/kg were found in 11% (7–18%). In blocks of flats, only one case of a sealant joint with a high PCB concentration was found indoors around a window in a staircase, while sealants with a high concentration (typically over 100,000 mg/kg) used outdoors between concrete elements were found in many properties. On the basis of the survey, it is possible to state that indoor sealants containing high concentrations are not widespread, as has for example been observed with some existing PCB cases. However, the possibility that such sealants could be present in a small percentage of all blocks of flats cannot be excluded. Paint containing ≥50 mg/kg and up to 19,000 mg/kg was particularly found indoors on staircases and in laundry rooms, storage rooms, bicycle basements and boiler rooms. The paint had been applied to floors, walls, downpipes and metal railings.

Public institutions and public office buildings

Extensive data are available for public institutions and public office buildings from surveys conducted by municipal authorities. In most municipalities, surveys have exclusively been aimed at sealants, and the results of the surveys can only be considered to be representative as regards sealants. Overall, the frequency of buildings containing PCB at concentrations ≥50 mg/kg in sealant in public institutions and offices specified at location level was 14% (12–16%) (a location is a school, care home, etc.). An analysis of the results from the municipalities for which data were available for all the individual buildings at all locations (e.g. all buildings at a particular school) showed that the frequency at location level was approx. 20% higher than when specified at building level. The frequency of buildings with PCB in paint and floor compounds has been estimated on the basis of the ENS survey results, as most surveys conducted by municipalities did not include these materials. Overall, 19% (11–30%) of buildings contained paint or flooring containing ≥50 mg/kg.

High occurrences of PCB in sealant are more frequent in schools than in other public buildings. Amongst 87 schools across the country which took part in the municipal authorities' screenings, sealants with a high PCB concentration (≥5,000 mg/kg, but typically ≥100,000 mg/kg) were found in 31% of the schools.

Private office buildings

The results of surveys of 36 office buildings show that the presence of materials containing PCB in the buildings largely corresponds to that seen for public buildings. Thus, materials containing ≥50 mg/kg were found in 36% (23–51%) of the properties, while materials containing ≥5,000 mg/kg were found in 17% (8–30%).

Temporal distribution

Both the ENS survey and the municipal authority surveys clearly show that sealants containing PCB were used far more frequently during the period 1965–1974 than during the other sub-periods. As regards paints and flooring, the period-related differences are less marked, which may well be due to the fact that these materials were incorporated into the buildings a number of years after their erection.

Survey of Danish Defence buildings

Alongside the present survey, a survey of Danish Defence's buildings was carried out for the Danish Defence Estates and Infrastructure Organisation (FBE). The FBE survey studied 115 depots/workshops, 81 offices/frequently used buildings and 104 buildings used for living quarters. The results obtained from Danish Defence's buildings correspond well with the results of the ENS survey, and only minor differences were found in the use of materials containing PCB between the two surveys.

On the whole, the differences between the building categories within the ENS and FBE surveys were greater than the overall differences between the two surveys. The results of the FBE survey could therefore be used to supplement those of the ENS survey in analyses of connections between PCB in materials and PCB in indoor air.

Sealed glazing units

It has been demonstrated that a significant proportion of the sealed glazing units that are currently being disposed of still contain materials containing PCB. Based on information concerning year of manufacture, 69% of the windows could be excluded as having been manufactured outside the PCB period. In the others, concentrations ≥50 mg/kg were found in sealant adhesive in 34% of the windows, while concentrations ≥50 mg/kg were found in sealant tape in 29% of the windows. There was a link between the presence of PCB in sealant adhesive and sealant tape, and overall 35% of the windows had ≥50 mg/kg in either the sealant tape or the sealant adhesive.

On the basis of the results, the average amount of PCB in windows containing concentrations ≥50 mg/kg can be calculated at 36–45 g/m^2 of window in sealant adhesive and 0.6–1.8 g/m^2 in sealant tape. In 13% of the windows, there was sealant adhesive containing >100,000 mg/kg PCB (>10%) and in these windows, the average PCB concentration in the sealant adhesive was 63–79 g/m^2. A clear link was demonstrated between PCB in sealant adhesive and sealant tape, indicating that the presence of PCB in sealant tape is primarily a tertiary contamination from PCB in the sealant adhesive (via the air gap between the window and the window frame). However, there were 10 cases of PCB concentrations in sealant tape in the interval 50–10,000 mg/kg where the presence in the sealant tape is greatest, indicating that PCB in sealant tape could be a primary source.

The secondary and tertiary presence of PCB in wood in window frames was not studied, but it is likely that some of the PCB in the primary sources has penetrated into the wood.

Fluorescent lamp capacitors

To investigate the presence of PCB in fluorescent lamp capacitors, 516 fluorescent lamps were surveyed, of which 480 were collected via two electronic waste companies which primarily receive such light fittings from recycling centres. It was possible to eliminate 62% of the light fittings, either because they did not have a capacitor (more recent types of lamp are not fitted with a separate capacitor), or because the capacitor had a stamp on it indicating that it had been manufactured after 1986.

Of the 38% of the light fittings selected from which samples were taken, 23% contained actual PCB capacitors with a PCB concentration >100,000 mg/kg. This corresponds to approx. 9% of all the fluorescent lamps studied containing a PCB capacitor. There was also some PCB present in lower concentrations, and around 42% of the capacitors analysed contained ≥50 mg/kg PCB, corresponding to around 16% of all lamps studied having capacitors containing ≥50 mg/kg PCB. Around 37% of the capacitors studied contained PCB in the interval 0.1–50 mg/kg. It should be noted that until the entry into force of the POP Regulation in 2004, capacitors (and other products) could be sold with a PCB content of up to 50 mg/kg, and the cut-off date of 1986 does not apply to these capacitors. On average, the capacitors contain around 30 g of pure PCB. Of the actual PCB capacitors examined, 91% contained free phase PCB. In the event of small leaks in the capacitor, this PCB can be released into the surrounding environment, while in the event of a major leak in the capacitor, PCB can drip from the capacitor. Leaks from capacitors have been shown to result in PCB concentrations in indoor air above the Danish Health and Medicines Authority’s recommended action values.

PCB with differing degrees of chlorination has been used in the capacitors, but around half of the capacitors are very low chlorinated and have a proportion of PCB 28 which is far higher than the other primary sources, such as sealants and paint. In many of the buildings surveyed, there were clear indications that capacitors were the reason behind the high levels of PCB in the indoor air. In these buildings, a characteristic pattern was observed with a very high proportion of PCB 28 in both materials and indoor air, while concentrations in indoor air were high and concentrations in materials were low, being as low as 50 mg/kg. This indicates that the materials surveyed contained tertiary contamination originating from fluorescent lamp capacitors.

In one case from a municipality where it has been demonstrated that capacitors are the source of PCB concentrations in indoor air in classrooms varying from 1,000 to 3,400 ng/m^3, a precisely corresponding congener profile was measured in capacitor oil, indoor air and materials containing tertiary contamination.

Secondary and tertiary presence of PCB

PCB from primary sources will penetrate adjoining materials and create the basis for secondary PCB presence in these materials.

The results of this study show that penetration into pine, lightweight concrete and brick is best described as a power function, which means that PCB penetrates a relatively long way into the materials and that the concentration will not decrease to 0.1 mg/kg until a considerable distance from the source. The measurement series display considerable differences in concentrations in the materials within the first 0.5 cm from the source, which is primarily sealant. This is interpreted as indicating that some of the sealant penetrates inside holes and cracks in the adjoining materials in certain areas. For example, the concentrations in pine at a distance of 0–0.5 cm from a primary source with around 100,000 mg/kg vary from 200 to 20,000 mg/kg. At this distance, penetration is therefore determined not by the migration of PCB in the wood, but by the penetration of the sealant which contains

PCB. Further into the material, additional penetration is determined by the migration of PCB into the wood, and relatively uniform migration coefficients are observed in the various measurement series. The considerable differences over the first 0–0.5 cm are thus propagated as substantial differences throughout the entire measurement series.

The results show that PCB penetrates deeper into the pine than it does in the other materials, and at a distance of 4–5 cm from the source there was still ≥50 mg/kg in two out of seven measurement series, while it varied between 2 and 38 mg/kg in the others. Based on the calculated migration coefficients, it can be estimated that there will still be between 0.3 and 30 mg/kg at a distance of 20 cm from the source.

In lightweight concrete, the penetration is similarly deep. At a distance of 1 cm from the source, the concentration in all measurement series is close to <50 mg/kg, while for the measurement series with the highest penetration in the first 0.5–1 cm, the concentration would, based on the migration coefficient, not fall below 50 mg/kg until a distance of 12 cm from the source is reached. This is not because the migration coefficient is different in this measurement series, but simply because of the greater penetration at a distance of 0–0.5 cm from the primary source.

1.1.2 Presence of PCB in materials in buildings in Denmark

The number of buildings with PCB in sealant, paint or flooring

Based on the results of the ENS survey and a number of surveys in municipalities across the country, the total numbers of buildings in Denmark which contain paint, sealant and flooring with a PCB concentration of ≥0.1 mg/kg, ≥50 mg/kg and ≥5,000 mg/kg respectively have been estimated as shown in the following table.

Table 1 Proportion and number of buildings in Denmark dating from the PCB period which contain PCB in sealant, paint or flooring.

Building type	Proportion and number of buildings in Denmark from the PCB period with materials over the specified concentration (90% confidence interval)		
	≥0.1 mg/kg	≥50 mg/kg	≥5,000 mg/kg
Detached and semi-detached houses	390,000–470,000 67–79%	80,000–140,000 13–24%	20,000–60,000 4–11%
Blocks of flats *1	12,600–14,100 84–95%	3,600–5,900 24–40%	1,000–2,700 7–18%
Private office buildings	13,900–19,900 60–86%	5,300–11,800 23–51%	1,700–7,000 8–30%
Public institutions and office buildings *2	In sealants 4,700–5,700 22–27% In paint and flooring 13,000–18,000 62–83%	In sealants 2,100–2,900 10–13% In paint and flooring 2,400–6,500 11–30%	In sealants 1,200–1,800 6–9% In paint and flooring 300–2,800 1–13%

*1 Note that it is the number of blocks of flats that is specified, not the number of flats, which is at least 10 times greater.

*2 There is an overlap for many buildings, with some buildings containing both sealants and paint at concentrations ≥50 mg/kg PCB; hence the total number of buildings containing one of the materials is significantly less than the sum of the two intervals.

Residual amounts of PCB in materials

The total amounts of PCB in building materials and fluorescent lamp capacitors are shown in the following table. The total quantity of PCB is estimated at 17–87 tons. The largest quantity is estimated to comprise sealants, with sealed glazing units representing the second largest individual source.

The calculated quantities in paint are subject to considerable uncertainty, but the total quantity is probably somewhat lower than the quantity in sealants, even though paint containing PCB can be found in a high proportion of all buildings. The calculated amounts of PCB in flooring are also very uncertain, but flooring is in any case considered to be a minor source.

The estimates for residual amounts of PCB in sealants, sealed glazing units and fluorescent lamp capacitors correlate closely with corresponding estimates made in Norway. It is estimated that there is still 5–15 tons of PCB in sealed glazing units, and that a significant proportion of the quantities that are currently being disposed of are probably not being disposed of in accordance with the rules which apply to hazardous waste. The same would appear to be the case for fluorescent lamps with capacitors, with the residual quantity being estimated to be 2–7 tons of PCB.

Table 2 Residual amount of PCB in buildings in Denmark.

Material/equipment	Residual amount of PCB Tons	% of total
Sealant around doors and windows	7–35	40%
Sealant between other building elements	2–15	16%
Paint	0.3–5	5%
Flooring	0.1–2	2%
Sealed glazing units	5–15	19%
Fluorescent lamp capacitors	2–7	9%
Secondary and tertiary presence	0.7–7.5	8%
In total	17–87	

1.2 PCB in indoor air

1.2.1 Survey of PCB in indoor air

Selection of buildings

Based on a structural review and PCB concentration levels in building materials, a total of 67 buildings were selected within the three building categories in which PCB measurements were taken in indoor air.

The buildings were selected on the basis of the criteria that there should either be indoor materials containing more than 50 mg/kg PCB or outdoor materials containing more than 5,000 mg/kg PCB. Using these selection criteria, it was anticipated that the measurement programme would cover all buildings in which

PCB concentrations of more than 300 ng/m^3 could occur as a result of PCB as a primary source in sealants, paint or flooring.

However, a number of owners of the selected buildings did not wish to take part in the survey, and this has compromised the results of the study and rendered extrapolating them to the entire building stock more difficult.

Measurements were only taken in two rooms in each building, and the results presented are based on the highest value measured in each building. No attempt was made to determine the number of rooms in each building which contained PCB in indoor air above the specified value, but there is at least one room in each building.

Detached and semi-detached houses

PCB in indoor air was measured in 15 of the 20 detached and semi-detached houses surveyed, while five building owners did not wish to participate. A concentration ≥300 ng/m3 was found in one of the detached and semi-detached houses surveyed. In none of the surveyed houses was a concentration ≥2,000 ng/m^3 found. Concentrations of less than 30 ng/m^3 were found in 71% of the buildings in which indoor air measurements were taken.

Blocks of flats

PCB in indoor air was measured in 20 of the 31 blocks of flats selected, while a housing association with 11 selected properties did not wish to participate. A concentration ≥300 ng/m^3 was found in one of the blocks of flats surveyed. In none of the blocks of flats surveyed was a concentration ≥2,000 ng/m^3 found. Concentrations of less than 30 ng/m^3 were found in 75% of the buildings in which indoor air measurements were taken. As with the results of the survey of PCB in materials, it can be stated that blocks of flats with extensive PCB contamination, such as the examples that have been highlighted in recent years, are not a widespread phenomenon.

Office buildings and public institutions

There was a markedly higher frequency of both private office buildings and public institutions with ≥300 ng/m^3. In 12 of the 33 buildings surveyed (36%), at least one room with a concentration ≥300 ng/m^3 was found, and a concentration ≥3,000 ng/m^3 was found in one building. The frequencies of buildings containing ≥300 ng/m^3 were 42% and 33% of the office buildings and public institutions surveyed respectively. The results correlate well with the results of the survey of materials, which concluded that the extensive presence of indoor materials with a high concentration of PCB was most widespread in office buildings and public institutions.

When consideration is given to the prior selection of buildings with a high concentration of PCB in materials, the results for public sector offices and institutions correspond well with the results of surveys carried out by municipal authorities.

The results of 1,377 indoor air measurements at 507 locations (schools, nursery schools, town halls, etc.) in 16 municipalities are summarised in this survey. The overwhelming majority of the data set is represented by surveys where measurements were taken at all locations (where appropriate within a sub-category of buildings only) or a random sample without any prior selection based on measurements of PCB in materials. As measurements from 507 locations provide an excellent statistical basis, the results of these surveys were used to estimate PCB in indoor air in all Danish public sector offices and institutions.

The summary shows that concentrations ≥300 ng/m^3 were found in 7% of the locations surveyed. Concentrations ≥3,000 ng/m^3 were found in two locations, corresponding to 0.4% of the locations surveyed.

Ventilation in surveyed buildings

For all building categories, it can be seen that many rooms experienced remarkably little air exchange during the measurements, as the median values for a detached/semi-detached house, block of flats and offices and public institutions were 0.10 h^{-1}, 0.23 h^{-1} and 0.32 h^{-1} respectively. In approx. 40% of all measured rooms in homes, an air exchange of less than 0.10 h^{-1} was measured, and approx. 60% of measured rooms have an air exchange of less than 0.20 h^{-1}. In relation to the requirement laid down in the Danish building regulations for a minimum air exchange of 0.5 h^{-1}, the PCB measurements were therefore taken during relatively low air exchanges.

The surveys were carried out while the rooms were not in use, i.e. windows and doors were not opened, forced extraction from extractor hoods and bathrooms etc. did not take place. If the air exchanges for the detached and semi-detached houses are considered in relation to the measured air exchanges and the normal use of a bedroom, as shown in previous studies, the measured air exchanges can be estimated at between four and 17 times higher than those measured during the surveys. In reality, the figures will be even higher, as the measured air exchanges also include air which has entered from other rooms.

Amongst the buildings in which a number of measurements were taken in the same rooms, there is a general trend for PCB concentrations to be around 1.8 times lower in the case of measurements taken while a room is in use compared with measurements taken while the room is not in use. Higher concentrations of PCB in indoor air can similarly be seen at higher temperatures. The results confirm that higher temperatures and air exchanges impact on PCB concentrations, a fact that has also been observed in other studies.

The results thus confirm that maintaining a low temperature, such as 20°C, and increasing the air exchange can have benefits if the building has elevated concentrations of PCB in indoor air. It has been demonstrated that measured indoor air concentrations can be reduced by a factor of two to five by reducing the temperature and increasing the air exchange.

1.2.2 Relationship between PCB in indoor air and materials

The relationships between PCB in indoor air and materials have been studied partly by considering relationships between congener compositions in materials and indoor air and partly by looking at relationships between concentrations.

Congener composition

In 47 buildings from the ENS survey, relationships between the PCB congener profile in indoor air and the congener profile in the material from the room, which is assumed to be the primary source of PCB in indoor air, were analysed. Although the picture is fragmented, a general link can be seen between the congener composition in the materials and the indoor air. As a general rule, materials with a profile displaced towards lower chlorinated congeners also result in a displacement in indoor air towards lower chlorinated congeners, as can be seen for example in measurements where the source is assumed to be sealants, compared with profiles where the primary source is paint or flooring.

As noted previously, a number of the buildings stand out with a very high proportion of PCB 28 in both materials (in which the concentrations of total PCB are low) and indoor air. This points to capacitors as a possible primary source, or alternatively that the primary source has been removed. In such a case, the presence of PCB in indoor air would stem from the fact that all materials in the room contain tertiary contamination. Analyses of relationships between primary sources and materials containing secondary and tertiary contaminants show that some displacement takes place towards lower chlorinated congeners in the materials containing tertiary contaminants, but this would not give rise to PCB 28 ratios as high as those seen in four buildings in which the above phenomenon has been observed. The results indicate that capacitors are responsible for at least four of the cases (approx. 12% of all cases) where more than 300 ng/m^3 has been found in indoor air. The type of capacitor which is markedly different and can be identified as a primary source comprises only around half of the capacitors. The total number of cases where capacitors are responsible for the high levels in indoor air may therefore be much higher. In connection with this, it should be noted that capacitors could legally contain PCB until 1986, and buildings constructed right up to this year may therefore have this source of PCB in indoor air.

Concentrations

A detailed analysis has been carried out of the connection between PCB concentrations in materials and indoor air. A summary has also been prepared based on the municipal surveys and other studies, along with a collective summary of the ENS and FBE surveys. In the latter summary, there is considerable certainty that the materials were found in rooms in which PCB was measured in indoor air.

Both summaries show that there is some connection between high concentrations in materials and high concentrations in indoor air, but there is considerable variation and the relationship is not particularly clear. This particularly applies to paint and flooring. In order to investigate the importance of air exchange, temperature, surface area, etc., various normalisations were carried out and source strengths and source potentials were calculated. However, it was not possible to describe relationships more clearly in this way. The analysis shows that a considerably better correlation can be achieved if only PCB 28 is considered, rather than looking at PCB_{total}. Nevertheless, as the results cannot subsequently be converted unambiguously to PCB_{total}, such a correlation cannot be used to predict the PCB content in indoor air on the basis of the PCB 28 content in materials. In numerous cases, concentrations of more than 300 ng/m^3 were found in rooms in which the highest measured value in materials did not exceed 50 mg/kg, yet there are also many examples of the presence of large painted surfaces with PCB concentrations of several thousand mg/kg not giving rise to such high indoor air concentrations. There is much evidence to suggest that paint and flooring in particular are in many cases not the actual primary source. In a significant proportion of the measurements above 300 ng/m^3, it has been shown that capacitors are likely to be the primary source, and the capacitors will probably also contribute to PCB in materials and indoor air in many of the measurements with lower values and could hide the relationships between materials and indoor air.

In order to use these relationships between materials and indoor air to extrapolate to buildings where only materials were measured, so-called confidence ellipses were calculated which describe the relationships between materials and indoor air. In the model, all values for materials have been merged, as there are insufficient values for the individual materials. In particular, it is a weakness that no clear relationship is apparent between concentrations in materials and indoor air for flooring, presumably because the flooring is not actually the primary source in most cases. The probability of a room containing a material with a given concentration in materials having indoor air containing more than 300 ng/m^3, for example, was calculated on this basis. These probabilities are specified with a confidence interval. By calculating a probability for all surveyed buildings, the numbers of buildings that would be expected to contain PCB at concentrations ≥300 ng/m^3, ≥300–2,000 ng/m^3, ≥2,000–3,000 ng/m^3 and ≥3,000 ng/m^3 were calculated. These have been calculated using what is known as a prediction interval. Using this method, it was calculated that, of the total of 352 buildings overall, 15 buildings would be expected to contain ≥300 ng/m^3, which corresponds closely with the 15 surveyed buildings which were found to contain ≥300 ng/m^3. This confirms the expectation that buildings with less than 50 mg/kg will make a very modest contribution to the total number. However, for the individual types of buildings, there are significant differences between the anticipated number and the actual measured number, primarily because there will be a wide variation in the actual measured number due to the modest number of indoor air measurements for each building type. For office buildings, the anticipated number relative to the number of actual measurements is low, which may be linked to the fact that concentrations ≥300 ng/m^3 were found in many of the buildings, yet concentrations in materials were low.

Although the relationship between PCB concentrations in materials and indoor air in an individual building is not particularly clear, the relationship may be used to estimate how many buildings within each individual building type could contain PCB above a certain concentration when the PCB concentration in materials is known for a large number of buildings.

A more detailed analysis of the buildings in which elevated concentrations were found shows that these cases involve:

- Buildings with high PCB concentrations (>100,000 mg/kg) in indoor sealant
- Buildings with PCB concentrations (>5,000 mg/kg) in indoor sealant
- Buildings with capacitors which contain PCB
- Many buildings with relatively low concentrations in paint and flooring where it cannot be stated exactly why high PCB concentrations are found in indoor air in these particular buildings.

The latter group includes, for example, detached and semi-detached houses, which contained high PCB concentrations in one room, where the only source is paint in the basement which contained PCB. In these cases, however, sealed glazing units were considered likely to contain PCB. In many other cases, this will not result in such high concentrations in one room.

High concentrations were found in some of the rooms which are not used as living rooms, e.g. storage rooms in basements and corridors, but as illustrated in the example above, PCB from these rooms could migrate to other rooms in the buildings. It is particularly important to focus on basements which are used for teaching purposes, as wall and floor paint can often contain PCB.

The results indicate that surveys of PCB in indoor air in individual buildings can be conducted most efficiently by directly investigating PCB in indoor air and subsequently investigating the presence of PCB in materials if the concentration in the indoor air is too high. This may also help to indicate whether there have previously been any primary sources which have now been removed or whether capacitors are causing high PCB levels in the indoor air.

1.2.3 PCB in indoor air in buildings in Denmark

The available data are summarised in the following table, which presents the number of buildings within each building type which are estimated to contain one or more rooms contaminated with PCB at various concentration levels.

The model used to calculate the number of buildings is considered to be very robust as regards the aforementioned mean values. The prediction intervals are surprisingly narrow, and it is possible that some uncertainty must be attached to the model assumptions, in particular the fact that the relationship between PCB in materials and indoor air was considered collectively for all materials and that it was assumed that the 354 buildings in which PCB was measured in materials are representative of all the buildings in the country within the building types concerned. However, it is not possible to take account of this additional uncertainty in any precise way, which may well mean that the uncertainty intervals will be twice the stated intervals.

The table also shows the proportion of all buildings (not only those from the PCB period) for each building type containing PCB in indoor air at various concentration levels. The calculation does not take into account the fact that some of the buildings constructed before the PCB period may contain PCB in materials which were added during the PCB period and may give rise to PCB in indoor air. There will therefore be a tendency for the proportions to be underestimated, yet there are no data to indicate the extent of the underestimation.

Table 3 Calculated number of buildings with PCB in indoor air (90% prediction intervals, rounded values).

	Number of buildings from the PCB period (90% prediction interval)			Proportion of all buildings (90% prediction interval) *3		
	≥300 ng/m³	300–3,000 ng/m³	≥3,000 ng/m³	≥300 ng/m³	300–3,000 ng/m³	≥3,000 ng/m³
Detached and semi-detached houses	19,300–22,800	18,900–22,000	390–810	1.3–1.6%	1.3–1.5%	0.03–0.1%
Blocks of flats *1	610–800	590–750	7–31	0.7–0.9%	0.7–0.9%	0.01–0.03%
Public institutions and office buildings as well as private office buildings *2	1,600–2,600	1,600–2,400	30–230	0.9–1.5%	0.9–1.4%	0.02–0.14%

*1 Note that it is the number of blocks of flats that is specified, not the number of flats, which is at least 10 times greater.

*2 The intervals were calculated through the simple addition of the respective intervals for public institutions and office buildings and private office buildings.

*3 Stated as a percentage for all buildings in Denmark, not just buildings from the PCB period. Note that there is a difference between the building types as regards the proportion of the total building stock erected during the PCB period.

1.3 General conclusion

In summary, it can be concluded that PCB is widespread in buildings erected during the PCB period between 1950 and 1977. Paint, sealant or flooring containing PCB concentrations ≥0.1 mg/kg, which means that the materials must be destroyed upon disposal in accordance with the recommended limit values, were found in more than 75% of the buildings surveyed. This result is consistent with the outcome of the survey of Danish Defence’s buildings and data collected concerning refurbishments and demolitions reported by the Danish Environmental Protection Agency in 2012. In addition, a significant proportion of buildings from the period still contain PCB in sealed glazing units or have fluorescent lamps with capacitors which contain PCB. As capacitors containing PCB were manufactured right up until 1986, the PCB period for this PCB source is longer than for the other sources.

In most of the buildings, PCB concentrations were so low that they did not give rise to PCB concentrations in indoor air above the Danish Health and Medicines Authority’s recommended action values. For all building types, it is estimated that 0.7 to 1.5% of all buildings in Denmark may contain PCB concentrations in indoor air above the Danish Health and Medicines Authority’s lowest action value.

2 Introduction

2.1 Objective

As part of the Government's "Action Plan on Managing PCB in Buildings" dating from May 2011, the Danish Energy Agency has, in partnership with the Danish Environmental Protection Agency, initiated a nationwide systematic survey of the presence of PCB in the Danish building stock. The survey is one of 19 initiatives in the action plan which will form the basis for the effective and safe management of residual PCB in buildings and reduce the population's exposure to PCB.

The overall objectives of the ENS survey are:

› To identify materials which contain PCB in connection with the refurbishment or demolition of buildings, in order to take account of the working environment and ensure that waste containing PCB is separated out at the demolition site.

› To identify the relationship between the level of PCB in building materials and in indoor air, in order to facilitate a targeted initiative aimed at reducing PCB concentrations in indoor air.

› To increase our understanding of the types of PCB which typically occur in building materials and the types of PCB that evaporate into indoor air.

› To assess the residual amount of PCB in the Danish building stock based on an assessment of the migration of PCB to adjoining materials.

2.2 Background

Another initiative under the Government's "Action Plan on Managing PCB in Buildings" is the establishment of the PCB guide (www.pcb-guiden.dk), which presents information on PCB. The following is an extract from the PCB guide. See the guide for more information on PCB.

PCB is an environmentally harmful substance which can harm both people and the environment. PCB was previously used in building materials and in industry until it was discovered in the 1970s that PCB can have harmful effects on both people and the environment. Today, all use of PCB is prohibited, but the substance is still present in our surroundings.

› PCB is an abbreviation for polychlorinated biphenyls, and the substance is an undesirable environmental toxin.

› PCB can be passed to humans through diet, inhalation or skin contact with materials which contain PCB. Food is the biggest source of PCB in the body for the population as a whole.

- PCB has been used in construction in Denmark. The substance may be present in buildings erected or refurbished during the period 1950–1977. PCB was used in building materials such as sealant and sealed glazing units until 1977 and in capacitors and transformers until 1986.

- The use of PCB has been prohibited in building materials since 1977 and in electrical equipment since 1986.

- Products and waste containing PCB must be handled correctly in order to avoid spreading PCB to humans and the environment.

- PCB can be harmful to health, but the substance is not believed to cause acute illness following short-term exposure. Long-term exposure results in damage to the skin and has a negative effect on fertility. In addition, the long-term accumulation of PCB has been linked to damage to the liver, thyroid, immune system and hormone system. PCB is also suspected of being carcinogenic.

- Newborn babies and pregnant and breastfeeding women are particularly vulnerable groups.

- PCB is initially identified on the basis of the building's age. In addition, visual inspections of possible sources and actual measurements of relevant building materials and indoor air are also used. Even if there is PCB in a building, it is not inevitable that the presence of the PCB will be associated with an increase in health risk.

- PCB is subject to limit values which determine when materials containing PCB are defined as hazardous waste, and action values which determine how great the concentration in indoor air must be before it is considered an elevated health risk.

Waste

Construction and engineering waste containing PCB is divided into hazardous waste and non-hazardous waste according to the PCB concentration in the waste. It has been established at EU level that waste containing a concentration ≥50 mg/kg is defined as hazardous waste, and that waste containing a concentration above 1 mg/kg may not be disposed of at facilities for the disposal of inert waste.

As regards waste with a concentration below 50 mg/kg, the Danish Environmental Protection Agency has issued guidelines specifying recommended limit values and recommendations concerning the handling of waste containing PCB (Danish Environmental Protection Agency, 2011). The Danish Environmental Protection Agency is currently in the process of drawing up final limit values for PCB in waste.

Limit values		
>50 mg PCB/kg Requirement	Hazardous waste	Destroyed at an approved incineration plant or buried underground in landfill (abroad).
Approx. 0.1–50 mg PCB/kg Guideline	Non-hazardous waste	Should be destroyed at an approved incineration plant, but may be sent to landfill if it is difficult to handle (e.g. concrete). It is the Danish Environmental Protection Agency's view that waste containing PCB should not be disposed of at a landfill site for hazardous waste, but as follows: Waste with a PCB content of less than 1 mg/kg may be disposed of at a landfill site for inert waste. Waste with a PCB content of between 1 and 50 mg/kg may be disposed of at a landfill site for mineral waste or mixed waste. As regards the disposal of waste containing PCB at a landfill site for *mineral* or *mixed waste*, the Danish Environmental Protection Agency recommends that waste containing PCB should be deposited in separate cells which can subsequently be located. As regards the disposal of waste containing PCB at a landfill site for *inert waste*, the content of PCB is so low that the Danish Environmental Protection Agency does not recommend the disposal of waste containing PCB in separate cells at these sites.
Approx. <0.1 mg PCB/kg Guideline	Considered not to be contaminated with PCB	May be reused in accordance with applicable regulations and following notification to the municipal authority.

The concentration of PCB in waste is determined in accordance with the guidelines set out in Danish Standard DS/EN 15308.

The limit values are stated as PCB_{total}, i.e. measurement of the seven selected congeners (PCB_7) which are to be included in the analysis according to the standard, multiplied by a correction factor of 5.

Indoor air

The table below shows the Danish Health and Medicines Authority's recommended action values for concentrations of PCB in indoor air, together with the recommended action based on the results of measurements of PCB in indoor air. The action values are based on users and residents being able to stay in the building 24 hours a day, 365 days a year.

Danish and foreign studies of residents in homes with and without PCB have shown that PCB in the indoor climate makes a significant contribution to PCB in the residents' blood. The health-related consequences of this are unknown.

Even if PCB is found in an indoor climate, it is not inevitable that there will be an increase in health risk. The municipality concerned, in consultation with the relevant medical officer if appropriate, will assess the results of the actual measurements with a view to determining the need for measures to counter the health risk posed by the PCB.

Recommended action values for periods of stay in a building are shown in the table below:

>3,000 ng PCB/m^3 air	Highest level which requires action without unnecessary delay. If the concentration in indoor air exceeds 3,000 ng/m^3, the Danish Health and Medicines Authority believes, on the current scientific basis, that extended periods of stay may be associated with a significant health risk and must be considered as an obvious health hazard. Action without undue delay is recommended.
300–3,000 ng PCB/m^3 air	Middle level at which a plan is drawn up to reduce the concentration to below 300 ng PCB/m^3 in indoor air in the long term. Until vacation and refurbishment of the premises, temporary mitigation measures, such as ventilation and cleaning, should be initiated.
<300 ng PCB/m^3 air	Lowest level at which there is not considered to be any elevated health risk.

2.3 Implementation of the survey

2.3.1 The elements and phases of the survey

The survey was carried out in four phases:

- Phase 1: Preparation of a detailed plan for a survey of PCB in materials in the Danish building stock. This phase was described in a separate report in October 2012.
- Phase 2: Implementation of a survey of PCB in materials in the Danish building stock. Estimation of the total number of buildings containing PCB in Denmark.
- Phase 3: Information on secondary and tertiary materials, and a study of PCB in capacitors and sealed glazing units.

› Phase 4: Study of the relationship between PCB in materials and indoor air. Estimation of the total number of buildings containing PCB in indoor air. Estimation of the total amount of PCB in the Danish building stock. Preparation of consolidated report on the survey.

The survey covers public institutions and offices, privately owned offices, blocks of flats and detached and semi-detached houses.

2.3.2 Statistical model and method

None of the existing accounts of PCB in building materials contain information which indicates that there have been significant geographic differences in the content and use of PCB in building materials during the PCB period.

Based on PCB surveys in 13 municipalities spread across the country, it has been shown that there were no systematic differences between the individual regions or between urban and rural municipalities, based on the subdivision of municipalities according to the rural district index as regards the presence of PCB in concentrations ≥50 mg/kg in municipal buildings. For this purpose, the municipalities were divided into rural municipalities (comprising "peripheral municipalities" and "rural municipalities") and urban municipalities (comprising "intermediate municipalities" and "urban municipalities"); see the Danish Ministry of Food, Agriculture and Fisheries' classification of the Danish municipalities into four classes (Ministry of Welfare, 2009).

The absence of general geographic differences in the presence of PCB in buildings was confirmed in the ENS survey.

As there are no systematic differences between rural areas or between urban municipalities and rural municipalities, there is no basis for weighting measurements taken in the various municipalities. On the other hand, an effort was made to obtain the maximum possible variation amongst the various building types within the individual municipalities.

As a starting point, it was assumed that there may be differences in the proportion of buildings containing PCB depending on when during the PCB period the buildings were erected. An effort was therefore made to ensure that the total number of buildings from which measurements were taken had an age distribution which is in line with the distribution of buildings across the country; see the extract from Offentlige Informationsserver (OIS). OIS is a government database which collates information on properties in Denmark. Based on the results of the ENS survey and studies conducted by municipalities, it has been demonstrated that sealant containing PCB was used to a significantly greater extent during the period 1965–1974 compared with the other sub-periods. The difference is so marked that it is possible to weight the data where necessary.

The data that are available contain no evidence to suggest that there are differences between the four building types, and an appropriate number from each type was therefore selected wherever possible. The results have shown that there are statistically significant differences in the presence of materials containing PCB between detached and semi-detached houses and the other building types, which indicates that it is necessary to process data for detached and semi-detached houses separately.

Wherever possible, the number of samples taken was proportional to the number of buildings dating from the period within the municipality.

The frequency of buildings with PCB was calculated using a dichotomous variable based on relevant cut-off values:

- 0.1 mg/kg, which is the recommended limit value at which materials must be destroyed at an incineration plant approved for the destruction of waste containing PCB.
- ≥50 mg/kg, which means that upon disposal the materials must be handled as hazardous waste and the PCB content must be destroyed.
- ≥5,000 mg/kg, which in the ENS survey was used as an indication of the presence of materials which may give rise to particularly high exposure to humans and the environment. The value of 5,000 mg/kg was also used as a cut-off value in relation to the selection of buildings for the investigation of PCB in indoor air (in buildings where only external primary sources exist).

A confidence interval was calculated to investigate the extent to which the observed frequency of random samples can be used to estimate the actual frequency of PCB in the total number of buildings in Denmark for each building type (in statistical terms “the population”). The interval indicates with a certain level of confidence (90% in this case) that the true frequency in the population is actually located in the interval. The confidence intervals were calculated on the basis of binomial distributions, which are used to describe frequencies. In the case of low random sample sizes, the confidence interval will not be symmetrical around the frequency that is found, while in the case of larger random samples, the distribution will approximate a normal distribution with a symmetrical confidence interval around the observed frequency.

For a given frequency, the span of the confidence interval will generally be proportional to the square root of the number of buildings surveyed (stated as n in a statistical analysis). The higher the frequency, the lower the relative uncertainty will be and the more symmetrical the confidence interval will be around the observed frequency.

A standard chi-square test was performed to investigate whether the observed differences between the four building types are statistically significant. The method tests whether the populations from which the random samples were taken could be identical despite the observed frequencies. The test results are indicated through a p value, which indicates the probability that, despite the apparent differences that have been observed, the data sets being compared may have been taken from populations which ultimately have identical frequencies. A low p value, such as $p<0.05$, thus indicates that a difference is significant at a 5% significance level.

A statistical analysis was carried out by Henrik Spliid at DTU Dataanalyse using the program system “R” and in this program system using the program called “glm”.

2.3.3 Selection of buildings for the study of PCB in materials

This section describes the selection of buildings for the study of PCB in materials. The approach used for the selection of buildings for the study of PCB in indoor air is described in more detail in section 3.4.5.

Detached and semi-detached houses

The survey encompassed 154 detached and semi-detached houses distributed across the country. The category covers the building types which are specified in the OIS database as:

110 Farmhouse for agricultural property
120 Free-standing detached house (bungalow)
130 Terraced, link or semi-detached houses (vertical separation between units)

The buildings included in surveys for the building type “detached or semi-detached house erected during the PCB period” are buildings which are owned by employees of COWI or Grontmij, terraced houses in housing associations in the five selected municipalities, and a number of detached and semi-detached houses owned by regional authorities or the selected municipalities.

The figure below shows the distribution of the 154 detached and semi-detached houses surveyed compared to the national total for this building type. There is a slight overrepresentation of terraced/link houses compared with bungalows, yet bungalows still account for 80% of the total number of buildings surveyed, and overall it is considered that the minor deviations from the national total are of no significance to the representativeness of the buildings selected. The average size of the buildings is 133 m^2, compared to 135 m^2 at national level.

A preliminary study of the presence of PCB in detached and semi-detached houses dating from 2009 concluded that it must be expected that many of the building materials and building products containing PCB which were used in larger buildings would also have been used in detached and semi-detached houses, particularly sealant and flooring compounds, durable floor and wall paints and, last but not least, sealed glazing units (Jensen et al., 2009).

As is apparent from the results of the survey, the frequency of buildings containing PCB does not remain constant during the period, but peaks for buildings erected during the sub-period 1965–1974. It is therefore important for the representativeness that the proportion of buildings from this period corresponds well with the distribution in OIS, so that this does not subsequently have to be corrected for. As can be seen from the figure below, there is a good correspondence between the national total and the detached and semi-detached houses surveyed that date from the period 1965–1974.

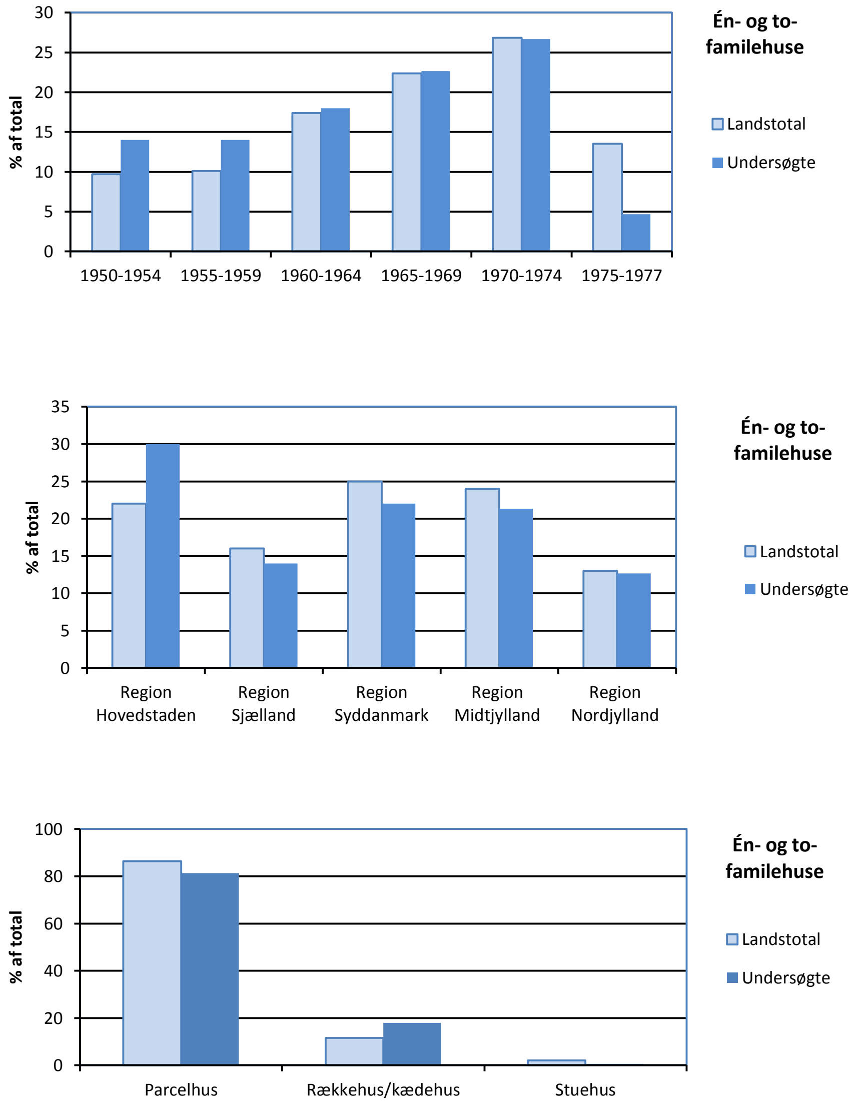


Figure 1 *Distribution of surveyed detached and semi-detached houses compared with the national total (OIS) taking into account the year of construction, distribution between regions and type of building (150 buildings).*

Blocks of flats and municipal institutions

In order to obtain a wide variation and subsequently investigate whether certain parameters could explain the observed differences between municipalities, an effort was made to ensure that the survey covered a relatively high number of buildings in a small number of municipalities. The surveys of municipal institutions and offices, as well as blocks of flats, therefore focused on five municipalities.

When selecting the municipalities, an attempt was made to supplement the measurements which had already been taken in the country's municipalities. No attempt was generally made to determine the extent to which measurements were taken in buildings other than municipal buildings in the various municipalities, but the availability of existing surveys of blocks of flats within the municipalities was investigated during phase 1 of the project. No such surveys were available.

The following municipalities contributed to the survey:

- Holbæk Municipality: Region Zealand, rural municipality
- Odense Municipality: Region of Southern Denmark, urban municipality, the country’s second largest municipality.
- Herning Municipality: Central Denmark Region, rural municipality, medium-sized town with major development during the PCB period.
- Hjørring Municipality: North Denmark Region, rural municipality.
- Ballerup Municipality: Capital Region of Denmark, urban municipality.

Given the extensive information that is available concerning PCB in municipal buildings, an effort was made to ensure that at least half the offices were non-public office buildings.

The distribution of floor area erected during the period 1950–1977 in the five municipalities expressed in terms of square metres compared with the national average is described in the phase 1 report and the trend in the five municipalities (collectively) largely follows the national trends. The distribution of the surveyed office buildings and public institutions and the national total (see the OIS database) is shown in Figure 2.

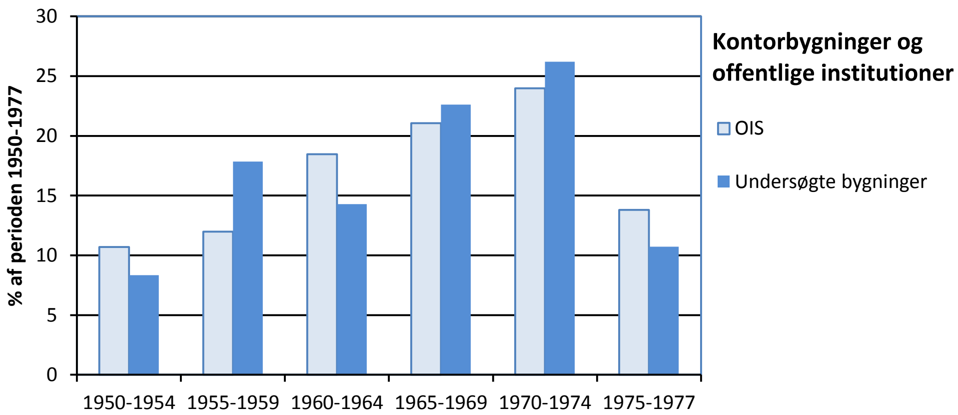


Figure 2 *Distribution of surveyed office buildings and public institutions (93 buildings) compared with the national total (OIS), taking into account year of construction.*

Office buildings

It proved to be impossible to identify a sufficient number of privately owned office buildings in the five municipalities. At a general level, it proved to be very difficult to find building owners willing to participate in the survey. In addition to contacting building owners, particularly owners who have a broad building portfolio such as banks and pension funds, an effort was made to include private office buildings where the five municipal authorities or the state are tenants. This method was chosen in order to ensure that a broad spectrum of building owners with varying access to operations and maintenance was represented. Even using this method, it was still not possible to obtain a sufficiently large number of buildings across the five municipalities. It was therefore necessary to alter the approach model, so that buildings which were distributed randomly across the country were chosen, corresponding to the model that was used for detached and semi-detached houses.

Blocks of flats

Local housing associations in the five municipalities and major national housing associations with local offices in the municipalities were contacted in order to ask them to participate in the survey. During the selection process, an effort was made to cover as many different types of building owner as possible, whilst at the same time ensuring that samples from generally taken from two buildings from each local office. The survey covered 105 buildings from 52 local offices of seven housing associations in the five urban centres. The distribution of the surveyed municipalities and the national average (see the OIS database) is shown in the following figure.

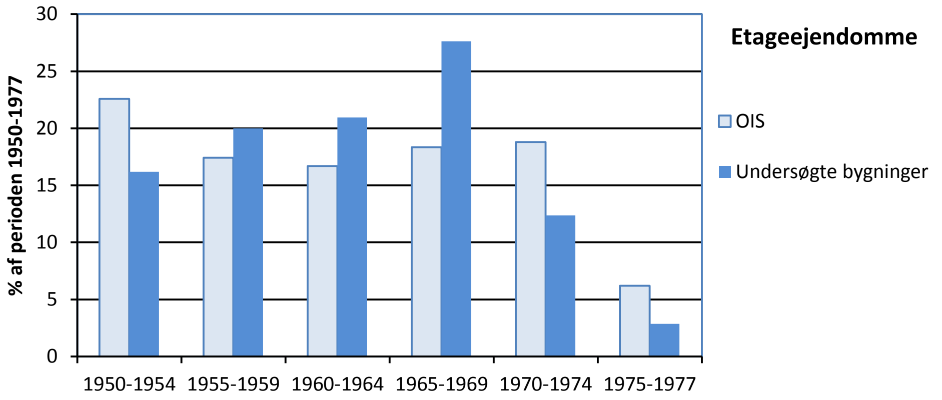


Figure 3 *Distribution of surveyed blocks of flats (105 buildings) compared with the national total (OIS) taking into account year of construction.*

2.3.4 Presence of PCB in sealed glazing units and fluorescent lamp capacitors

The building surveys did not cover PCB in sealed glazing units or fluorescent lamp capacitors, as destructive testing would have been required.

A survey of PCB in sealed glazing units and fluorescent lamp capacitors was therefore carried out in connection with waste management. Sealed glazing units were collected at recycling centres in the five selected municipalities and examined for the presence of PCB. Capacitors in fluorescent lamps collected by two national processors of electrical and electronic waste were examined. The selection process and investigation methods are described in more detail in the respective sections for these two categories.

2.3.5 Selection of buildings for the study of PCB in indoor air

The results of the measurements of PCB in materials in the 352 selected buildings were used as a basis for the selection of buildings for the measurement of PCB in indoor air. So as not to waste resources on measurements in a large number of buildings in which it was unlikely that high PCB concentrations would be found in indoor air, it was decided to take measurements in buildings in which the highest concentrations of PCB in materials were found.

On the basis of results of associated measurements of PCB in materials and indoor air from existing surveys, as presented in section 4.3.2, it was concluded that there is very little probability of finding PCB concentrations in indoor air ≥300 ng/m^3 if there was no:

- indoor source with ≥50 mg/kg, or
- outdoor source with ≥5,000 mg/kg.

Against this background, 20 detached and semi-detached houses, 31 blocks of flats and 33 office buildings and public institutions which fulfilled the above conditions were selected.

It subsequently became apparent that some building owners did not wish to take part in the indoor air surveys. Amongst the buildings selected, the owners of five detached and semi-detached houses, eleven blocks of flats (all belonging to the same housing association) and one office building did not wish to take part in the subsequent surveys.

2.3.6 Contact with contributors

An agreement with building owners was drawn up at the start of the surveys.

Communication plan

All communication with building owners followed a detailed communication strategy and communication plan, which had been approved by the project's steering group. An example of an analysis and study report for building owners is presented in Annex 4.

3 Results of measurements of PCB in materials

3.1 PCB in sealant, paint and flooring

3.1.1 Sampling and analysis

Based on our existing knowledge of building materials which could contain PCB as a primary source, the measurements taken in the buildings included in the survey covered the following materials:

- Sealants: All flexible sealants used both indoors and outdoors.
- Paint: Anti-corrosion paint (e.g. on metal doors), outdoor facade paint (e.g. balconies and galleries) and indoor durable floor and wall paints. Other paint types may be secondarily contaminated and are not included in the survey.
- Floorings: Anti-slip flooring, leveling floor compounds and floor coverings such as linoleum, vinyl and cork and adhesive for the installation of flooring.

The following were also investigated as special elements of the survey:

- Sealed glazing units, collected at recycling centres in five municipalities.
- Fluorescent lamp capacitors collected by two national processors of electronic waste.
- Penetration of PCB into adjoining materials (secondary presence of PCB)

Sampling in connection with the latter three elements is described in the respective sections, while the procedure used for surveying materials in the buildings is described briefly here.

As a basis for the sampling, detailed sampling instructions were drawn up which described communication with contact persons, building review, sampling procedure and registrations in the field, as well as the use of personal protective equipment.

For the sampling, an iPad-based app was developed which guides sample takers through the building review and a review for each material sample. This ensures a consistent sampling procedure and reporting for all buildings and material samples. All information, including photographic documentation, was uploaded directly to a database, to which the results of the laboratory tests were subsequently linked.

In cases where a building review did not find any materials which could potentially contain a primary presence of PCB, it was concluded that the building did not contain any primary presence of PCB and no samples were taken. This assessment was primarily used for buildings that have been comprehensively refurbished since the PCB period.

During the sampling process, samples of all relevant materials were taken, and the sampling site was subsequently repaired and made good as necessary.

The samples were analysed in a laboratory using the GC-MSD-SIM method for the following seven PCB congeners: PCB #28, #52, #101, #118, #138, #153 and #180 (collectively referred to as "PCB_7"). Total PCB was calculated as five times the sum of the seven congeners. A detection limit of 0.02 mg/kg was used for each PCB congener.

3.1.2 Results across materials and building categories

During the survey, samples were taken from buildings spread across the entire country, but centred particularly on the five selected municipalities. The distribution of the buildings surveyed, broken down between the three building types and concentrations above or below 50 mg/kg, is shown in the map below. Each building type has a separate colour and the intensity of the colour indicates whether the concentration is above or below 50 mg/kg.

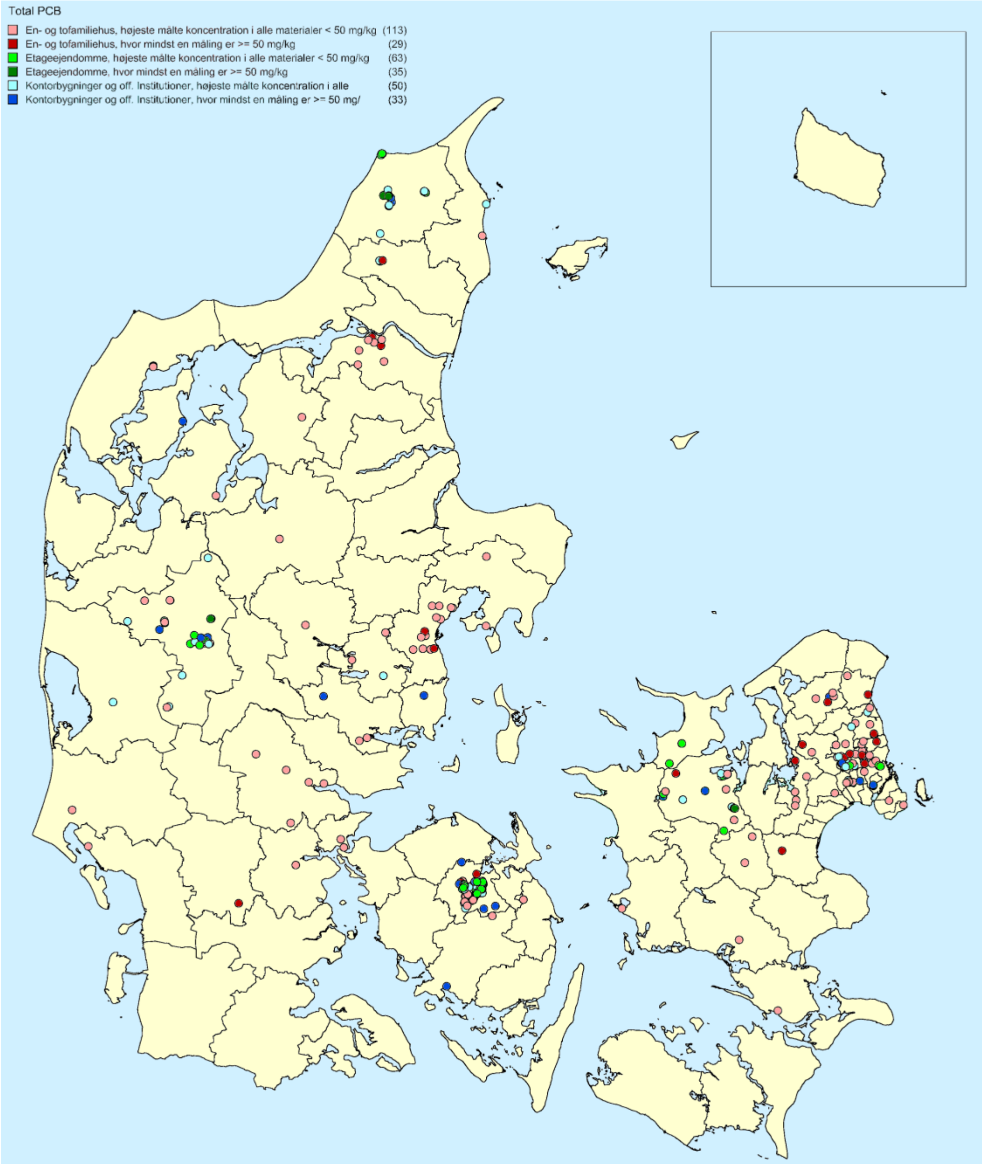


Figure 4 *Geographic distribution of surveyed buildings and buildings in which ≥50 mg/kg PCB was found in one or more materials.*

Table 4 shows for each building type how many of the surveyed buildings contained PCB in various concentration intervals. A total of 352 buildings were surveyed, with samples being taken from 323 of these.

The concentration intervals indicate the highest measured value for each building, regardless of material type. The number of buildings with materials in numerous relevant concentrations and the total number of buildings with concentrations ≥0.1 mg/kg, ≥50 mg/kg and ≥5,000 mg/kg respectively are stated. In this report, these cut-off values will generally be used to indicate the frequency of buildings in which there is a problem with PCB.

As can be seen, materials containing ≥50 mg/kg were found in 19% of the surveyed (and analysed) detached and semi-detached houses, in 33% of the blocks of flats and in 35% of office buildings and public institutions. The results show that PCB is widespread in all building types, although its presence in indoor materials in detached and semi-detached houses is less than for the other building types. A more detailed statistical analysis of the results is presented in section 3.1.12. The results for each building type and material type are discussed in separate sections below.

It is notable that 75% of the surveyed detached and semi-detached houses, 90% of the blocks of flats and 80% of the office buildings and public offices to some extent contain materials containing ≥0.1 mg/kg, which means that the materials must be destroyed upon disposal. The validity of this outcome and the origins of the PCB are discussed in the following sections.

*Table 4 Surveyed **buildings** broken down according to the highest measured PCB concentration in materials, regardless of material type.*

	Detached and semi-detached houses		Blocks of flats		Office buildings and public institutions	
Number surveyed (352)	154		105		93	
Number sampled (323)	142		98		83	
PCB_{total}, mg/kg	Number	% of total *1	Number	% of total *1	Number	% of total*1
All materials	142		98		83	
<0.1	27	18%	3	3%	9	10%
0.1–50	86	56%	60	57%	41	44%
50–500	15	10%	18	17%	10	11%
500–5,000	4	3%	5	5%	8	9%
≥5,000	10	6%	12	11%	15	16%
Total ≥0.1	115	75%	95	90%	74	80%
Total ≥50	29	19%	35	33%	33	35%
Materials located indoors	109		95		73	
<0.1	20	13%	2	2%	5	5%
0.1–50	73	47%	67	64%	42	45%
50–500	9	6%	16	15%	13	14%
500–5,000	1	1%	4	4%	5	5%
≥5,000	6	4%	6	6%	8	9%
Total ≥0.1	89	58%	93	89%	68	73%
Total ≥50	16	10%	26	25%	26	28%

*1 The total number includes the buildings from which no samples were taken, as it was believed that these buildings would not contain PCB.

The table below (Table 5) shows, for each building type, the number of buildings containing PCB in different concentration intervals broken down according to materials located outdoors and indoors respectively. The same data are shown in Table 6 as frequencies (%) of the total number of buildings surveyed in each building category.

The concentration intervals also indicate the highest measured value for each building for the individual materials and location. As an example of how the table should be interpreted, sealant containing ≥50 mg/kg was found outdoors in eight detached and semi-detached houses, corresponding to 5% of all surveyed detached and semi-detached houses. Note that the numbers located both outdoors and indoors are stated for the same building, i.e. the total number of buildings in which sealant containing ≥50 mg/kg was found cannot be calculated by adding together the two values (as some buildings contain the material concerned both indoors and outdoors).

As regards the sealants, there is a tendency for high concentrations ≥5,000 mg/kg to primarily occur outdoors in detached and semi-detached houses and blocks of flats, while the picture is different for office buildings and public institutions, where a significant presence of sealants indoors can also be observed.

Paint containing ≥5,000 mg/kg was found outdoors in three buildings and indoors in 10 buildings. Paint containing ≥5,000 mg/kg was therefore found in 3.4% of all buildings surveyed.

Paint containing ≥50 mg/kg was found indoors in 51 (14%) of the buildings, while sealant containing ≥50 mg/kg was only found indoors in 13 (4%) of the buildings, which is a surprising result. Sealant containing ≥5,000 mg/kg was found indoors in seven (2%) of the total number of buildings, but in 5% of office buildings and public institutions.

This may indicate that paint may be acting as the primary source in a large number of buildings, as discussed below.

Table 5 *Surveyed **buildings** broken down according to the highest measured PCB concentration in materials broken down according to material type and whether the material was located outdoors or indoors.*

	Detached and semi-detached houses		Blocks of flats		Office buildings and public institutions	
Number surveyed	154		105		93	
Number sampled	142		98		83	
All materials, mg/kg	Outdoors 104	Indoors 109	Outdoors 62	Indoors 95	Outdoors 55	Indoors 73
No materials *1						
<0.1	40	20	21	2	20	5
0.1–50	50	73	28	67	17	42
50–500	6	9	3	16	1	13
500–5,000	3	1	4	4	7	5
≥5,000	5	6	6	6	10	8
Total ≥50	14	16	13	26	18	26
Sealant, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	42	15	25	11	19	10
0.1–50	33	10	8	8	13	9
50–500	4	0	1	1	1	2
500–5,000	1	0	2	1	6	2
≥5,000	3	1	6	1	9	5
Total ≥50	8	1	9	3	16	9
Paint, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	12	14	10	2	8	7
0.1–50	26	64	26	70	7	47
50–500	2	8	2	15	0	9
500–5,000	2	2	2	3	1	4
≥5,000	2	4	0	4	1	2
Total ≥50	6	14	4	22	2	15
Flooring, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	0	15	0	10	0	7
0.1–50	0	16	0	12	0	22
50–500	0	1	0	2	0	3
500–5,000	0	0	0	0	0	2
≥5,000	0	2	0	1	0	1
Total ≥50	0	3	0	3	0	6

*1 The total number includes the buildings from which no samples were taken, as it was believed that these buildings would not contain PCB.

Table 6 *Surveyed **buildings** broken down according to the highest measured PCB concentration in materials broken down according to material type and whether the material was located outdoors or indoors. Stated as frequencies of the total number surveyed.*

	Detached and semi-detached houses		Blocks of flats		Office buildings and public institutions	
Number surveyed	154		105		93	
Number sampled	142		98		83	
All materials, mg/kg	Outdoors 104	Indoors 109	Outdoors 62	Indoors 95	Outdoors 55	Indoors 73
No materials *1						
<0.1	26%	13%	20%	2%	22%	5%
0.1–50	32%	47%	27%	64%	18%	45%
50–500	4%	6%	3%	15%	1%	14%
500–5,000	2%	1%	4%	4%	8%	5%
≥5,000	3%	4%	6%	6%	11%	9%
Total ≥50	9%	10%	12%	25%	19%	28%
Sealant, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	27%	10%	24%	10%	20%	11%
0.1–50	21%	6%	8%	8%	14%	10%
50–500	3%	0%	1%	1%	1%	2%
500–5,000	1%	0%	2%	1%	6%	2%
≥5,000	2%	1%	6%	1%	10%	5%
Total ≥50	5%	1%	9%	3%	17%	10%
Paint, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	8%	9%	10%	2%	9%	8%
0.1–50	17%	42%	25%	67%	8%	51%
50–500	1%	5%	2%	14%	0%	10%
500–5,000	1%	1%	2%	3%	1%	4%
≥5,000	1%	3%	0%	4%	1%	2%
Total ≥50	4%	9%	4%	21%	2%	16%
Flooring, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
No materials						
<0.1	0%	10%	0%	10%	0%	8%
0.1–50	0%	10%	0%	11%	0%	24%
50–500	0%	1%	0%	2%	0%	3%
500–5,000	0%	0%	0%	0%	0%	2%
≥5,000	0%	1%	0%	1%	0%	1%
Total ≥50	0%	2%	0%	3%	0%	6%

*1 The total number includes buildings from which no samples were taken, as it was believed that there were no relevant materials.

The total frequency of buildings containing PCB in individual materials across all building types is shown in Table 7. The table indicates frequencies of buildings from which samples of the material were taken and frequencies of the total number of buildings (regardless of whether or not samples of the material concerned were taken). Across all buildings, sealant containing ≥50 mg/kg was found in 11% of the buildings, while the corresponding values for flooring and paint are 3% and 16% respectively.

Table 7 *Frequency of **buildings** with the individual material types across building types. Highest measured value per building.*

PCB_{total} mg/kg	Sealant			Flooring			Paint		
	Number of buildings	Freq-uency of sampled	Freq-uency, total number	Number of buildings	Freq-uency of sampled	Freq-uency, total number	Number of buildings	Freq-uency of sampled	Frequency, total number
Number of sampled buildings	238			105			490		
Total number of buildings	352			352			352		
≥0.1	122	51%	35%	64	61%	18%	265	54%	75%
≥50	38	16%	11%	12	11%	3%	58	12%	16%
≥5,000	21	9%	6%	4	4%	1%	13	3%	4%

*1 90% confidence interval determined on the basis of a binomial distribution.

The results of all analysed material samples are shown in Table 8. These data were used in the subsequent calculations of residual amounts of PCB in the building stock.

Table 8 *All **material samples** broken down according to building type, PCB concentration, material type and location of the material (indoors/outdoors).*

All materials	Detached and semi-detached houses		Blocks of flats		Office buildings and public institutions	
	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
<0.1	168	106	134	189	100	139
0.1–50	118	188	78	404	49	283
50–500	14	15	5	32	7	37
500–5,000	5	2	10	9	12	16
≥5,000	11	9	9	8	29	20
Sealant, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
<0.1	133	28	93	35	74	38
0.1–50	77	16	24	32	38	20
50–500	11	0	1	3	7	5
500–5,000	2	0	7	2	11	6
≥5,000	9	2	9	2	27	16
Paint, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
<0.1	35	48	41	124	26	74
0.1–50	41	151	54	347	11	209
50–500	3	14	4	27	0	28
500–5,000	3	2	3	6	1	7
≥5,000	2	4	0	5	2	3
Flooring, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
<0.1	0	30	0	30	0	27
0.1–50	0	21	0	25	0	54
50–500	0	1	0	2	0	4
500–5,000	0	0	0	1	0	3
≥5,000	0	3	0	1	0	1

3.1.3 PCB in paint

Table 9 shows the presence of PCB in paint as a function of the use of the paint. Note that the frequencies indicate the frequency of the analysed samples and not the frequency of surveyed buildings, as in the previous section.

A total of 1,277 paint samples were analysed. Paint containing high PCB concentrations was found in all building types, both indoors and outdoors.

The analyses were carried out on the combined layer of paint, of which paint containing PCB would only constitute a part in many cases. The PCB content of the original paints would therefore have been higher.

The highest values were found for paint which had been applied to metal outdoors, with the average for 66 paints being 1,900 mg/kg and the highest concentration 80,000 mg/kg. The following tables give mean values for each type of measurement, as these values will subsequently be used for estimating total amounts of PCB in the building stock. The highest values were primarily found on railings, such as balconies. Paint containing PCB for application on metal was primarily used (see foreign sources) on ships and for the corrosion protection of industrial installations (cited in Jensen et al., 2009), but it has also been used for the corrosion protection of metal outdoors in homes.

The levels found on facades and bases outdoors were significantly lower than reported in the Danish Environmental Protection Agency's study of PCB in materials from renovations and demolitions, where in 59 samples ≥50 mg/kg was found in 37% of the samples, compared with 3% in the ENS survey (Alslev et al., 2013; data described in section 5.4). There is no obvious explanation for this significant difference, as the facade samples in the Danish Environmental Protection Agency's survey similarly primarily originated from homes.

The PCB concentrations found indoors on metal were generally significantly lower than the values found outdoors, with a single stair banister as the only exception. Paint on radiators generally came at the low end, with two measurements of around 100 mg/kg.

As expected, the concentration of PCB in paint on wood was low, with slightly higher values indoors than outdoors, but the number of measurements is small, and samples of paint on wood were not collected systematically because it was assumed not to be a primary source. Indoors, the levels for paint in the brick/base category were only slightly lower than those for paint on floors. Painted floors and walls were typically located on staircases and in corridors, basements, laundry rooms, storage rooms and toilets, with a few exceptions where walls in living rooms had been painted.

Table 9 Distribution of analyses of paint containing PCB.

	Painted material			
	Metal	Wood	Floors	Brick/base
Outdoors				
Number of samples	66	13	0	147
Frequency ≥0.1 mg/kg *1	62%	54%	-	52%
Frequency ≥50 mg/kg	24%	0%	-	3%
Frequency ≥5,000 mg/kg	5%	0%	-	1%
Mean, mg/kg	1,906	0.4	-	182
Maximum, mg/kg	80,000	1	-	25,000
Indoors				
Number of samples	502	22	109	417
Frequency ≥0.1 mg/kg	75%	68%	84%	77%
Frequency ≥50 mg/kg	13%	5%	10%	5%
Frequency ≥5,000 mg/kg	1%	0%	2%	2%
Mean, mg/kg	41	13	228	123
Maximum, mg/kg	16,500	115	11,500	110,000

*1 Note that frequencies are specified here as a percentage of the total number of samples, not the number of buildings.

Cumulative distribution function

A Norwegian study of facade paint showed that around 45% of the paints contained ≥0.1 mg/kg and 19% contained ≥50 mg/kg (Jartun et al., 2009). The article contains an analysis based on a cumulative distribution function which showed that a high proportion of the measurements fell into one of two groups within the intervals 1–10 mg/kg and 1,000–3,000 mg/kg and the authors suggest that this is the result of two differing original uses of the PCB in the paint. At the high concentrations, PCB has been used to plasticise the paint to increase its chemical and thermal resistance, while PCB at low concentrations has presumably been present in raw materials as binding agents or pigments, and performed no actual function in the finished paint. As the analysed paints were facade paints, the low concentrations were assumed not to be a result of contamination from primary sources (Jartun et al., 2009).

The cumulative distribution functions of all paint samples taken outdoors and indoors in the ENS survey are shown in the figure below. Note the logarithmic scale on the x-axis. The figure shows that both indoors and outdoors around 10% of the samples contain ≥50 mg/kg, but the proportion of indoor samples containing PCB in the interval below 50 mg/kg is significantly higher. The majority of the indoor samples are distributed evenly between 1 and 10 mg/kg, and the majority of outdoor samples are distributed between 1 and 5 mg/kg. At the higher end of the concentration scale, there is no evidence to suggest that the samples are concentrated in a particular interval (steep areas on the curve). If the original source of the PCB in both indoor and outdoor paint had been the same, it would have suggested that a significant proportion of the indoor samples may have been contaminated by a different source. This means that the frequency of samples with demonstrated PCB is higher in the indoor paints and that the average concentration is slightly higher at the lower end of the concentration interval. Differences in the average concentration may however simply be a function of the number of layers of paint that have been applied since the PCB period.

However, it is worth noting that 55% of the paint samples taken outdoors still contained ≥0.1 mg/kg, which is in line with the results of the Norwegian survey. The problem is discussed further in section 3.1.9.

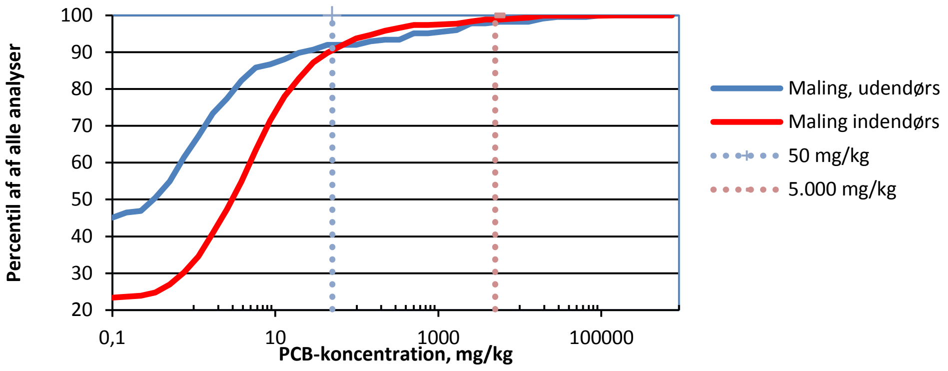


Figure 5 Cumulative distribution functions for all paint samples.

3.1.4 PCB in sealants

Table 10 shows the presence of PCB in sealants as a function of the location of the sealants. Note that the frequencies indicate the frequency of the analysed samples and not of surveyed buildings.

A high proportion of the sealants contained several hundred thousand mg/kg and mean values for all analysed sealants outdoors were calculated at around 20,000 mg/kg.

Indoors, a marked difference can be observed between sealant joints around windows and doors and those between concrete elements. Thus 52% of the joints between concrete elements contained ≥5,000 mg/kg, while just 2% of those around windows and doors contained such high concentrations. The explanation may well be that the joints around doors and windows are generally replaced during refurbishment to a much greater extent, while concrete element joints are not replaced.

Table 10 Presence of PCB in sealant joints as a function of the use of the sealant.

PCB_{total}	Around doors and windows	Between concrete elements	Other uses
Outdoors			
Number of samples	199	105	26
Frequency ≥0.1 mg/kg	46%	51%	27%
Frequency ≥50 mg/kg	22%	32%	4%
Frequency ≥5,000 mg/kg	8%	18%	4%
Mean, mg/kg	18,465	20,457	21,156
Maximum, mg/kg	550,000	310,000	550,000
Indoors			
Number of samples	130	29	46
Frequency ≥0.1 mg/kg	51%	86%	28%
Frequency ≥50 mg/kg	13%	55%	4%
Frequency ≥5,000 mg/kg	2%	52%	4%
Mean, mg/kg	3,332	81,399	5,675
Maximum, mg/kg	215,000	310,000	255,000

*1 Note that frequencies are specified here as a percentage of the total number of samples, not the number of buildings.

Sealant samples were taken from between concrete elements or between concrete and masonry outdoors from 44 buildings in all categories. Samples containing ≥5,000 mg/kg (typically more than 100,000 mg/kg) were found in 18% of samples, broken down between six office buildings and public institutions, three blocks of flats and a single bungalow.

Samples from sealant joints around windows and doors were taken in 82 buildings in all categories. Sealant joints containing ≥5,000 mg/kg (typically more than 100,000 mg/kg) were found outdoors in seven buildings: four office buildings and public institutions, two detached and semi-detached houses and one block of flats (Table 11).

Table 11 Presence of PCB in sealant joints as a function of the use of the sealant, broken down according to building type.

	Number of buildings containing ≥5,000 mg/kg		
	Around doors and windows	Between concrete elements	Other
Outdoors, number of buildings from which samples were taken	82	44	18
Office buildings and public institutions	4	7	1
Blocks of flats	1	6	0
Detached and semi-detached houses	2	1	0
Indoors, number of buildings from which samples were taken	48	13	17
Office buildings and public institutions	1	4	1
Blocks of flats	1	0	0
Detached and semi-detached houses	0	1	0

Note that the same building may be counted in several places.

A total of 36 sealant samples fell in the interval 500–6,500 mg/kg: 14 between concrete elements and 22 around windows, of which a significant proportion was stated by the building owners as having been replaced during refurbishment. Concentrations in this interval were primarily presumed to be the result of contamination from previous joints with several hundred thousand mg/kg via the secondary presence of PCB in masonry or concrete. New joints around windows which had been replaced were not systematically sampled, as the focus of the survey has primarily been on primary sources, and this hypothesis can therefore not be confirmed by the results.

As expected, the presence of sealants containing PCB depended on whether the windows had been replaced. The table below shows the significance of window replacement on the observed frequency of joints containing PCB (both around windows/doors and between concrete elements) in the buildings. A distinction is drawn between one group where it had been stated that the windows had been replaced and another group where the windows had apparently not been replaced (determined partly by reading the age of sealed glazing units) or no information was available. The frequency of sealant joints containing ≥5,000 mg/kg was therefore twice as high when the windows had not been replaced. However, in the buildings in which the windows had apparently been replaced, certain sealant joints were found which had high concentrations around doors and windows, typically around certain doors and windows which had not actually been replaced, and between concrete elements. At a very general level, the data show that there are many cases where only some of the windows in a building had been replaced and there is therefore no clear distinction between the two groups.

In addition to the primary presence of PCB which is considered here, sealants which have replaced sealants containing PCB will contain tertiary PCB as a result of the migration of PCB which has accumulated in the source wall.

The table also shows that information simply to the effect that windows have been replaced will not be sufficient to ensure the certainty that there are no joints with a high content of PCB in the buildings.

Table 12 Frequency of PCB in sealant joints (all types) as a function of information concerning window replacement.

	Frequency of PCB in sealant joints, % of number of buildings		
Number of buildings	352	171	181
≥0.1	29%	27%	30%
≥50	11%	5%	15%
≥5,000	6%	4%	8%

3.1.5 PCB in flooring

A total of 200 samples of flooring were analysed. Flooring containing ≥500 mg/kg was found in all building types.

Floor compounds containing ≥2,500 mg/kg were found in two detached and semi-detached houses and two public institutions and one block of flats – in all cases in basements (equivalent to approx. 1.5% of all buildings). However, the samples generally contained both floor compound and the overlying paint, and the PCB may therefore originate from the paint to some extent. All other samples of floor compounds were below 50 mg/kg.

Floor coverings consisted of linoleum, vinyl, cork or glued carpets. The sample that was taken generally consisted of the covering, including some of the adhesive. Four of the samples contained ≥50 mg/kg and one material from an office building differed markedly by containing 2,450 mg/kg (which increased the mean). Compared with paint and sealant, the frequency of flooring samples containing ≥50 mg/kg was relatively low given that a total of 200 samples had been taken and analysed.

Table 13 Frequency of PCB in flooring (proportion of samples).

PCB_{total}	Adhesive *1	Floor compound	Flooring *2
Number of samples	86	52	62
Proportion with ≥0.1 mg/kg	56%	56%	58%
Proportion with ≥50 mg/kg	15%	12%	6%
Proportion with ≥5,000 mg/kg	0%	8%	0%
Mean, mg/kg	15	1061	47
Maximum, mg/kg	500	23,500	2,450

*1 Adhesive beneath cork, linoleum, vinyl, etc.

*2 Linoleum, cork, carpets with backing, vinyl.

It is still unclear to what extent PCB in the flooring materials originates from the adhesive or contamination via indoor air, or whether linoleum and other flooring contain small amounts of PCB themselves. In a press release, Brancheforeningen Gulvbranchen, the Danish trade organisation for flooring suppliers and fitters, recently announced that Gulvbranchen's linoleum suppliers stress that PCB has never been a component or otherwise been used in the manufacture of linoleum, either today or in the past.

In order to determine whether there was a pattern, congener profiles were analysed for the adhesives and floorings, but no pattern could be identified because the materials contain PCB with markedly different congener profiles. The floor adhesives could be divided into three groups depending on concentration, and these three groups had very different congener profiles. The average of the normalised profiles for the three groups can be seen in Figure 6 together with two technical mixtures, the German Clophen A60 and Arochlor 1242 from the USA. Group 3 has Clophen A60's characteristic profile around PCB #111, #118, and #138 and is very similar to the profiles that are observed for many paints. Group 1 is similar to Arochlor 1242, but is not an exact match. However, as the concentrations in the adhesives are relatively low (mean of 15mg/kg), it is most likely that tertiary contamination from various primary sources (referred to in the next section) is involved.

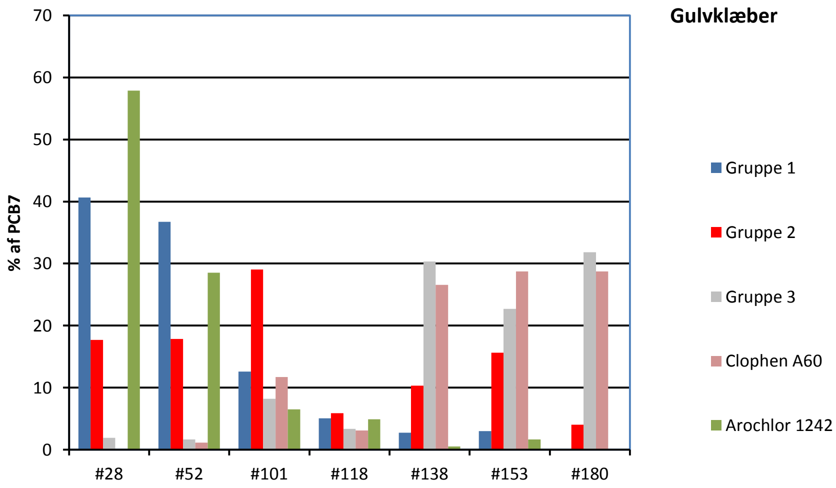


Figure 6 *Congener composition of three groups of samples of floor adhesives and two technical PCB mixtures.*

3.1.6 Presence in detached and semi-detached houses

The survey shows that PCB is widespread in detached and semi-detached houses, with materials containing ≥50 mg/kg in 19% of the houses. However, as will be shown later, the presence was statistically significantly less than in the other two types of building. The lower frequency is particularly marked in the case of materials with concentrations ≥5,000 mg/kg, which were found in 6% of the buildings.

The majority of these materials containing ≥50 mg/kg comprised paint used either indoors or outdoors. Indoors, paint was for example found on water pipes in toilets, and on floors in larders, laundry rooms, offices and storage rooms, while outdoors paint had been applied to stairs. Floor compounds containing ≥5,000 mg/kg were found in two buildings in a laundry room and an office. Sealant joints with high concentrations (≥100,000 mg/kg) were found in two buildings around windows and doors, outdoors in one of the buildings and indoors in another. In all cases, only a proportion of the sealant joints contain a high concentration of PCB. No cases were found of sealant between concrete elements or sanitary sealant in bathrooms with high PCB concentrations. The sources that have been the most frequently occurring sources of PCB in indoor air in institutional buildings and blocks of flats thus occur at a much lower frequency in detached and semi-detached houses.

3.1.7 Presence in blocks of flats

In the blocks of flats, there were widespread occurrences of sealant joints containing high concentrations between concrete elements and some occurrences around windows/doors. A single example was found of an indoor joint around a window in a staircase which contained 6,500 mg/kg.

Paint containing concentrations ≥5,000 mg/kg was found indoors in four buildings – two cases of paint applied to concrete in basements, one case of paint applied to metal banisters and one case of paint applied to a metal door frame in a staircase.

Cases of paint containing 50–5,000 mg/kg (40 samples) were particularly found indoors on staircases and in laundry rooms, storage rooms, bicycle basements and boiler rooms. The paint had been applied to concrete, downpipes and metal railings. There were no cases of paint containing ≥50 mg/kg in living rooms. Only two examples of facade paint containing PCB in this concentration interval were found. Most outdoor paints containing PCB had been applied to iron railings.

On the basis of the survey, it is possible to state that there is no widespread occurrence of indoor sealants with high concentrations, as has for example been seen in Farum. However, the possibility that such sealants could be found in a small percentage of all blocks of flats cannot be excluded.

The results indicate that paint containing PCB in blocks of flats has often been applied to metal and indoors as a painted surface on staircases, and in communal areas of blocks of flats. PCB was found in floor compound in a single case.

3.1.8 Presence in office buildings and public institutions

As mentioned previously, it was very difficult to identify sufficient private owners of office buildings who were willing to take part in the survey, and the total number of private office buildings surveyed was therefore just 36, whereas the aim was to survey 50 such buildings. It was therefore decided to include more public institutions in the survey than originally planned.

Table 14 shows the virtually identical frequencies of the presence of PCB ≥50 mg/kg and ≥5,000 mg/kg in both groups of building. Very limited data are available concerning PCB in private office buildings, but the results here show that there is no basis for assuming that the frequency should be lower than that in public buildings. As a starting point for the survey, these two groups of building have been treated as a combined building type, but the two groups were separated upon subsequent extrapolation to the total number of buildings in Denmark. The principal reason for this is that a substantial amount of data is available for municipal institutions from the municipal authorities which was used in the statistical analysis, but cannot be assumed to be representative of the private office buildings.

As regards public institutions, there is less of a predominance of buildings which have not been refurbished compared with the average for the municipalities (overall, around half of the buildings have been declared as having been refurbished), but this was not the case for the office buildings which were selected randomly, as samples were taken from all the buildings which were registered for the survey. No data are available for the private buildings which can be used to assess the representativeness as regards the degree of refurbishment.

When analysing in more detail where PCB was found in high concentrations, there is no longer any statistical basis for generalisations, but the results that were obtained can be used as examples.

In the office buildings, all samples containing ≥5,000 mg/kg were found outdoors in the form of sealant joints between concrete elements, joints around windows and doors and outdoor paint on metal. The fact that no PCB concentrations ≥5,000 mg/kg were found indoors may be a statistical aberration. The widespread presence of PCB at concentrations ≥50 mg/kg in the office buildings (37% of the buildings) shows that it will also be necessary to carry out broad screenings for this type of building if the presence of high concentrations of PCB is to be identified.

In institutions, six of the samples containing ≥5,000 mg/kg were found indoors and comprised sealant joints between concrete elements (three buildings), floor compound and paint (two buildings). The three outdoor samples containing high concentrations in the sealant all occurred between concrete elements.

A more detailed comparison of these results with the results obtained in surveys conducted by municipal authorities follows in section 5.1, which describes the results of surveys in municipalities, and section 6.1, which summarises the results across the surveys.

Table 14 Frequency of PCB in all materials in office buildings and public institutions.

PCB_{total}	Public institutions		Office buildings	
	Number	Frequency, % of total number	Number	Frequency, % of total number
≥0.1	47	82%	27	75%
≥50	20	35%	13	36%
≥5,000	9	16%	6	17%
Total number of buildings	57		36	

3.1.9 Primary versus tertiary sources

PCB has been used in the form of technical mixtures with varying degrees of chlorination and different congener profiles. Using the data from the Danish Health and Medicines Authority's study in Farum based on a principal component analysis, Frederiksen et al. (2012) showed that sealant compounds from buildings could be divided into four groups, of which two approximately matched the technical mixtures Aroclor-1232 and Aroclor-1254, while two groups could not be matched with the known mixtures.

The fact that the primary sources do not have a uniform fingerprint (congener profile) but are very variable makes it very difficult to distinguish between primary and tertiary sources and determine whether a sample can be attributed to one or other type of source.

However, some of the sources stand out.

A general distinction is made between three types of source:

- Primary sources, where the PCB was contained in the materials at the time they were first used. The presence may be intentional, as will generally be the case for the higher concentrations, or unintentional contamination caused during the manufacture of the materials.
- Secondary sources, which have been contaminated by PCB from adjoining primary sources through migration between materials.
- Tertiary sources, which have been contaminated by PCB from primary sources via another medium, which will normally be the indoor air.

In order to analyse the composition of primary sources, an analysis was carried out of sealants containing >100,000 mg/kg, paint and floor materials containing ≥5,000 mg/kg and three types of capacitor (referred to in more detail in section 3.2.4). Within each material type, it is possible to analyse whether some groups could be formed by looking at the ratios between different congeners.

The figures below compare the primary sources with four types of Clophen, the German-manufactured PCB, taken from Takasuge et al. (2006). The medium chlorinated PCBs are shown in both figures. PCB from a number of manufacturers with slightly different congener compositions has presumably been used, but it is possible to see some common groups of PCB. The designations used here, which have been derived from the Clophen types, were chosen for practical reasons. The US Arochlor types (which are often used by laboratories for matching purposes) or other manufacturers may equally have been used.

Capacitor A30 is the only one of the sources which matches the low chlorinated Clophen A30, while there is both a type of capacitor and a type of sealant joint which matches Clophen A40. The same applies to Clophen A50, although the capacitors differ to some extent as they have a relatively high proportion of PCB 188.

The high chlorinated Clophen A60 matches a type of sealant, a type of paint and a type of flooring. Sealant A40 has only been found indoors, while sealant A60 has only been found outdoors, but these finds may well have been a matter of chance.

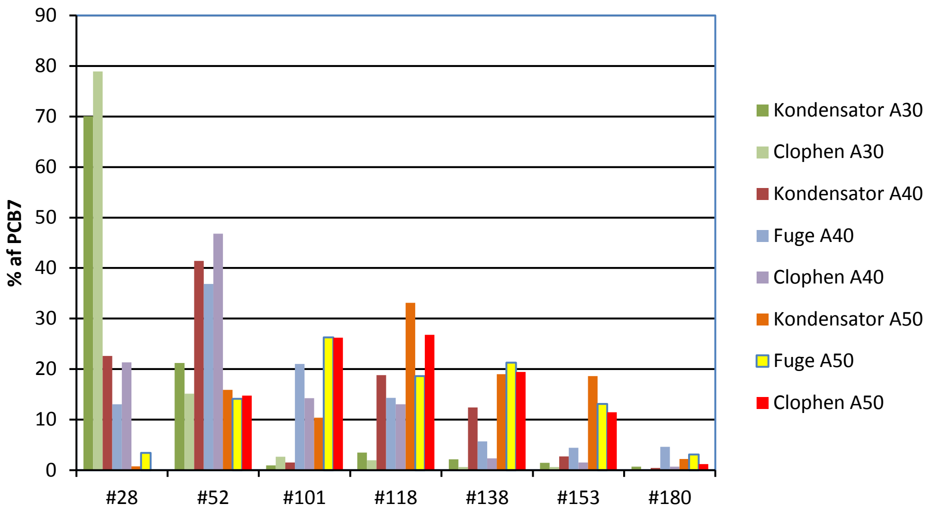


Figure 7 Primary sources based on low to medium chlorinated PCB.

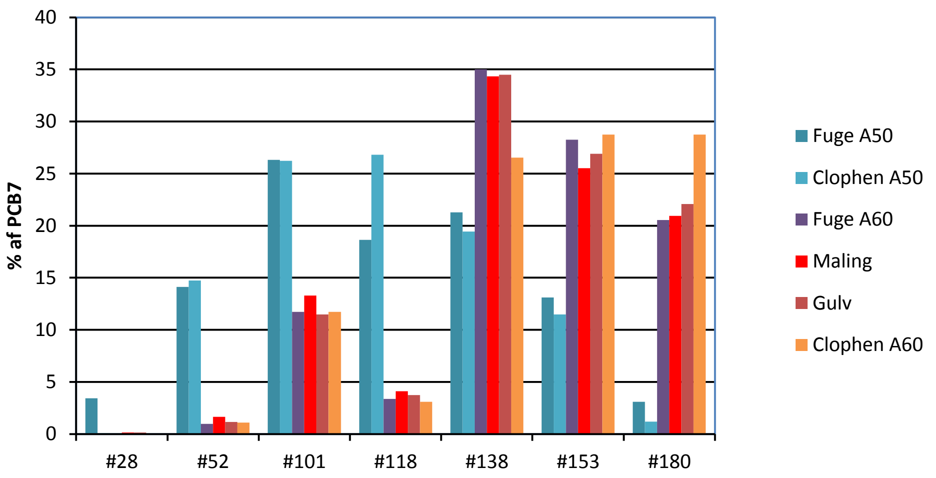


Figure 8 Primary sources based on medium to high chlorinated PCB.

As mentioned previously, there is some variation within each group. In order to determine whether certain parameters can be used to characterise the sources unambiguously, the ratios between congeners in the materials were reviewed.

As is apparent from the following, capacitor A30 differs markedly in having a high level of PCB 28 and a high level of the sum of PCB 28 and PCB 52. This type of capacitor also differs from PCB in sealed glazing units, as shown in Figure 16.

Capacitor A40 differs from sealant A40 in having a higher level of PCB 118 and PCB 28. As there are only two examples of sealant A40, this represents too sparse a basis on which to say anything about the variation that could be present within the low chlorinated sealant compounds. Capacitor A50 does not differ from sealant A50.

Overall, only capacitor A30 differs sufficiently to enable the congener composition to be used to determine the primary source.

Table 15 Characteristics of three types of PCB in capacitors, sealants, paint and flooring. Mean values with the lowest and highest values in parentheses.

Type	Number	#28 / PCB_7	#28+#52 / PCB_7	#118/PCB_7	#118 / #28
Capacitor A30	22	70% (58–85%)	92% (78–97%)	2% (1–6%)	0.03 (0.01–0.1)
Capacitor A40	7	23% (18–25%)	64% (59–66%)	12% (11–15%)	0.6 (0.5–0.8)
Sealant A40	2	13% (13–14%)	50% (49–51%)	6% (6–6%)	0.03 (0.01–0.1)
Capacitor A50	16	1% (0.2–6%)	17% (13–26%)	19% (13–24%)	30 (3–89)
Sealant A50	12	2% (1–4%)	14% (11–18%)	23% (21–26%)	12 (6–24)
Sealant A60	13	0.05% (0.004–0.12%)	1% (0.3–2%)	35% (30–39%)	1787 (286–9,091)
Paint	12	0.1% (0.004–0.3%)	2% (0.3–10.8)	33% (25–36%)	1746 (131–9,524)
Flooring	8	0.3% (0.01–1.8)	2% (0.4–4)	34% (30–37%)	976 (18–3,368)

It is well known that a shift in the congener composition in indoor air compared with the low chlorinated congeners can be observed, as shown in the figure below. The link between congener compositions in materials and indoor air is discussed further in section 4.3.6. As a general rule, the tertiary sources would be expected to be shifted in the same direction.

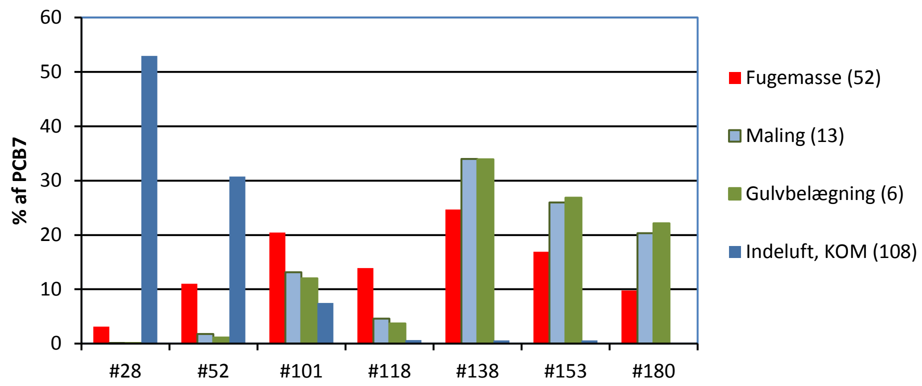


Figure 9 *Congener composition of sealant, paint and flooring containing ≥5,000 mg/kg, compared with PCB in indoor air in 108 measurements with ≥100 ng/m³ from the municipal authority surveys (number of measurements in parentheses).*

An analysis was therefore carried out of the congener composition in the analysed materials which indicated that the concentrations found in paint at local concentrations could constitute both a primary and a tertiary presence of PCB.

To investigate in more detail the extent to which the congener composition could help to identify whether a material represents a primary or a tertiary source, further samples were taken of materials from 12 buildings in connection with the taking of samples of indoor air. In connection with these measurements, analyses were carried out for 27 congeners, as one aim of this part of the study was to investigate the presence of dioxin-like PCBs and other non-dioxin-like PCBs than the seven indicator PCBs.

The results of the analysis of the measurements does not give a clear picture, but some general trends can be identified. Figure 10 shows four examples of congener profiles of materials taken from the same room. The concentration in mg/kg is stated for each material after the material specification. Three of the examples shown are also described in more detail as cases in Annex 3, which includes a description of the room, measurement situations and the results obtained.

The locations of the materials relative to the primary source is stated in the table below. It is assumed that low concentrations of PCB in paints on walls and ceilings are tertiary occurrences. However, the possibility that these paints have also had a primary presence with the same congener composition as in the primary source cannot be excluded if the primary source is paint.

Table 16 Materials that have been analysed for PCB content in the four examples of composition of primary, secondary and tertiary sources. In Annex 3.

Building *1	Mat-erial no.	Presumed source type	Concen-tration mg/kg	Description
A	2	Primary	205,000	Internal expansion joints between concrete elements.
	2	Secondary	22,500	Paint on wall, taken 2 cm from primary source.
	3	Secondary	2,200	Concrete, taken 2 cm from primary source.
	4	Tertiary	290	Plastic banister, taken 7 cm from primary source.
	5	Tertiary	10	Wooden door, taken 5 m from primary source.
B Case Block of flats	1	Primary	265,000	Internal joints around windows.
	2	Secondary	290	Wooden window frames, taken 2 cm from primary source.
	3	Secondary (tertiary)	100	Paint on wall, taken 7 cm from primary source.
	4	Tertiary	70	Plastic skirting boards, taken 50 cm from primary source.
	5	Tertiary	50	Paint on wall, taken far from primary source.
C Case School	1	Primary	90,000	Internal joint between concrete elements.
	2	Secondary (tertiary)	275	Paint on wall, taken 2 cm from primary source.
	3	Secondary	20,000	Plastic skirting board, partially in contact with expansion joint between concrete elements.
	4	Tertiary	33	Plasterboard taken more than 30 cm from primary source.
	5	Tertiary	27	Wooden table top taken more than 30 cm from primary source.
	6	Primary	140,000	Internal joint between concrete elements.
	7	Secondary (tertiary)	2,000	Paint on wall, taken 2 cm from primary source.
	8	Secondary	22	Concrete, taken 2 cm from primary source.
	9	Tertiary	13	Wood from table top more than 30 cm away from primary source.
	10	Tertiary	7	Plastic, cover for cables more than 30 cm from primary source.
D Case Home	1	Primary	70,000	Paint on floor.
	2	Secondary	115	Carpet.
	3	Secondary/tertiary	3,050	Wooden door frame, taken from bottom of frame.
	4	Tertiary	6.5	Fabric and cardboard on pipe.
	5	Tertiary	1,250	Paint on wall and ceiling.

*1 Case numbers refer to cases in Annex 3.

Buildings A and B are a typical result for the situation, where the primary source is sealant of the type Clophen A40. The other materials largely follow the congener pattern in the sealant, but there is a marked tendency for congeners PCB 28 to PCB 74 to account for a greater proportion of the other materials, which indicates that a displacement towards the low chlorinated congeners occurs upon contamination via indoor air. Building C is characteristic of the situation where the primary source is sealant of the type Clophen A40.

The results of the indoor air measurements taken in the same room from which material samples were taken in building A are presented in Figure 33 (1B). It is clearly apparent that the congener profile for the other materials is closer to that of the primary source than the profile for indoor air.

For the paints, a substantial difference can be seen between buildings A and B. In building A, where the paint contains secondary contamination, the profile of the paint corresponds to that of the sealant, while the profiles for the two paints in building B are markedly shifted towards the higher chlorinated congeners. Here, the tertiary contaminated paints in building B contain 50 and 100 mg/kg, while tertiary contaminated plastics in the two buildings contain 290 and 70 mg/kg. The tertiary sources thus have concentrations above the thresholds for hazardous waste, and the same may well be the case for most fixtures in the rooms. In building D, a concentration of 115 mg/kg was found in a carpet placed on top of a floor painted with a paint containing PCB.

Building D is typical for rooms where the highest concentration is found in paint. An almost identical picture is seen in all the buildings surveyed in which paint is the primary source (other results not shown).

Overall, the profiles of secondary contaminated materials are close to that of the primary source, while for tertiary contaminated materials there is a slight shift towards the lower chlorinated congeners. Paint that is secondary or tertiary contaminated by PCB from a sealant has a very different congener profile than paint which has been contaminated by another paint. However, where sealants with differing degrees of chlorination have been used, the unambiguous determination of whether one particular sealant joint was the primary source should not be expected.

In all buildings, it was nevertheless possible to identify the primary source from amongst the surveyed materials. In most cases, it will therefore be possible to analyse the materials in order to determine whether a material is the primary source or whether the primary source has been removed or overlooked.

The same mechanisms which result in a higher proportion of the lower chlorinated congeners being released into the atmosphere from the primary source (desorbed from the surface) also contribute to a tendency for higher chlorinated congeners to adsorb onto the surface of tertiary contaminated materials. After this adsorption, the PCB migrates slowly into the materials and is absorbed.

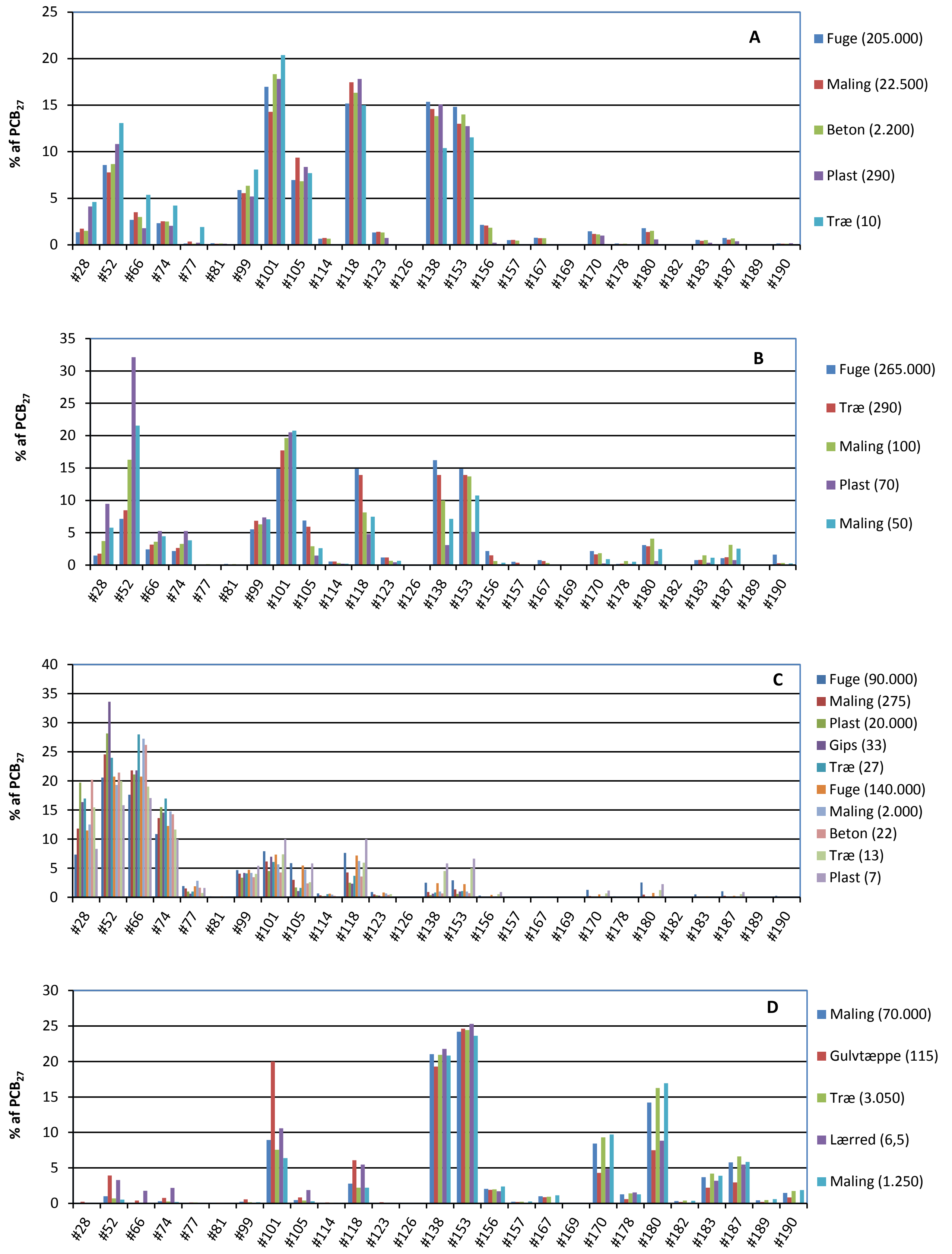


Figure 10 *The PCB composition of various materials from the same rooms. The concentration in the individual materials is stated in mg/kg in parentheses after the material designation.*

Dioxin-like PCBs represent a relatively small proportion of the total amount of PCB in indoor air, but will often account for a greater proportion in the materials. In order to determine whether there are significant differences between primary and tertiary sources, the table below shows the average proportion that the dioxin-like PCBs constitute of the total content of PCB. The dioxin-like PCBs account for a greater proportion of the sealant materials, while no significant difference is apparent between paint as a primary source and the tertiary contaminated materials. In the indoor air samples, PCB 118 (which is included in PCB_7) typically accounted for around half of the total content of dioxin-like PCBs. This is not the case for the mean of the sealants, where it only accounts for 20%, but it is the case for the mean of the paints and tertiary contaminated materials.

Table 17 Proportion of dioxin-like PCBs in primary and tertiary sources.

Average dioxin for:	Paint (primary)	Sealant (primary)	Tertiary
Dioxin as % of PCB_{27}	13%	25%	16%
Dioxin as % of PCB_{total}	4%	7%	4%
PCB 118 as % of the dioxin-like	20%	49%	48%

In order to determine the extent of tertiary contamination, the congener composition of material samples was subdivided according to materials and concentration interval for all samples across buildings types, as shown in Figure 11. Each profile in this figure is the average of all the normalised profiles within the concentration interval.

The aim of this analysis was to determine whether or not there are significant differences between the congener composition of the materials containing high concentrations (primary sources) and those containing low concentrations (primary, secondary or tertiary sources), depending on their location outdoors or indoors. It is assumed that the presence of tertiary sources outdoors will be very limited.

Congener profiles for the primary sources are presented in Figure 11 (A), although the profile for sealant compounds is based on various types of sealant. For all three materials, Figure 11 (B, C, D) shows the same tendency for the average profiles to shift towards the lower chlorinated congeners, which would be in accordance with a greater proportion of the samples containing PCB being the result of tertiary contamination.

The shift towards lower chlorinated congeners can be seen more clearly in Figure 11 (E and F), which presents the differences between paint located indoors and paint located outdoors. As regards paint containing PCB in the interval 1–50 mg/kg, the profiles are largely identical for paint outdoors and paint indoors in the cases where no primary sources with higher concentrations were found in the building concerned. A very weak tendency for the indoor paint to be displaced towards the lower chlorinated congeners can be observed. The profiles are largely identical to that of paint containing ≥5,000 mg/kg in Figure 11 (A). In cases where a primary source with a higher concentration was found in the same building, a marked shift towards the lower chlorinated congeners can be observed. This clearly indicates that, for the majority of the 143 paint samples taken indoors for which no primary source was found, the PCB originates from the production of the paint in the same way as is the case for the outdoor paint. However, it may also originate from another paint if a paint which acts as a primary source in the room has been overlooked.

No paint samples were found in the interval 0.1–1 mg/kg (Figure 11 (F)) in the buildings in which there was another source. The concentration in all samples from these buildings was greater than 1 mg/kg. However, for the buildings in which no other sources were found, the profile indicates that there is still a predominance of samples where PCB is present in the paint as a primary source. The profiles for the interval 0.1–1 mg/kg also illustrate that the many measurements at low concentrations are not an analysis error caused by interference with other substances such as chloroparaffins in the paints, as the profile is unmistakably a PCB profile. Tests were also conducted in the laboratory to verify that there is no interference, but the above is reaffirmed by this study.

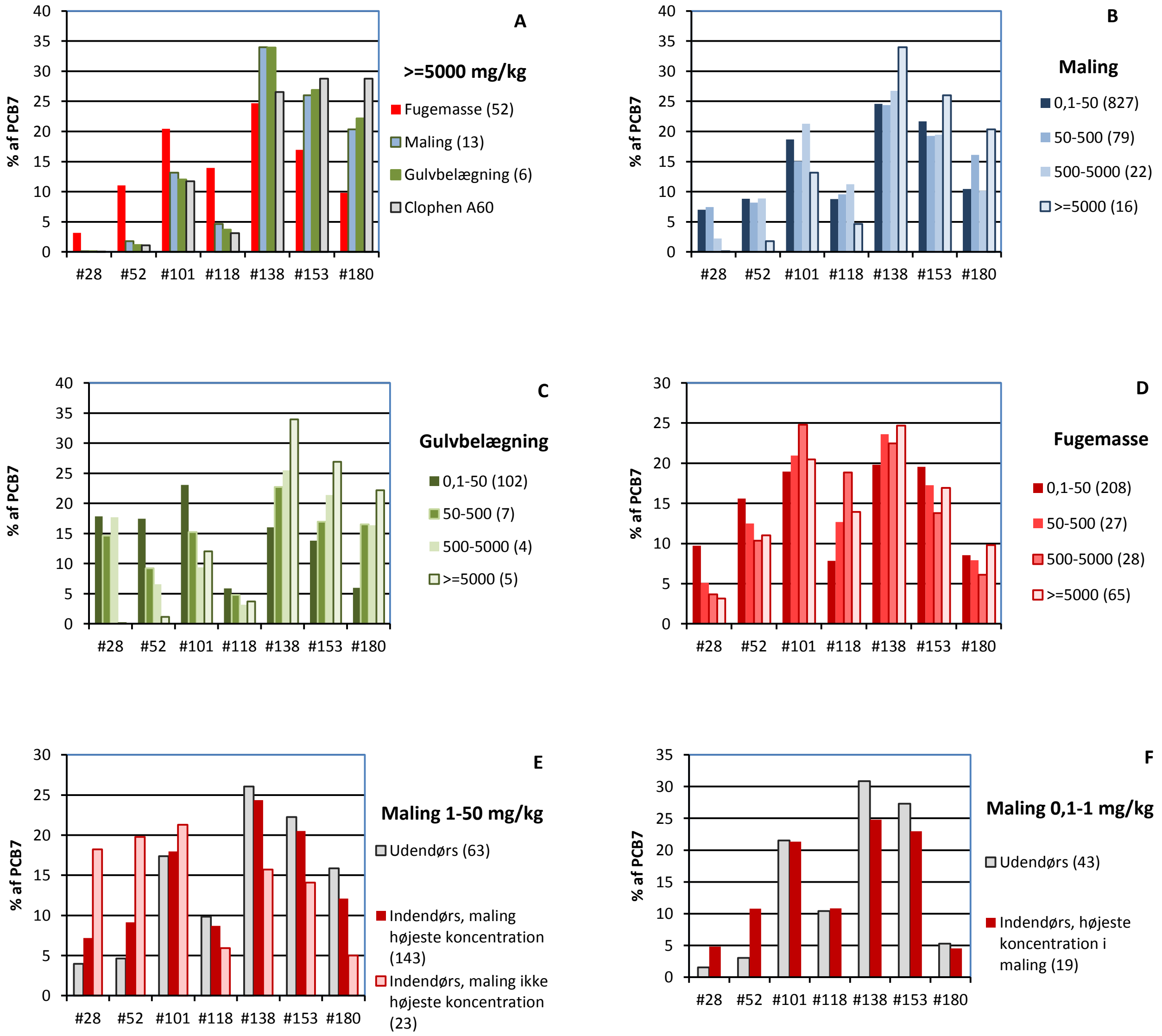


Figure 11 *Congener composition of surveyed materials (PCB_{total} concentrations in mg/kg, number of analyses in parentheses).*

3.1.10 Distribution functions

As mentioned previously, a Norwegian study (Jartun et al., 2009) of PCB in facade paint, based on a cumulative distribution function, has shown that the measurements tend to cluster around two concentration intervals, which may be linked to two different reasons for the presence of PCB in the paint.

The figure below shows the cumulative distribution function for all analyses of paint and sealant. The results of the municipal surveys of PCB, which are referred to in section 5.1, are shown in the same figure. Note the logarithmic scale on the x-axis.

Some very different distributions for sealant and paint respectively can be observed. With regard to sealants, there are two steeper sections of the curve at 1–10 mg/kg and 50,000–500,000 mg/kg. The top interval represents the intended technical application of PCB in sealants, while the bottom interval may be the result of contamination at the manufacturers or tertiary contamination.

With regard to paint, most of the samples are in the interval 1–100 mg/kg, with only a few above 5,000 mg/kg. The fact that the frequency of buildings with PCB concentrations ≥50 mg/kg is almost the same for the two materials does not mean that the total amounts of PCB are the same. The average concentration in all samples of sealant is 14,900 mg/kg, while the average concentration of PCB in paint is 350 mg/kg; in other words, four times less. The same average values from the municipal surveys are 19,000 and 694 mg/kg respectively.

As noted under the section on paint, the profiles for paint from both this survey (ENS) and those of the municipalities do not give any indication of PCB being used to any great extent in some concentration intervals, but this may dissipate over time due to varying numbers of new paint layers being applied on top of the paint containing PCB.

It is worth noting that the surveys carried out by the municipalities, which will be referred to later, actually identify a higher frequency of paint containing ≥50 mg/kg in the samples analysed than that found in this study. The reason for a lower frequency of locations with PCB in paint being observed in the complete data set from the municipalities is that samples of paint were not taken for most of the surveys.

The marked difference in the interval 0.1–1 between this survey and those of the municipalities is due to the influence of the detection limit, since most studies use a detection limit for PCB_{total} that is slightly over 0.1 mg/kg, and the fact that measurements of the individual congeners of PCB under the detection limit are assumed to be 0 here.

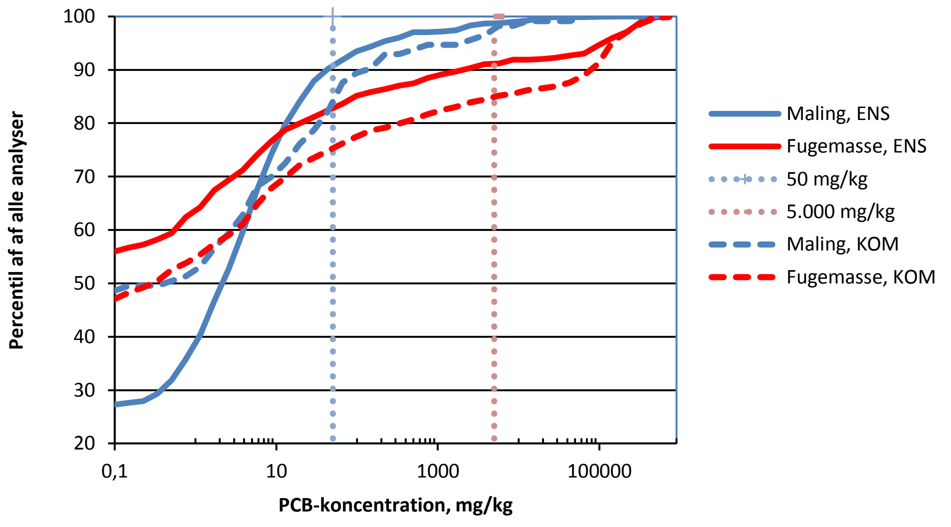


Figure 12 Cumulative distribution functions for paint and sealant samples.

3.1.11 Temporal distribution

The distribution of materials containing concentrations ≥50 mg/kg, across all building types, is shown in the figure below together with the distribution of buildings surveyed. A corresponding figure can be found in section 5.1 for a data set from the municipalities.

The figure indicates that PCB was used throughout the period 1950–1977, but particularly in the period 1965–1974. This is especially true for sealants, for which there is a significantly higher frequency in the period 1965–1974, which can also be seen in the data set from the municipalities.

It is to be expected that buildings constructed at the start of the PCB period may be painted and fitted with flooring later in the period, so the presence of paint and flooring containing PCB in buildings from the first part of the period does not necessarily mean that the materials were used as part of the construction process.

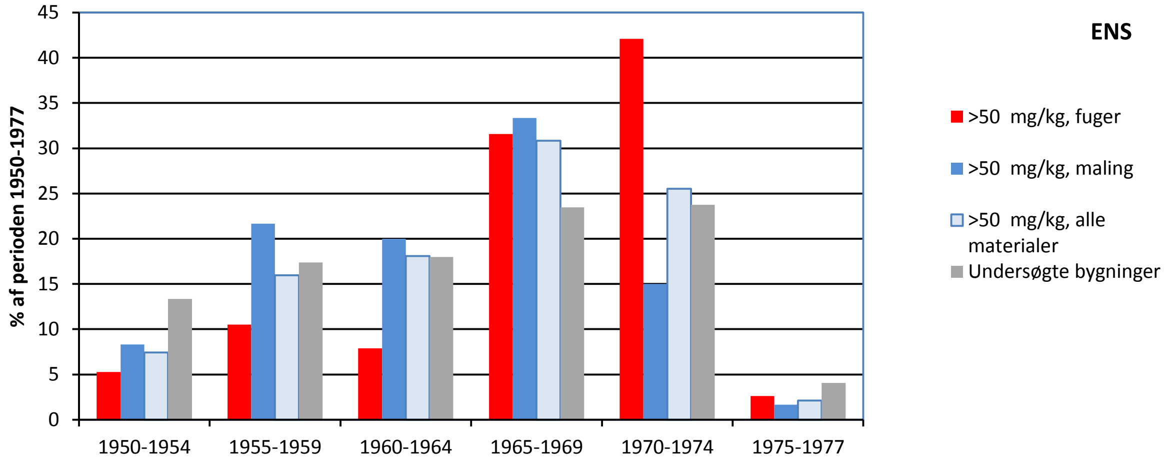


Figure 13 Temporal distribution of buildings with ≥50 mg/kg in all materials, sealant and paint compared to the temporal distribution of all buildings surveyed.

The same data are illustrated in the next figure, which shows the frequency of buildings from each sub-period with the presence of PCB. With regard to sealant, both this data set and the data set from the municipalities show that there is a much higher frequency of buildings with PCB from the period 1965–1974 than from the previous period. The trend is less clear for paint, which, as mentioned previously, may be due to the buildings being painted later during the period. It was decided to pre-empt the description of the studies from the municipalities by demonstrating the time profile for buildings with ≥5,000 mg/kg in sealant from the data set in which a frequency of almost 25% is observed in sealants with high concentration in public institutions from the period 1965 to 1969.

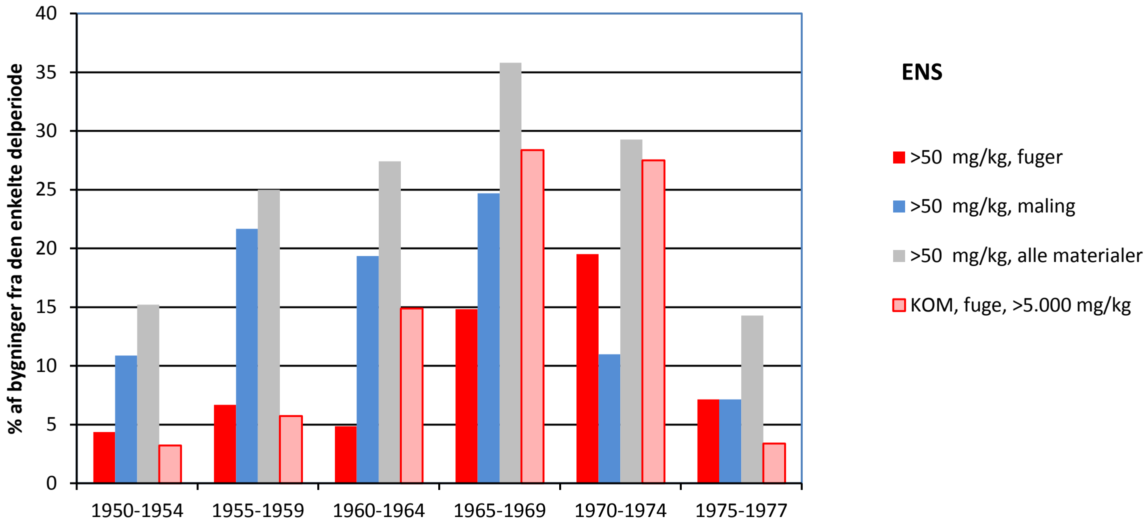


Figure 14 *Frequency of buildings from each sub-period with the presence of PCB, together with data from municipalities (KOM) for buildings with sealants containing ≥5,000 mg/kg.*

3.1.12 Extent of materials in the buildings

In the previous section, the primary focus was on how many of the buildings have a PCB problem as a result of the building containing one or more materials with PCB content above a given concentration. In some buildings, there was just a single painted object, whereas in most buildings there were large quantities of materials spread across the entire building. Data collection involved gathering information on the extent of materials, such as the total length of sealant in a room or the floor area in m^2 in a painted room, enabling the estimation of the total amount of PCB in each building.

An indication of the extent of PCB in the buildings can be obtained from the number of samples taken in each building. In blocks of flats, office buildings and public institutions, more than five samples containing ≥0.1 mg/kg of PCB were taken in almost half of the buildings, which shows that materials containing low PCB concentrations are widespread in buildings. Office buildings and public institutions differ from the other building types because there are significantly more buildings in which more than three samples with ≥5,000 mg/kg have been taken, indicating that there are several buildings with a more extensive PCB problem in this group of buildings. Since the group of privately owned office buildings is somewhat under-represented in the studies, this group is considered to be equivalent to public office buildings and institutions.

Table 18 Number of samples per building greater than or equal to 0.1 mg/kg, 50 mg/kg and 5,000 mg/kg respectively.

	Number of buildings		
Number of samples	≥0.1 mg/kg	≥50 mg/kg	≥5,000 mg/kg
Detached and semi-detached houses (154)			
1	25	14	5
2	29	10	3
3	20	1	1
4	17	2	0
5	4	0	0
>5	20	2	1
Blocks of flats (105)			
1	3	13	7
2	19	14	5
3	3	2	0
4	17	2	0
5	12	1	0
>5	41	2	0
Office buildings and public institutions (93)			
0	9	9	9
1	7	10	3
2	13	4	5
3	8	6	1
4	7	6	2
5	1	0	1
>5	38	7	3

3.1.13 Statistical test of observed frequencies

A statistical test was carried out of the observed frequencies in this survey, the results of which are set out in the table below. With regard to public institutions, in section 6.1.1 these are also compared to the results of surveys from the municipalities and tested for the significance of differences between the two data sets.

As indicated in the table, the actual frequencies of materials containing ≥50 mg/kg in the four building types are estimated to be 13–24%, 24–40%, 25–47% and 23–51% respectively (90% confidence intervals). These values are also used in section 6.1.1 to estimate the number of buildings containing PCB in Denmark. With regard to public institutions and office buildings, the frequency of buildings with PCB in sealants is primarily based on the studies from the municipalities, which are referred to in section 5.1.

A standard chi-square test was performed to investigate whether the observed differences between the four building types are statistically significant. On the basis of this test, it can be established that the frequency of detached and semi-detached houses with PCB in materials is significantly lower than the frequency of buildings with PCB in materials in the other three building categories. The calculated *p* value is 0.002, which means that the difference identified is very significant. It can also be established that there is no significant difference between the observed frequencies for the other building types.

Table 19 Observed frequencies of buildings with PCB broken down into the four building types with 90% confidence intervals.

PCB_{total} mg/kg	Detached and semi-detached houses			Blocks of flats			Public institutions and office buildings			Private office buildings		
	Number of buildings	Freq-uency	90% CI *1	Number of buildings	Freq-uency	90% CI for frequency *1	Number of buildings	Freq-uency	90% CI *1	Number of buildings	Freq-uency	90% CI *1
Surveyed	154			105			57			36		
≥0.1	113	73%	67–79%	95	90%	84–95%	47	82%	72–90%	27	75%	60–86%
≥50	28	18%	13–24%	33	31%	24–40%	20	35%	25–47%	13	36%	23–51%
≥5,000	10	7%	4–11%	12	11%	7–18%	9	16%	9–26%	6	17%	8–30%

*1 90% confidence interval determined on the basis of a binomial distribution.

The observed frequencies across all building types broken down by region are shown in the table below. A test of the significance of the differences between the regions gives a *p* value of 0.25, which means that differences in observed frequencies between the regions are not significant in any way. This is consistent with the assumptions of the statistical model applied when planning the survey.

Table 20 Observed frequencies of buildings with PCB in materials in all building categories broken down by region with 90% confidence intervals.

PCB_{total} mg/kg	Jutland/Funen (North Denmark Region, Central Denmark Region and Region of Southern Denmark)			Zealand (Region Zealand and Capital Region of Denmark)		
	Number of buildings	Frequency	90% CI *1	Number of buildings	Frequency	90% CI *1
<50	151	71%	65–76%	107	77	70–83%
≥50	62	29%	24–35%	32	23	17–30%

*1 90% confidence interval determined on the basis of a binomial distribution.

3.1.14 Summary and partial conclusion

The survey of materials in the 352 buildings focused on the primary presence of PCB in sealants, certain types of paint and flooring. Two other sources, sealed glazing units and capacitors, were examined individually.

Materials containing PCB concentrations ≥0.1 mg/kg were found in more than 75% of the buildings surveyed.

Detached and semi-detached houses

PCB was found to be widespread in detached and semi-detached houses, with materials containing ≥50 mg/kg being found in 18% (13–24%, 90% confidence interval) of the buildings. However, concentrations were statistically significantly less than in the other two types of building. This is particularly marked in the case of materials with concentrations ≥5,000 mg/kg, which were found in 6% (4–11%) of the buildings. Most of the materials containing PCB were paints used either indoors or outdoors. Indoors, paint was for example found on water pipes in toilets and on floors in larders, laundry rooms, offices and storage rooms, while paint outdoors had been applied to stairs. Sealant joints with high concentrations (≥100,000 mg/kg) were found in two buildings around windows and doors, one outdoors and one indoors. No cases were found of sealant between concrete elements or sanitary sealant in bathrooms with high PCB concentrations.

Blocks of flats

In blocks of flats, materials containing ≥50 mg/kg were found in 31% (24–40%) of the properties, while materials containing ≥5,000 mg/kg were found in 11% (7–18%). In blocks of flats, only one example of sealants with a high PCB concentration was found indoors around a window in a staircase, while sealants with a high concentration (typically over 100,000 mg/kg) used outdoors between concrete elements were found in many properties. Paint containing ≥50 mg/kg and up to 19,000 mg/kg was particularly found indoors on staircases and in laundry rooms, storage rooms, bicycle basements and boiler rooms. The paint had been applied to floors, walls, downpipes and metal railings.

Public institutions and public office buildings

Extensive data are available for public institutions and public office buildings from surveys conducted by municipal authorities. In most municipalities, surveys have exclusively been aimed at sealants, and the results of the surveys can only be considered to be representative as regards sealants. Overall, the frequency of buildings containing PCB at concentrations ≥50 mg/kg in sealant in public institutions and offices specified at location level was 14% (12–16%) (a location is a school, care home, etc.). An analysis of the results from the municipalities for which data were available for all the individual buildings at all locations (e.g. all buildings at a particular school) showed that the frequency at location level was approx. 20% higher than when specified at building level. The frequency of buildings with PCB in paint and floor compounds has been estimated on the basis of the ENS survey results, as most surveys conducted by municipalities did not include these materials. Overall, 19% (11–30%) of buildings contained paint or flooring containing ≥50 mg/kg.

High occurrences of PCB in sealant are more frequent in schools than in other public buildings. Amongst 87 schools across the country which took part in the municipal authorities' screenings, sealants with a high PCB concentration (≥5,000 mg/kg, but typically ≥100,000 mg/kg) were found in 31% of the schools.

Private office buildings

The results of surveys of 36 office buildings show that the presence of materials containing PCB in the buildings largely corresponds to that seen for public buildings. Thus, materials containing 50 mg/kg were found in 36% (23–51%) of the properties, while materials containing ≥5,000 mg/kg were found in 17% (8–30%).

Primary versus tertiary sources

The primary sources with concentrations above 5,000 mg/kg (where it can be determined fairly reliably that these are primary sources) can be broken down into several groups. There are thus three distinct groups of PCB in capacitors and three groups in sealants, while paints and floors appear to be characterised by a single group of highly chlorinated PCB. There is a certain amount of variation within the individual groups, but for some parameters the groups are distinct and cluster around PCB, reminiscent of the German-made technical mixtures Clophen A30, A40, A50 and A60. There will presumably also be other types, e.g. US-made PCB mixtures. Capacitors containing PCB in the group designated here as A30 are markedly different to the others containing a high level of PCB 28 and a high level of the sum of PCB 28 and PCB 52. A single source cannot be unambiguously identified for the others.

Overall, the profiles of secondary contaminated materials are close to those of the primary source, while for tertiary contaminated materials there is a minor shift towards the lower chlorinated congeners. Paint that is secondary or tertiary contaminated by PCB from a sealant has a very different congener profile than paint which has been contaminated by another paint. However, where sealants with differing degrees of chlorination have been used, the unambiguous determination of whether one particular sealant joint has been the primary source should not be expected because the low chlorinated PCB profiles in sealants are close to the low chlorinated PCB profiles in capacitors.

Temporal distribution

Both the ENS survey and the municipal surveys clearly show that sealants containing PCB were used far more frequently during the period 1965–1974 than during the other sub-periods. For paints and floor compounds, the period-related differences are less marked, which may well be due to the fact that these materials were incorporated into the buildings a number of years after their erection.

3.2 PCB in sealant tape and sealant adhesive in sealed glazing units

3.2.1 Background

Sealed glazing units installed before 1980 may contain PCB in the sealant adhesive used to seal the edges of the windows. The use of adhesives and other sealant materials containing PCB was banned in Denmark in 1977, but foreign-made sealed glazing units were permitted to contain PCB up until 1980.

A PCB report from 1983 estimated the total use of PCB in sealant adhesive in sealed glazing units in Denmark to be 86–100 tons (Hansen, 1983). These amounts were primarily based on Norwegian figures and the estimate appears to be more uncertain than indicated by the interval.

Based on:

› figures for the production of sealed glazing units during the period;

› the assumption that 1.5kg (1 litre of 1.5kg/litre) of sealant adhesive was used per 4–5m^2;

› the fact that 75% of the market used PCB in sealant adhesive during the period; and

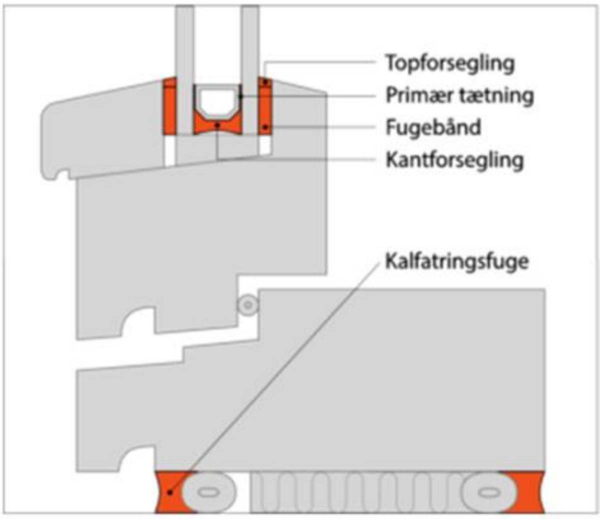
› that this contained 20% PCB,

it is estimated in the subsequent Environmental Project no. 1084 from 2006 that 200 tons of PCB have actually been used for sealed glazing units in Denmark (Trap et al., 2006).

In connection with a number of studies conducted before this survey, Grontmij recently stated that PCB can occur in both the sealant adhesive and the sealant tape placed between the sealed glazing unit and the glazing bead around the window frame. Since it has been demonstrated in several cases that PCB was only found in the sealant tape, it appears to be possible that sealant tape can act as a primary source. It was therefore decided to also take samples of sealant tape in an attempt to obtain more evidence of this possible PCB source.

A cross-section of a sealed glazing unit in a window frame in a wall, taken from the new Danish Building Research Institute Guidelines no. 24 on the investigation and assessment of PCB in buildings (SBi, 2013), is reproduced below. The edge seal of the sealed glazing unit (designated as “sealant adhesive” here), sealant tape, primary seal, top seal and the joints in the brickwork are marked in orange.

There is a spacing profile made from stainless steel or aluminium between the two layers of glass in the sealed glazing unit. The edge seal, which may contain PCB, is located underneath the spacing profile. We have not found any information in the literature on the use of PCB in sealant tape. Sealant tape is often self-adhesive, meaning that it is certainly possible for PCB to have been present in the adhesive on the tape, although PCB could also have been used in the sealant tape in order for it to maintain its elasticity.



3.2.2 Sampling and analysis

For the purposes of this study, sealed glazing units have been collected from recycling centres in the five municipalities included in the study: Ballerup, Herning, Hjørring, Holbæk and Odense. They were collected during the period from December 2012 to March 2013.

At the sampling sites the sealed glazing units were collected in containers by staff at the recycling centres. As part of the sampling process, the collected sealed glazing units were sorted and samples taken from the following units:

› Sealed glazing units which are clearly from the PCB period. The use of PCB was permitted in sealed glazing units until 1977 in Denmark, but foreign-made sealed glazing units could contain PCB up to 1980. For this reason, the period during which PCB could be present in the sealed glazing units was assumed to be 1950–1980 for sampling purposes.

› Sealed glazing units for which the year of manufacture cannot be determined.

› Sealed glazing units which are not clearly PCB-free.

In some cases, staff at the recycling centre had already compiled a selection from which single-glazed windows and sealed glazing units not from the period had been discarded. In these cases, the number of discarded windows is a rough estimate based on information provided by the centre staff.

In conjunction with the sampling, it was noted how many sealed glazing units were discarded because they were not from the period in question. In cases where there were several identical sealed glazing units, a sample was only taken from one of the windows and it was noted how many identical windows there were.

Samples were taken from 205 sealed glazing units. From each sealed glazing unit the following was taken:

› One sample of sealant tape from between the glass and the wooden frame glazing strip.

› One sample of sealant adhesive from between the window pane and the aluminium strip.

Methods for analysis of PCB and determination of PCB_{total} are described in section 3.1.1. Unless indicated otherwise, the specified concentrations express PCB_{total}.

Sampling took place between June 2012 and June 2013. The winter of 2012–13 saw a clear reduction in the collection of sealed glazing units in all the municipalities. A limited number of sealed glazing units were collected in the period November 2012 to April 2013 in all the municipalities.

3.2.3 Results of the study

The table below shows the number of windows collected and analysed. Overall, it could be determined that a total of 69% of the sealed glazing units collected did not date from the PCB period based on information about the year of production. There was a large spread between the distribution of sealed glazing units in the five municipalities in that the percentage varied from 29 to 79%. There is nothing obvious to suggest there are differences between urban municipalities and rural municipalities, but the number of municipalities included is too small to draw any certain conclusions concerning this.

Of the 34% that could potentially date from the PCB period, samples were taken from 214 windows, while 156 of the windows were considered to be identical to the windows from which samples were taken.

Table 21 PCB in sealant adhesive and sealant tape in the sealed glazing units examined.

Municipality **	Number of windows				
	Collected during sampling period	Non-PCB period		Potentially from PCB period	
		Discarded, not from PCB period	% of Collected	Discarded, identical to those analysed	Analysed
Odense, urban municipality	365	256	70%	37	72
Herning, rural municipality	228	144	63%	50	34
Holbæk, urban municipality	288*	223*	79%	29	36
Hjørring, rural municipality	48*	14*	29%	0	34
Ballerup, urban municipality	259*	185*	47%	40	38
In total	1,188	822	69%	156	214

* Estimated figures.

** The municipalities are divided into rural municipalities (comprising "peripheral municipalities" and "rural municipalities") and urban municipalities (comprising "intermediate municipalities" and "urban municipalities"), cf. Danish Ministry of Welfare's classification of the Danish municipalities according to the rural district index (Ministry of Welfare, 2009).

From a total of 214 sealed glazing units, 210 samples of sealant tape and 203 samples of sealant adhesive respectively were taken and analysed. The results of these analyses are set out in the table below. As can be seen, 34% of the windows examined contained sealant adhesive with a PCB concentration ≥50 mg/kg, while 29% contained sealant tape with a concentration ≥50 mg/kg PCB. However, the levels in sealant tape were significantly lower than in sealant adhesive. Consequently, 13% of the samples of sealant adhesive contained ≥100,000 mg/kg, while none of the samples of sealant tape contained more than 100,000 mg/kg. There was some correlation between PCB in sealant tape and sealant adhesive, but in two windows the concentration in sealant tape was greater than 50 mg/kg, while it was lower than this level in the sealant adhesive. Overall, 35% of the windows had a concentration <50 mg/kg in either sealant adhesive or sealant tape.

The rough calculation is that the 156 identical windows follow a distribution corresponding to that of the 214 windows analysed.

The average concentration of all samples of sealant adhesive was 40,500 mg/kg, while the average for sealant tape was 1,800 mg/kg, i.e. more than 20 times lower.

The average concentration in sealant adhesive in the 20% of windows where the concentration was >5,000 mg/kg, which is presumed to be the sealant adhesives in which PCB performed a technical function, was 207,000 mg/kg (21%). In the PCB report from 1983 (Hansen, 1983) it is stated that the typical concentration in sealant adhesive was 20%. This tallies well with the results found here, but the present results show that PCB has also been widespread in lower concentrations in sealant adhesive, since 41% of the adhesives contain PCB in the interval 0.1–5,000 mg/kg. The average concentration in the 34% of sealant adhesives containing ≥50 mg/kg is approx. 120,000 mg/kg.

Since 31% of the sealed glazing units collected potentially date from the PCB period, and 34% of these contain ≥50 mg/kg, it can be calculated that 11% of the windows collected contained sealant adhesive with concentrations higher than 50 mg/kg. It can correspondingly be calculated that 4% of the sealed glazing units collected contained sealant adhesive at levels >100,000 mg/kg.

Of the total amount of PCB in sealant adhesive in the windows, 99.6% is found in the windows with over 5,000 mg/kg, while windows with ≥50 mg/kg, which is the threshold for hazardous waste, represent 99.99% of the total amount. With regard to sealant tape, 99.96% of the PCB occurs in the sealant tapes with ≥50 mg/kg.

If it is assumed that 1.5 kg (1 litre of 1.5 kg/litre) of sealant adhesive is used per 4–5 m^2 (as indicated above), in the 20% of windows where the concentration is ≥5,000 mg/kg there will be 63–79 g/m^2, while for the 34% with ≥50 mg/kg on average there will be 36–45 g/m^2. In a detailed Norwegian study of PCB in sealed glazing units from 2004, it was assumed that on average there was approx. 50 g PCB per m^2 of sealed glazing unit in the sealant adhesive (Ruteretur, 2004). Reference is made to the fact that 50–70 g/m^2 was previously used as an assumption, but that studies have shown that sealed glazing units from the period containing PCB on average contained just under 50 g/m^2. The Norwegian studies did not examine PCB in sealant tape. The amounts found thus tally very well with Norwegian experience.

On a window measuring 1 m^2 there will be approx. 8 metres of sealant tape. The weight of the sealant tape will vary according to the width and density of the tape. The actual weight of the sealant tapes has not been determined. New sealant tapes that have been examined typically have a weight in the interval 13–37 g/m and, with 8 m per m^2 of window, this gives 90–300 g/m^2. The average concentration in sealant tapes with greater than 50 mg/kg is 6,040 mg/kg. The average PCB content per m^2 of sealed glazing unit in sealant tape containing >50 mg/kg PCB will be 0.6–1.8 g/m^2. This can be compared to the average of 36–45 g/m^2 in sealant adhesive. There will thus on average be approx. 20 times more PCB in sealant adhesive than in sealant tape, but in some cases where PCB is only found in the sealant tape the majority of PCB will of course be in the tape.

Table 22 PCB in sealant adhesive and sealant tape in the sealed glazing units examined.

PCB mg/kg	Sealant tape between glass and wooden frame			Sealant adhesive between window pane and aluminium strip		
	Number	Frequency	% of total PCB amount *1	Number	Frequency	% of total PCB amount *1
<0.1	93	44%	0%	67	32%	0%
0.1–<1	6	3%	0.001%	10	5%	0.0001%
1–<50	50	24%	0.1%	55	26%	0.01%
50–<500	7	3%	0.2%	16	8%	0.03%
500–<5,000	29	14%	18.3%	14	7%	0.3%
5,000–<100,000	25	12%	81.4%	14	7%	4.7%
≥100,000	0	0%	0%	27	13%	95.0%
≥0.1	117	56%	100%	136	65%	100%
≥50	61	29%	99.89%	71	34%	99.99%
≥5,000	25	12%	81.4%	41	20%	99.7%
In total	210	100%	100%	203	100%	100%

*1 It is assumed that on average the sealed glazing units in the individual intervals contain the same amount of sealant adhesive and sealant tape.

To investigate whether the presence of PCB in sealant tape is due to tertiary contamination from PCB in the sealant adhesive, the figure below shows the correlation between PCB in sealant adhesive and sealant tape in the individual sealed glazing units.

Correlation between PCB in sealant adhesive and sealant tape

As can be seen, there is a clear relationship between the concentration in sealant tape and sealant adhesive, while the concentration in sealant adhesive in many of the sealed glazing units is approx. 10 times higher than in sealant tape. This indicates that a significant proportion of PCB in the sealant tape is a result of tertiary contamination from the sealant adhesive. However, within the interval 50–10,000 mg/kg, there are 10 instances where the concentration is highest in the sealant tape. Two windows have been found where the concentration in the sealant tape was more than 50 mg/kg and less than 50 mg/kg in the sealant adhesive. In theory this could be due to the same sealant tape being used previously on a sealed glazing unit containing PCB although it is standard practice to replace the sealant tape at the same time as the unit. However, the possibility that the sealant tape sticking to the window frame has not been replaced cannot be ruled out, and that this is thus simply a matter of tertiary presence.

The results suggest that PCB can act as the primary source in both sealant tape and sealant adhesive, and that cross-contamination can be seen between the two materials. Most of the PCB in the sealant tape does, however, appear to be a result of tertiary contamination.

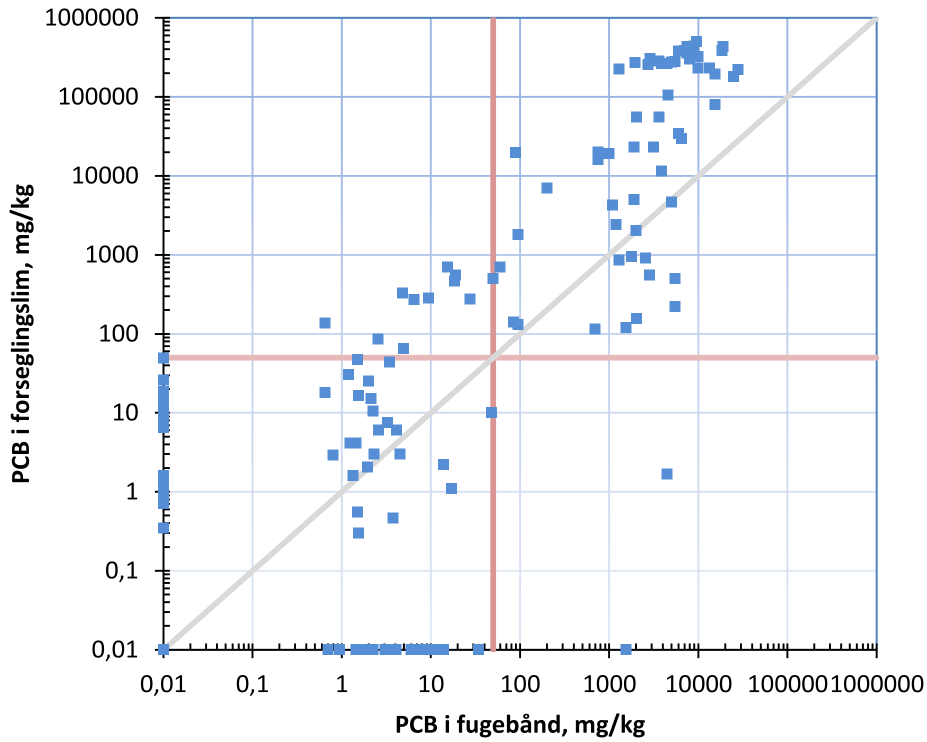


Figure 15 *Correlation between PCB in sealant adhesive and sealant tape. Note the logarithmic scale. 50 mg/kg is marked with red lines. The grey line is a construction line for reading the figure. Measurements below the detection limit are indicated here as 0.01 mg/kg to enable them to be shown on a logarithmic scale.*

To further illustrate the correlation between PCB in the two materials, Figure 16 shows four examples of congener profiles. In Figure 16 A and B, the concentration in the sealant adhesive is more than 10 times than that in the sealant tape. In the two windows, which are from Odense and Holbæk municipalities respectively, sealant adhesives with a very different degree of chlorination were used; this is reflected in the congener composition of the sealant tape. The data contains many examples of windows with both a high and low degree of chlorination. A slight shift towards the lower chlorinated congeners can be seen in the profile for sealant tapes. This shift is presumably due to the lower chlorinated congeners having a greater tendency to evaporate into the air space inside the window frame. Figure 16 C and D show two examples of windows from Ballerup and Herning respectively, where higher values are found in the sealant tape than in the sealant adhesive. A clear correlation between the profiles of the two materials can also be seen here. There are a number of examples in which the PCB concentration is highest in the sealant tape and where the peak of the congener profile occurs in the centre of the profile around PCB 118. In one of the two examples shown, there is a shift towards lower chlorinated congeners in the sealant adhesive. The profiles indicate that in some of the sealant tapes there will be a primary presence of PCB, presumably in the adhesive used to stick the sealant tape to the window frame.

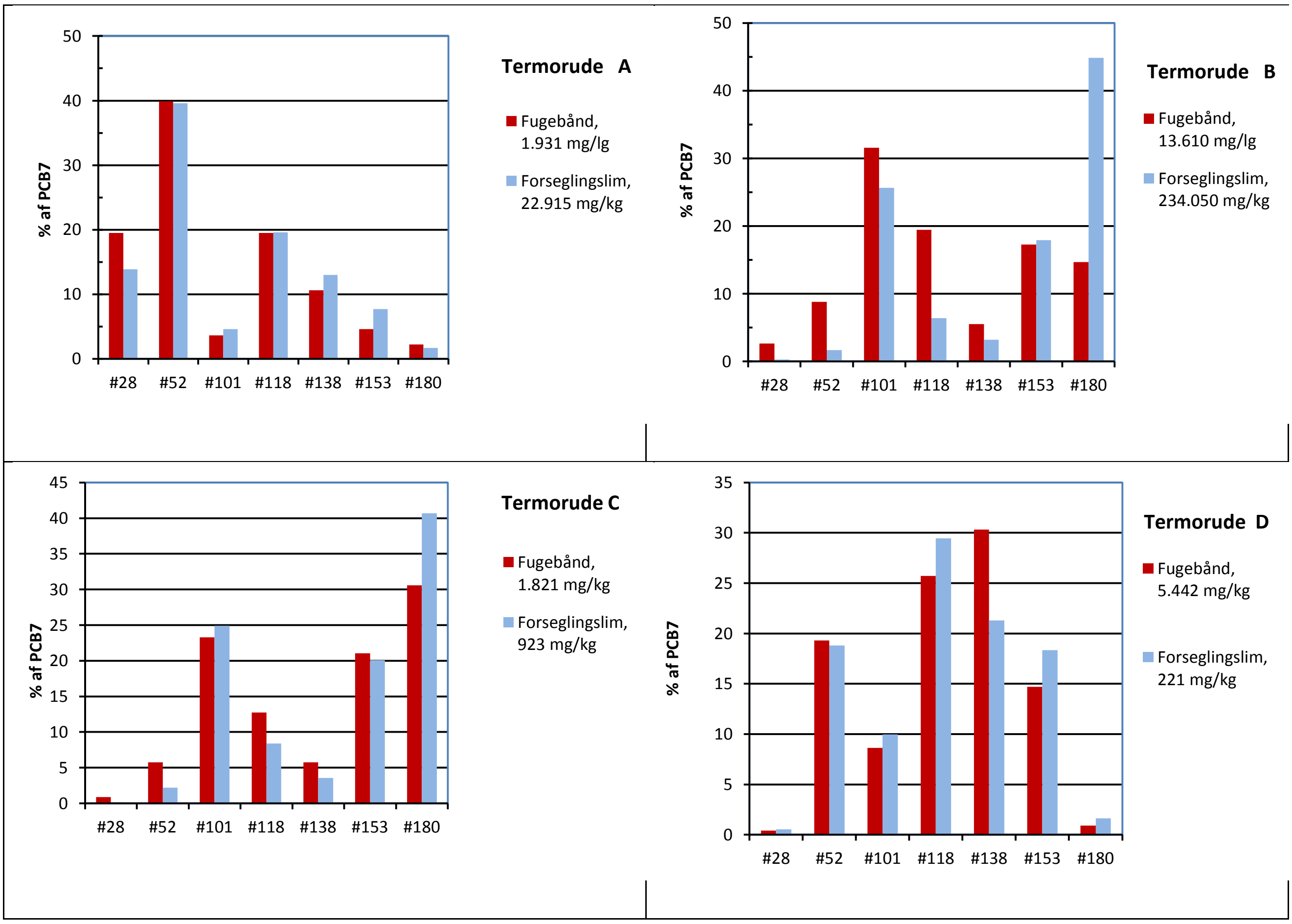


Figure 16 Correlation between congener composition in sealant tape and sealant adhesive.

3.2.4 Summary and partial conclusion

It has been demonstrated that a significant proportion of the sealed glazing units that are currently being disposed of still contain materials containing PCB. Based on information concerning year of manufacture, 69% of the windows could be excluded as having been manufactured outside the PCB period. In the others, concentrations ≥50 mg/kg were found in sealant adhesive in 34% of the windows, while concentrations ≥50 mg/kg were found in sealant tape in 29% of the windows. There was a link between the presence of PCB in sealant adhesive and sealant tape, and overall 35% of the windows had ≥50 mg/kg in either the sealant tape or the sealant adhesive.

On the basis of the results, the average amount of PCB in windows with ≥50 mg/kg can be calculated at 36–45 g/m^2 of window in sealant adhesive and 0.6–1.8 g/m^2 in sealant tape. In 13% of the windows, there was sealant adhesive containing >100,000 mg/kg PCB and in these windows the average PCB concentration in the sealant adhesive was 63–79 g/m^2. Residual amounts of PCB in sealed glazing units are described in more detail in section 7.1.2.

A clear link was demonstrated between PCB in sealant adhesive and sealant tape, indicating that the presence of PCB in sealant tape is primarily a tertiary contamination from PCB in the sealant adhesive (via the air gap between the window and the window frame). However, there were 10 cases of PCB concentrations in sealant tape in the interval 50–10,000 mg/kg where the presence in the sealant tape is greatest, indicating that PCB in sealant tape could be a primary source. No information on the primary presence of PCB in sealant tape has been found in reports from our neighbouring countries or the literature as a whole.

The presence of PCB found in sealant adhesive tallies well with the presence of PCB in sealed glazing units in Norway.

The secondary and tertiary presence of PCB in wood in window frames was not studied, but it is likely that some of the PCB in the primary sources has penetrated into the wood. Whether the concentration in the window frames is over 50 mg/kg is of relevance to the disposal of the windows.

3.3 PCB in fluorescent lamp capacitors

3.3.1 Background

In Europe, PCB was used in the production of small capacitors in the period from 1950 to around 1980. In certain countries this use may have continued for longer, although in Denmark a ban came into effect on 1 November 1986.

It should be noted that the original ban, as well as the applicable Executive Order on PCBs, PCTs and substitutes for these chemical compounds (Executive Order no. 925 of 13 December 1998), assume a threshold of 50 mg/kg – i.e. since the legislation came into effect, products are permitted to contain less than 50 mg/kg PCB, e.g. as impurities. Until the entry into force of the POP Regulation in 2004, which does not have a minimum threshold for PCB, capacitors (and other products) could be sold with a PCB content of up to 50 mg/kg.

In homes and office buildings, the capacitors were used for fluorescent tube light fittings, white goods, extractor fans and some types of electronics. Capacitors containing PCB were also used to a certain extent in some sodium and mercury vapour lamps. Mercury vapour lamps are primarily used for street lighting, but they are also used in industrial plants and sports facilities, e.g. swimming pools. The Danish report from 1983 (Hansen, 1983) estimated that 90% of this type of capacitor were used in fluorescent tube light fittings. The most significant numbers of small capacitors containing PCB still in use are presumed to be in fluorescent lamps and other light fittings, as these generally have a longer service life than the other equipment. Their long service life and low power consumption mean that fluorescent lamps are frequently reused, which in turn means that light fittings dating from the period 1950–1987 are often found in buildings erected more recently.

Capacitors are reported to typically contain 10–30 g pure PCB, but there are cases of them containing up to 100g. The length of the capacitor is usually 5–15 cm. The capacitors containing PCB usually contain a coiled piece of metal foil, where PCB was used as a dielectric insulator absorbed by the paper placed between the layers of metal foil. In many cases, the metal foil coil is also surrounded by PCB fluid, but in some capacitors PCB is only absorbed by the paper. Other oils that do not contain PCB have also been used for this purpose. Newer capacitors are typically dry capacitors, where a piece of plastic foil is placed between the layers of metal foil. The content of a capacitor can be seen in the image below, in which the metal foil coil is on the right-hand side. The image shows a typical capacitor that contains the insulator in liquid form.

The capacitor is usually located inside the fluorescent tube light fitting, as shown in the image below. Occasionally there may be several capacitors in each light fitting, or the capacitor may be found in a unit together with other electronics. This capacitor is referred to as a “ballast capacitor”. There is also a very small capacitor in the so-called “starter”, which is typically located in a visible position on the light fitting next to the fluorescent tube so it can be replaced. The possibility that this has also contained a small amount of PCB cannot be ruled out, but there is no mention of starters in the guidelines issued by Norway, Sweden, Canada and the United Nations Environment Programme (UNEP), for example. Starters have a shorter service life than capacitors and are easy to replace. The fact that the starter has often been replaced also means that the possibility of finding PCB in the capacitor is limited.

Around 2000, the European Commission drew up a list of manufacturers and type numbers of capacitors known to contain PCB (covering both the small ones referred to here and also medium and high voltage capacitors). The list has not been published, but has been circulated in relevant fields and can be found online. Unfortunately, the list does not cover manufacturers and type numbers of capacitors known not to contain PCB.

In larger installations, such as neon signs, the capacitors can be centrally located in a control box and will presumably be of a size covered by the disposal requirements in the PCB/PCT Executive Order.

There is a requirement in the PCB/PCT Executive Order that transformers or capacitors which contain PCB and which have a total weight of 1 kg or more or an output greater than or equal to 2 kVAr, should be identified and disposed of before 2000 (a previous executive order stipulated that they should be taken out of use before 1 January 1995). Capacitors in single fluorescent tubes with a total weight of 100–300 g have thus not been subject to these requirements.

Historic consumption

A survey report from 1983 (Hansen, 1983) estimates on the basis of Norwegian experience the accumulated consumption of small capacitors containing PCB in Denmark to be 8.5 million, and with reference to Norwegian data 90% of these are estimated to be used in fluorescent lamps. Total PCB consumption in Denmark of small capacitors during the period 1950–1980 is estimated to be 175–325 tons. It is not stated how large a proportion of the capacitors from the period contained PCB.

The study refers to US studies which show that PCB concentrations of 146 to 620 ng/m^3 with an average of 296 ng/m^3 were measured in kitchens in 10 US homes. Sources of PCB are stated to be capacitors in fluorescent lamps and in electrical appliances found in the kitchen. The emissions from the capacitors were estimated on the basis of US experience to be 33–650 mg/year per capacitor and total emissions in Denmark from this source in 1981 were estimated to be 1–20 tons/year.

The report calculates that in connection with capacitor burnout 10–15 g pure PCB can leak which is not absorbed into materials (primarily paper) inside the capacitor. Reference is made to a US study in which values of 11,600 ng/m^3 were measured after burnout on the day it took place. A value corresponding to the normal figure of 200 ng/m^3 was obtained after approx. three months. In its calculations the survey report assumes that an average Dane would be exposed to PCB concentrations of 40–300 ng/m^3 indoors. Based on this, the intake of PCB via indoor air in 1981 is calculated to have been 2 µg/day/person, while intake via food is calculated to have been 15 µg/day/person.

Relevance

The problem of PCB in indoor air is thus not a new one but has become relevant again. In recent years several examples have been found of fluorescent lamp capacitors acting as the source of high concentrations of PCB in the indoor environment. It has been documented in studies carried out in 2012–2013 by the consortium parties that PCB concentrations of 400 to 2,000 ng/m^3 can be measured in different building types originating from leakage in older fluorescent lamp capacitors.

Examples include school caretakers reporting oil dripping from fluorescent lamps, which can be pure PCB leaking from a capacitor after it has burst. The fact that PCB leaks from capacitors when they burst is illustrated in a new US report, as shown below in an image taken from a report by Guo et al. (2011).

Figure E.7. The light ballast that burst during the emission test with electrical load

Figure 17 PCB leaking from a capacitor that has burst (from Guo et al., 2011)

Collection of fluorescent tube light fittings

According to the Electronic Waste Executive Order (Executive Order no. 1296 of 12 December 2011), capacitors containing PCB must be removed during the selective processing of electrical and electronic waste.

In Denmark, DPA-System (Danish Producer Responsibility) is responsible for administration of the rules set out in environmental legislation on producer responsibility for waste from electrical and electronic equipment; this organisation also prepares statistics for the quantities that are collected.

The light source industry's WEEE association (LWF) is the collective producer scheme for light sources. To some extent, light sources are collected together with light fittings and for this reason LWF also has an interest in light fittings.

Handling of used light fittings

Since the founding of the DPA reporting system, LWF has been able to establish that the annual amount of used light fittings collected has been very low compared to the amount of light fittings sold; this is why in 2012 LWF commissioned COWI to conduct market research on the collection of used light fittings in Denmark and investigate whether the light sources in the light fitting are removed before the light fitting is processed. The study has not been published, but LWF has given permission for the following brief extract of the results to be reproduced here:

According to statistics from DPA-System, a maximum of 70 tons of used light fittings have been collected in a specific year and a lower amount in other years. This should be considered in view of the fact that 2,700–3,400 tons of light fittings are sold each year.

As part of the market research, three different types of market player were contacted:

1. Demolition companies and their industry organisation, the Demolition section of the Danish Construction Association

2. Selected WEEE processors and scrap dealers on Zealand and in Jutland

3. Selected municipalities on Zealand and in Jutland and Local Government Denmark.

The study showed that only one of the demolition companies contacted actually sorts used light fittings as electronic waste and that the remaining companies sort them as waste metal. The companies stated that used light sources (fluorescent tubes, light bulbs, etc.) and other electronics are removed before the light fittings are sent to the scrap dealer. The demolition companies stated that they mainly take used light fittings to a major Danish scrap dealer that operates across the country or to a scrap dealer close to the demolition sites. During a visual inspection of a number of demolition sites carried out by COWI, it was established that the used light sources in half of the cases were not removed from the light fittings.

The municipal utility companies, which are responsible for running the recycling centres, stated that in cases where users (private individuals and businesses) of recycling centres are familiar with the rules for sorting used light fittings, the light fittings will be sorted together with small household appliances such as electronic waste; otherwise they will be sorted as metal waste. No regular checks are made to ensure that light sources have been removed before being taken to the relevant containers.

Light fittings are generally collected as iron and metal waste or as electronic waste. In both cases it is assumed that light sources – to a certain extent and if they are identified – are removed before the light fittings are scrapped or dismantled. The scrap dealers who receive light fittings as mixed iron and metal waste stated that they carry out a visual check and remove any light sources, batteries and electronics where these components are obvious and easily accessible. The visual check is based on an assessment of whether there is more or less than 5% weight/weight impurities in the load they received.

The five recycling centres participating in the ENS survey stated that the fluorescent lamps end up either in the metal containers or in cages together with small household appliances. It varies from recycling centre to recycling centre how much goes where – at most of the centres the majority of the waste goes to the metal container, while at two of the centres all light fittings are disposed of in the metal container designated for the scrap dealer. There does not appear to be any systematic approach to the disposal of light fittings for either method; it depends on the individual user of the centres where the light fittings are taken. Cages containing household appliances are taken to electronic waste companies such as Averhoff A/S in Århus and DRC Miljø A/S in Roskilde. The recycling centres do not generally have any figures for how many light fittings are brought in, but one of the centres estimated that it could be around 10 per month.

3.3.2 Sampling and analysis

The study was carried out by investigating the presence of PCB in light fittings (mainly restricted to fluorescent tubes) which were handed in at the following two electronic waste companies:

- Averhoff A/S in Århus, which receives electronic waste from all across Denmark from both recycling centres and demolition companies.
- DCR Miljø A/S in Roskilde, which also receives electronic waste from all across Denmark from both recycling centres and demolition companies.

At both these electronic waste companies, the light fittings received were collected in metal cages during the period from December 2012 to March 2013.

During the sampling period, insufficient light fittings were collected by the two electronic waste companies; consequently those which were collected were supplemented by light fittings found in connection with demolitions and in storage at schools, offices and other sites. In all cases this involved discarded light fittings. To prevent the weighting of these extra light fittings being too skewed, at each location only two light fittings of each type were sampled at that location.

The collected light fittings were sorted by the project's sample takers, who divided them into the following groups:

- Light fittings without capacitors (primarily new fittings with HF coils that do not contain capacitors)
- Light fittings where there was an indication that the capacitor did not contain PCB or was manufactured after 1986.
- Other light fittings. The capacitor was removed from these and sent for analysis.

The selected capacitors were sent to the analysis laboratory where they were then opened. Capacitors not sent to the laboratory were taken to electronic waste companies for further processing.

An oil sample for analysis was taken from those capacitors containing sufficient oil in free phase and the result expressed in mg/kg of the oil. The analysis of the others was based on a sample from the metal foil coil and the result expressed as mg/kg of the foil coil.

None of the electronic waste companies identified large consignments of identical light fittings, which indicates that the fittings primarily originate from private individuals and tradesman who have handed them in at recycling centres, while large consignments from the renovation/demolition of institutions, industrial plants, offices, etc. must be disposed of in other ways, e.g. as metal waste or by being reused.

3.3.3 Results of the study

The distribution of PCB in the light fittings collected is shown in Table 23.

All in all, 62% of the light fittings could be discarded because there was no capacitor or there were indications that the capacitor was manufactured after 1986.

49% of the light fittings did not have a capacitor. Newer fluorescent lamps use high frequency coils (HF coils) and do not have a capacitor.

Of the capacitors, 66 (approx. 25% of all capacitors) were stamped with a year indicating that they were manufactured after 1986. Many of the capacitors manufactured before 1986 also had year stamps on them. Capacitors made after 1986 and up to 2004 are not included in these studies.

PCB-free capacitors produced after the problem with PCB became apparent in the mid-1970s may be marked “PCB-free”, “non-PCB” or “non-PCB”. A total of four capacitors were marked “PCB-free” – however the one dating from 1988 contained 115mg/kg when measured according to the method used in this study, although this is not wholly identical to the method used in the 1980s to determine whether the concentration was below the permitted 50 mg/kg. There is thus some indication that capacitors marked as being “PCB-free” may well contain PCB above the criterion for hazardous waste, and that it may be possible to demonstrate that up until 2004, when the POP Regulation came into effect, the content of PCB in capacitors was above the criterion for hazardous waste.

Table 23 Distribution of the fluorescent lamps examined

Collection point	Fluorescent lamps examined	Light fittings not containing PCB				Light fittings potentially containing PCB	
		No capacitor	Non-PCB indication	Capacitor after 1986	Total number discarded	Analysed	Analysed as % of those examined
DCR Miljø A/S	201	64	0	43	107	94	47%
Averhoff A/S	279	190	3 *1	21	211	68	24%
Various others	36	0	1 *1	2	2	34	94%
In total	516	254	4 *1	66	320	196	38%
% of those examined		49%	1%	13%	62%	38%	

*1 Also included in "Capacitor after 1986".

The results of the analyses of the capacitors are shown in Table 24. The results show the overall result for 63 measurements taken for the free oil and 131 measurements taken for the complete metal foil coil. In two measurements the PCB concentration could not be determined due to interference from hydrocarbons.

Of the 38% of the light fittings from which samples were taken, 23% contained actual PCB capacitors with a PCB concentration >100,000 mg/kg. This corresponds to approx. 9% of all the fluorescent lamps examined containing a capacitor with >100,000 mg/kg PCB. The calculation method used determined that 15 of these capacitors contained more than 1,000,000 mg/kg, which is due to this method, in which PCB_7 is multiplied by a factor of 5, overestimating the actual content for certain types of PCB. Pure PCB has typically been used, which corresponds to 1,000,000 mg/kg. Of the 45 capacitors with >100,000 mg/kg, 41 (91%) had free PCB around the metal foil coil. Of the capacitors analysed for the entire foil coil, four contained PCB in the range 255,000 mg/kg to 750,000 mg/kg, while all others contained less than 10,000 mg/kg. This indicates that PCB accounts for around 1/3 of the weight of the coils in the actual PCB capacitors.

Around 42% of the capacitors analysed contained ≥50 mg/kg PCB, corresponding to around 16% of all fluorescent lamps examined having capacitors containing ≥50 mg/kg PCB.

Around 37% of the capacitors contained PCB in concentrations in the interval 0.1–50 mg/kg. There has not been – nor is there today – a ban on selling capacitors with PCB concentrations in this interval. If the capacitors are filled with other dielectric oils with a certain chlorine content, it is quite possible that PCB may be present as impurities in these oils.

The PCB capacitors included both cylindrical and box-shaped types, although most of them were cylindrical. It is therefore not possible to give an opinion on the PCB content based on the shape of the capacitors.

The capacitors without PCB overwhelmingly did not have a free oil phase but there were also examples of the metal foil coil being surrounded by an oil. It is thus not possible to determine clearly whether the capacitor contains PCB on the basis of information indicating that a free liquid is present in the capacitor.

If it can be estimated roughly that on average the capacitors in each interval weigh the same (i.e. the weight of the capacitor depends on whether there is a high or low PCB concentration), it can be seen that 99.997% of all PCB will be present in capacitors at concentrations ≥50 mg/mg. Even if there are minor differences in weight, and taking into account the uncertainty associated with whether oil or complete foil coils are being analysed, the value will still be greater than 99.9%. A calculation using the same method shows that 99.96% of the PCB is found in capacitors containing more than 100,000 mg/kg PCB, while the other capacitors in which PCB may occur as contamination represent 0.04%.

Table 24 PCB in capacitors for fluorescent lamps selected for analysis.

PCB mg/kg	Number	Frequency	% of total PCB amount *1
Not detected. *2	2	1%	-
<0.1	41	21%	0%
0.1–<1	21	11%	0.00003%
1–<50	50	26%	0.003%
50–<500	28	14%	0.01%
500–<5,000	7	4%	0.02%
5,000–<100,000	2	1%	0.03%
≥100,000	45	23%	99.93%
≥0.1	153	78%	100%
≥50	82	42%	99.997%
≥5,000	47	24%	99.96%
In total	196	100%	100%

*1 It is assumed that on average the capacitors in the individual intervals weigh the same.

*2 Not detected due to interference.

There was considerable variation in the congener composition of PCB in the capacitors, but they could be classified into three main groups as illustrated in Figure 7 and Table 15 in section 3.1.9. As mentioned in section 3.1.9, PCB in the capacitors of the type referred to here as "capacitor A30" differs markedly from all other sources.
The characteristic congener profile may therefore help to indicate whether capacitors of this type are primary sources.

Capacitors with the manufacturer's name stamped on them

Around two thirds of the capacitors with >100,000 mg/kg indicated the name of the manufacturer: AEG, Exactor, Glamox, Louis Poulsen, Lyfa and Philips. Of these, Louis Poulsen and Glamox produce fluorescent lamps while the capacitors presumably originate from other manufacturers but have been stamped with the name of the light fitting manufacturer and its type number.

Of the six manufacturers named, AEG and Philips appear on the list drawn up by the European Commission. None of the type numbers of the 17 capacitors analysed that were made by the two manufacturers can be found on the EU list.

The results show that there is no reliable way of using such lists to determine whether the capacitors contain PCB.

In general, other manufacturer names appear on the capacitors with <1 mg/kg. These are SND, RFT, Arcotronics, Miflex, ITT, Vossloh Schwabe, ESTA, etc. However, there is too much uncertainty involved to state on this basis that capacitors from these manufacturers do not contain PCB.

3.3.4 Summary and partial conclusion

Of 516 fluorescent lamps examined, 62% could be eliminated, either because there was no capacitor (more recent types of light fitting are not fitted with a separate capacitor), or because the capacitor had a stamp indicating that it had been manufactured after 1986.

Of the 38% of light fittings selected from which samples were taken, 23% contained actual PCB capacitors with a PCB concentration >100,000 mg/kg. This corresponds to approx. 9% of all the fluorescent lamps studied containing a PCB capacitor. There was also some presence of PCB in lower concentrations, and around 42% of the capacitors analysed contained ≥50 mg/kg PCB, corresponding to around 16% of all fluorescent lamps examined having capacitors containing ≥50 mg/kg PCB. Around 37% of the capacitors studied contained PCB in the interval 0.1–50 mg/kg. It should be noted that until the entry into force of the POP Regulation in 2004, capacitors (and other products) could be sold with a PCB content of up to 50 mg/kg, and the cut-off date of 1986 does not apply to these capacitors. However, a single capacitor from 1988 marked “PCB-free” that was examined actually contained 115 mg/kg, and this may very well be the case for other capacitors manufactured after 1988. Due to differences in analysis methods, it is possible that testing of the capacitor with 115 mg/kg at the time of production indicated that it contained <50 mg/kg.

On average, the capacitors contain around 30 g of pure PCB. Of the actual PCB capacitors examined, 91% contained free phase PCB.

Residual amounts of PCB in capacitors are described in more detail in section 7.1.3.

PCB with differing degrees of chlorination has been used in the capacitors, but around half of the capacitors are very low chlorinated and have a proportion of PCB 28 which is far higher than the other primary sources such as sealants and paint as described in section 3.1.9. This causes a characteristic congener pattern in indoor air and tertiary contaminated materials, a factor which is discussed in section 4.3.6.

3.4 Migration of PCB to adjoining materials

3.4.1 Background

PCB from primary sources will penetrate adjoining materials and create a basis for secondary PCB presence in these materials.

This issue has previously been described in Swedish and Danish studies. A report from the Danish Environmental Protection Agency from earlier this year contains a study of the literature available on the penetration of PCB in building materials bordering sealant containing PCB, with special emphasis on concrete and brick (hereinafter referred to as "the literature study") (Andersen et al., 2013).

According to the literature study, it is Swedish studies primarily dealing with external sealants that show there is considerable variation in the penetration of PCB in building materials. Less penetration is seen in wood compared to concrete and brick, while the greatest penetration is seen in lightweight concrete. The porosity (permeability) of the materials is expected to be of significance, i.e. the more porous the material, the greater the penetration. There is no characterisation of the building materials in the Swedish studies.

The literature study also includes a number of sample series from exterior concrete, brick and lightweight concrete taken from the collection of data from renovation and demolition cases involving materials containing PCB. The data processed for the sample series from concrete and brick do not show any clear relationship between the concentration of PCB in sealant and that in the adjoining material sample. An analysis of the sealant concentration is therefore not sufficient to indicate whether the building materials have been contaminated. Spread is visible further away from the sealant on brick compared to concrete.

According to the literature study, no studies exist of the transport mechanism of PCB in building materials. A comparison of various estimates and guesses of the spread suggests that the diffusion coefficient calculated in Swedish studies underestimates the penetration. It is of great importance whether the penetration follows an exponential function (linear function in a simple logarithmic mapping) or a power function (linear function in a double logarithmic mapping). In the case of a power function, most of the PCB will penetrate deep into the material. According to the literature study, the penetration in concrete is best described as a power function, while penetration in lightweight concrete is best described as an exponential function.

Analysis of data from the literature and sample series suggests that the threshold for hazardous waste of 50 mg/kg PCB is not reached at a distance of 5 cm from the sealant in the materials examined. Concrete, however, may be an exception to this. In relation to the recommended limit value of 0.1 mg/kg PCB for reuse of waste, the studies of concrete show that based on the Swedish figures a distance of 18 cm is required to come under the limit value, while a distance of 11 cm is required based on the sample series analysed in the literature study and a worst case scenario approach.

For brick, the Swedish figures are comparable with the results for concrete. In the literature study's analysis of sample series with brick and the approach of calculating the worst case scenario, a distance of 46 cm from the sealant is calculated before a value of 0.1 mg/kg PCB would be expected to be reached. If this calculation is modified on the basis of an argument about physical penetration of sealant in the sample bordering the sealant joint, a distance of 28 cm is obtained.

3.4.2 Sampling and analysis

Since sampling for migration measurements is relatively destructive when the objective is to avoid any risk of contaminating the samples, samples were taken from buildings prior to their demolition.

The sampling was conducted in cooperation with three demolition companies. The companies notified the consortium whenever they identified the presence of PCB in a building and specified in which materials PCB had been found. Sampling was then conducted by sample takers from the consortium.

The following materials were included in the study: concrete, lightweight concrete, brick, mortar, stone, softwood (pine), hardwood, vapour barriers, foam tape, facade panels, glass cloth and veneer materials.

The intention was to take four to eight drill cores/depth cross-sections for each material which would then be analysed at four different distances from the known primary source.

The practical investigations were restricted to an area up to a distance of 6 cm from the primary source. The drill cores or panel samples were taken as large pieces of wall or flooring and were subsequently divided into the following sections initially: 0–0.5 cm, 0.5–1 cm, 1–1.5 cm, 1.5–2 cm, 2–3 cm, 3–4 cm, 4–5 cm and 5–6 cm by a sample taker at the location or at the companies' internal laboratories. To prevent friction heat altering the state of PCB in the sample material, the sample block was sectioned using a chisel and the outermost cutting surface from the drill cores – or the panel sample – was chiselled off before sectioning took place. A sample that was as undisturbed as possible could then be taken. It was assessed that the drilling of dust could not prevent friction heat from altering the material samples and so this method was consequently not used. The method is described in SBi Guidelines no. 241, but when these samples were taken the risk of the material samples' PCB content being altered was deemed too great; hence it was decided to section the samples by hand using a chisel.

Laboratory analyses were carried out on the sections measuring 0–0.5 cm, 0.5–1 cm, 1–1.5 cm and 5–6 cm. The other sections have been stored and can be analysed insofar as is necessary.

In the case of panels, samples were taken from all accessible materials at a distance of 15–30 cm from the primary source. Not all the collected materials were tested, but they were collected with a view to possibly taking and testing supplementary samples.

In order to achieve clear analysis results, only primary samples were used in the selection of material samples.

The sealant joint (primary source) was removed entirely, so that no sealant residue could contaminate the drill core or panel section (wall or floor), by pulling off sealant residue at the same time as the drill sample/panel sample was taken.

Samples for migration analysis were taken using an angle grinder, core drill or multi-cutter wherever possible. In exceptional situations it was, however, necessary to use special tools but in these cases it was ensured that the samples were taken in a way that enabled accurate sequencing. Drill cores/sections were sectioned at the location. The best possible method was also selected, ensuring that the cutting surface between concrete and blade did not exceed 80ºC. This was to prevent the spreading of PCB that had migrated into the material sample. The best way to prevent generating friction heat when a large sample is extracted is by subsequently splitting the sample using a chisel and taking the sample from the inner part of the material sample in order to prevent the spreading of PCB in the material and thereby altering the sample material. See also the description of analysis methods in section 3.1.1.

3.4.3 Results of the study

The results of the study are described in the next section.

The measurements were taken on sections for example in the interval of 0–0.5 cm distance from the primary source. The average value in this interval is represented in the figures and the calculations as a single value at a distance of 0.15 cm. The average distance is not used because steeply falling concentrations are involved; the mean concentration found is therefore more representative of the concentration at a distance of 0.15 cm from the source than at the average distance of 0.25 cm. The best value will depend on the actual fall in concentration (which also depends on which distance is determined), but for simplicity and to better compare the various measurement series it was decided to use the distances 0.15 cm, 0.65 cm, 1.15 cm and 5.3 cm. The subsequent modelling shows that this fits reasonably well with most of the series.

Pine

Seven measurement series of PCB penetration in pine frames from a sealant joint containing PCB are shown in Figure 18. In one measurement series, the results were below the detection limit and these results are not included in the figure. The results are shown with logarithmic x- and y-axes. Like the results for lightweight concrete mentioned above, the fall seems to follow a power function (with a linear fall on a double logarithmic scale) rather than an exponential function.

In the seven measurement series from a school and a nursery school respectively, widely varying penetration of PCB from the primary source is seen in the window frame.

The concentrations in the primary source, which is sealant, varied from 55,000 mg/kg to 200,000 mg/kg with both the highest and lowest values measured in the sealant from the school. A single measurement series has been omitted from the figure due to a very small value being found at a distance of 0–0.5 cm (0.15 cm on the figure) which appears to be an error. Very large differences in penetration in the wood can be seen.

The concentration at a distance of 0–0.5 cm (0.15 cm) from the source varies from 200 to 20,000 mg/kg. These large differences, which are visible over the first 0.5 cm, are presumably due to differences in the penetration of the sealant itself in the wood that will depend on whether there are small cracks in the wood and other factors. The gradient of the curves is far more uniform after this. There is a tendency for them to cluster around two different gradients, but this may be coincidental, and there is no obvious correlation between the gradients and where the measurements were taken. At a distance of 5–6 cm from the primary source, the concentration still exceeds 50 mg/kg in two of the sample series, while it is 1 to 30 mg/kg for the others. At this distance, the concentration in the measurements of wood from the same school vary from 2 to 190 mg/kg. Regression lines plotted on the figure are calculated on the basis of double logarithmic transformed data. With these regression lines, it can be calculated that the concentration will be less than 50 mg/kg at a distance of 10 cm from the primary source in all measurement series. It can also be calculated that the concentration in the wood will be between 0.3 and 30 mg/kg at a distance of 20 cm from the source. Since these results concern window frames, the concentration at a distance of 20 cm is only of theoretical significance, but the results could indicate that very deep penetration of PCB in materials in contact with the primary source should be expected in wood panels, for example.

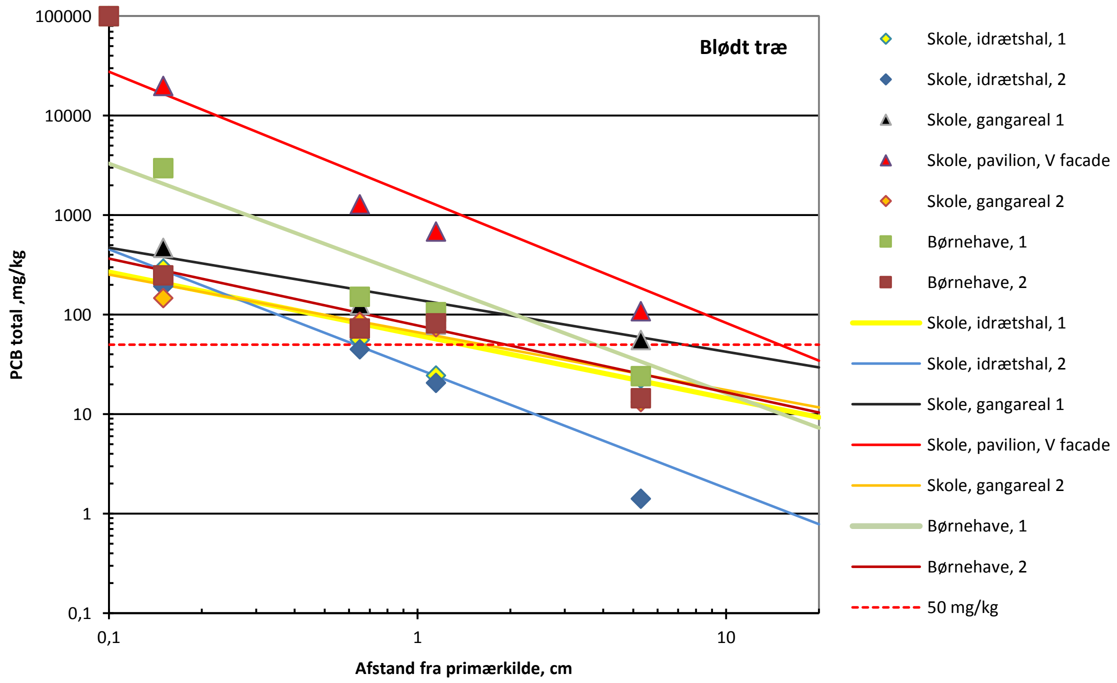


Figure 18 *Measurements of PCB penetration in pine from schools and nursery schools. The concentration in the primary source (sealant) is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Plotted lines are based on linear regression of the logarithmically transformed data.*

Lightweight concrete

Corresponding data for penetration in lightweight concrete are shown in Figure 19. Three measurement series in which the results are below the detection limit are not included in the figure. Penetration in this material would also be better described as a power function than as an exponential function. Compared to the data for wood, there is greater variation in the individual measurement series, which may be due to the heterogeneous and porous nature of the material.

As with the results shown in the literature study, there is a very high degree of penetration in lightweight concrete, and extrapolation of the regression lines shows that in four out of five measurement series the concentration is still above 0.1 mg/kg at a distance of 20 cm from the primary source, while in one of the series the concentration is still approx. 20 mg/kg at this distance. As can been seen in the wood measurement series, there is also very great variation in the penetration in lightweight concrete, with measurements at 0–0.5 cm (stated as 0.15 cm) varying from 160 to 35,000 mg/kg. Differences are presumably caused by variations in the penetration of the actual sealant material in lightweight concrete. Four of the series then follow largely the same development, which indicates that the PCB – from a distance of 0.5 cm from the primary source and further – will spread through the material using the same mechanism. In four out of five measurement series the concentration is below 50 mg/kg at a distance of 1.5 cm. In the last measurement series, a distance of 12 cm is reached before the concentration falls below 50 mg/kg.

One of the measurement series has a significantly higher drop due to a single high value at 0.25 cm.

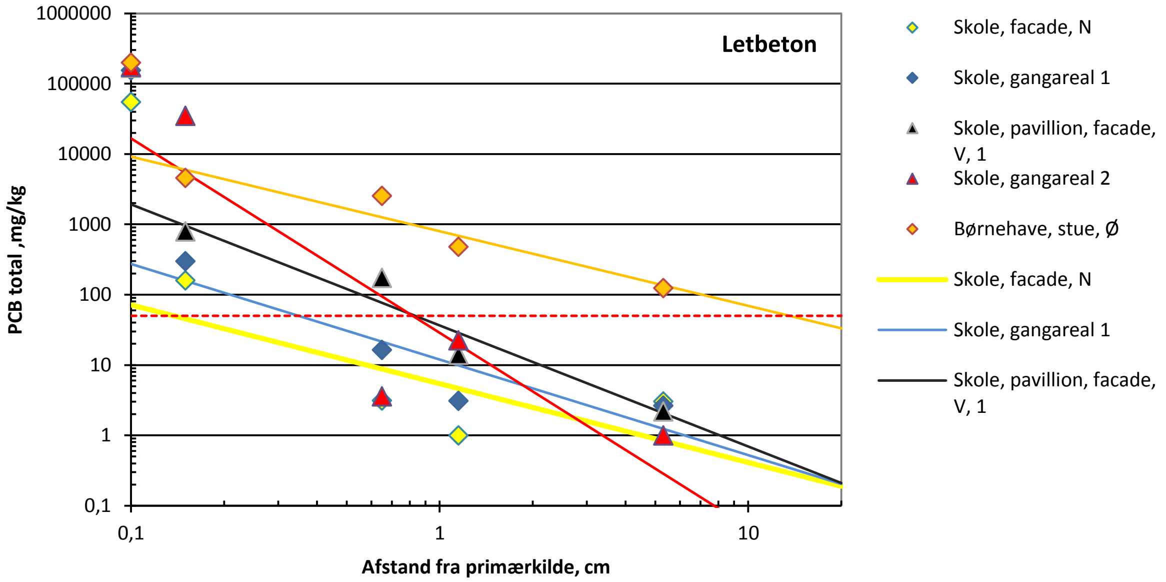


Figure 19 *Measurements of PCB penetration in lightweight concrete from schools and nursery schools. The concentration in the primary source (sealant) is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Plotted lines are based on linear regression of the logarithmically transformed data.*

Brick

The results for brick are shown in Figure 20. Three measurement series in which the results are below the detection limit are not included in the figure. For most of the measurement series, the penetration in brick is slightly less than that found in lightweight concrete, except for one measurement series in lightweight concrete that had significantly greater penetration (because of a single high value at 0–0.5 cm). In all measurement series, the concentration will be less than 50 mg/kg at a distance of 2 cm from the source. For two of the measurement series the concentration is still above 0.1 mg/kg at a distance of 10 cm from the source. The results correspond well with the results of the literature study, although there is a single measurement series with considerably greater penetration due to a high concentration at 0.5 cm.

In one of the samples, the primary source is paint. The regression line lies within the variation in the regression lines for those measurement series where the source is sealant.

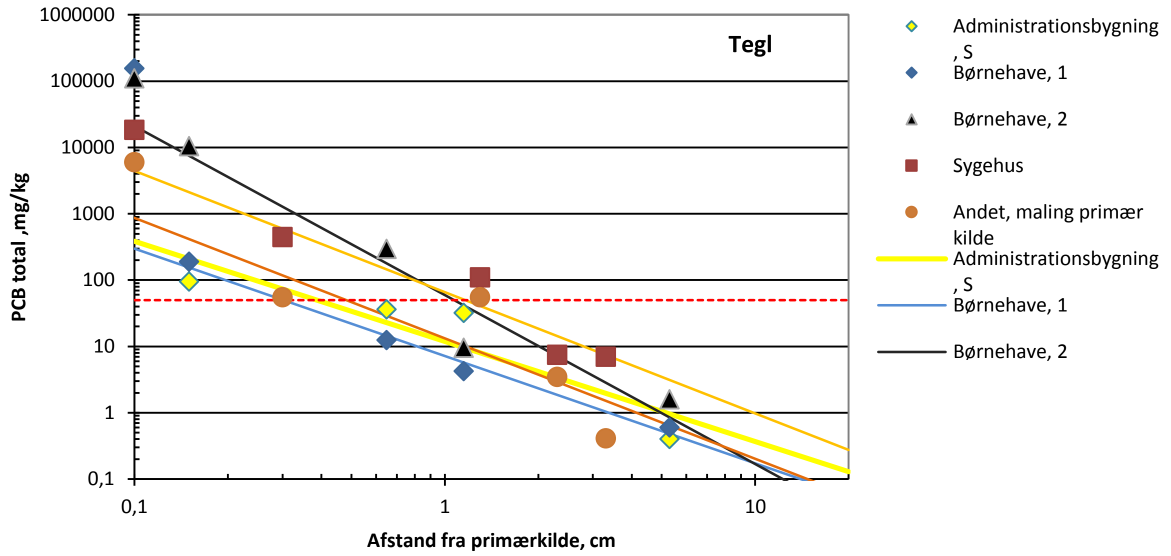


Figure 20 *Measurements of PCB penetration in brick in four different buildings. The concentration in the primary source is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Unless indicated otherwise, the primary source is sealant. The primary source for "Administration building S" is 155,000 mg/kg and is concealed behind the marking for "Hospital". Plotted lines are based on linear regression of the logarithmically transformed data.*

Mortar

Three profiles of PCB in mortar shown in Figure 21 have gradients of the same size as that seen for lightweight concrete and brick.

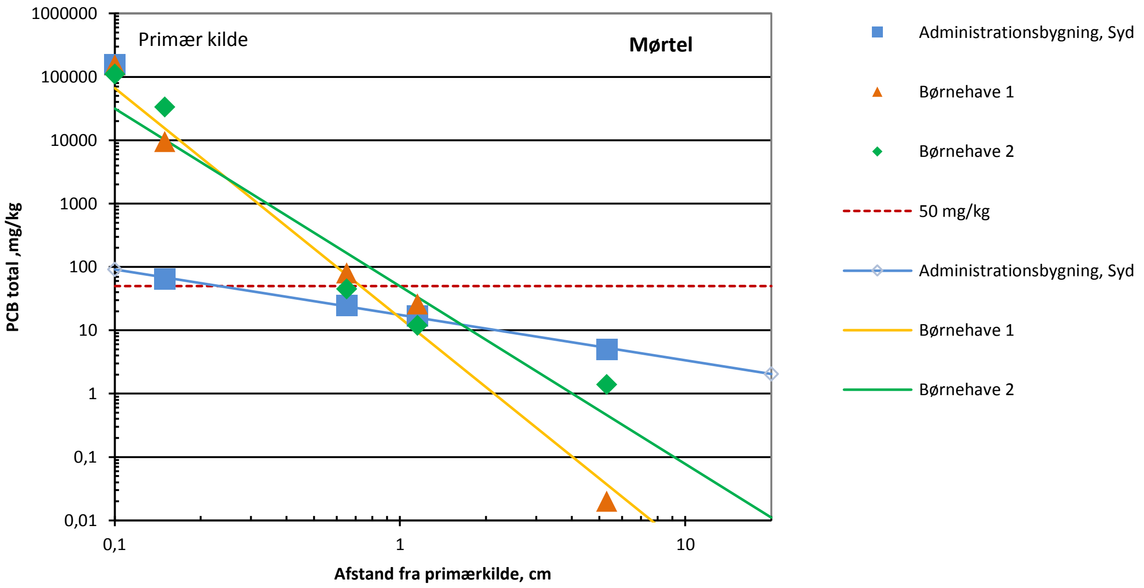


Figure 21 *Measurements of PCB penetration in mortar from two different buildings. The concentration in the primary source (sealant) is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Plotted lines are based on linear regression of the logarithmically transformed data.*

Concrete

The results for concrete are significantly different from the measurement series illustrated in the literature study, and only one of the measurement series shows a development corresponding to the developments presented in the literature study. Two of the measurement series in this study were taken from paint as the primary source. In both these measurement series, the measured concentrations in the underlying concrete at all depths are below 1.3 mg/kg, despite the two paints having concentrations of 20,000 and 6,000 mg/kg respectively. This is a somewhat different result than that for brick shown above, where the penetration corresponds more to the form observed when the primary source is a sealant. However, since there are only two measurement series the data are insufficient for it to be concluded that PCB will not migrate from paint to concrete on a noticeable scale.

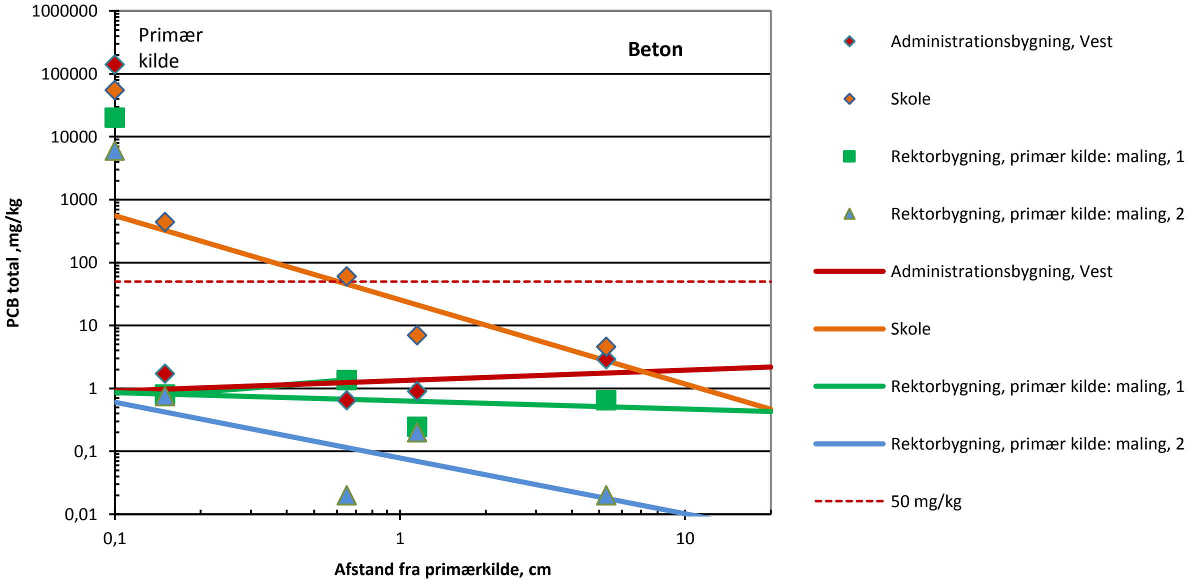


Figure 22 *Measurements of PCB penetration in other concretes from various buildings and with various primary sources. The concentration in the primary source is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Unless indicated otherwise, the primary source is sealant. Plotted lines are based on linear regression of the logarithmically transformed data.*

Other materials

Results for other materials where for various reasons fewer measurement series were obtained are shown in the figure below.

No fall is seen in relation to the distance in glass cloth adjacent to paint containing PCB either, which may very well be due to the glass cloth at the site being tertiary contaminated via the indoor air in the building. Once more, there are insufficient data for conclusions to be drawn.

The hardwood samples demonstrate both rising and falling concentrations according to the distance from the source and because of the modest number of measurements it is not possible to draw any conclusions.

In addition to the measurements shown, a number of measurements were also taken for vapour barriers, facade panels, veneer materials, insulation (glass wool), paint (off the sealant), chipboard and stone but these are not shown here – either because the primary source had such a low concentration that all measurements are below the detection limit or because a set of measurement series could not be obtained for other reasons.

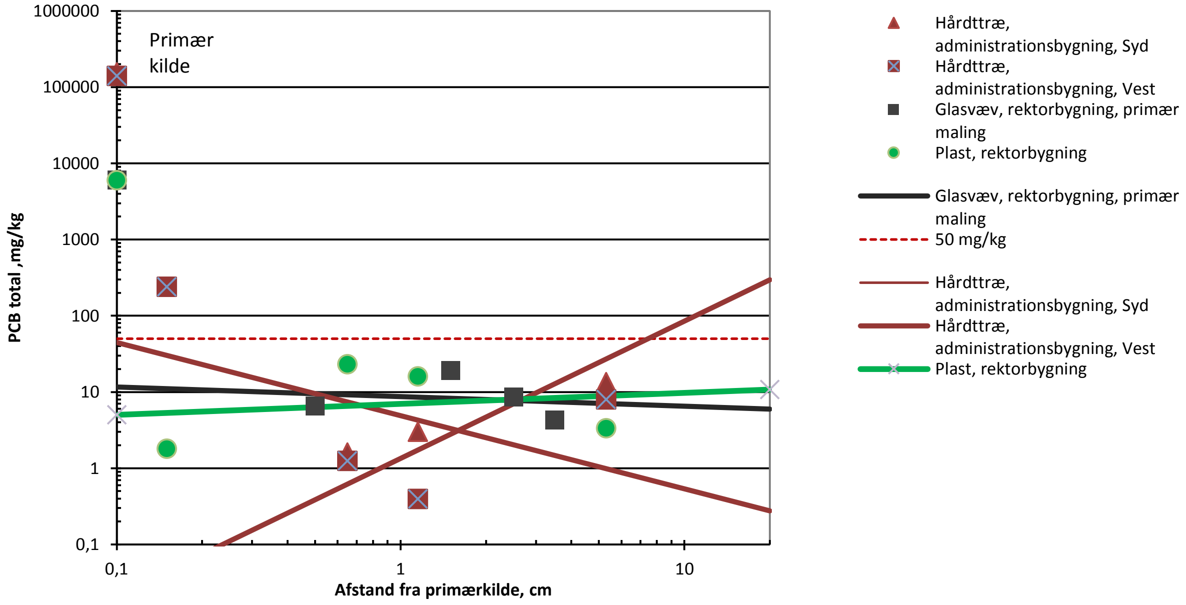


Figure 23 *Measurements of PCB penetration in other materials from various buildings and with various primary sources. The concentration in the primary source is shown as a measuring point at 0.1 cm and is not included in the calculation of regression lines. Unless indicated otherwise, the primary source is sealant. Plotted lines are based on linear regression of the logarithmically transformed data.*

Statistical differences between materials

One result all the materials have in common is that the PCB concentration is less than 50 mg/kg at a distance of 2 cm from the primary source. Similarly, many of the regression lines show that the PCB concentration is still above 0.1 mg/kg at a distance of 20 cm from the primary source.

Statistical analysis was used to examine whether there are significant differences between the diffusion coefficients found. The diffusion coefficient can be calculated as the gradient of the regression lines on the double logarithmic mappings. The analysis was only carried out for those materials for which a large number of measurements were taken: lightweight concrete, brick and wood.

It was first examined in this analysis whether or not the same coefficient can be applied to all measurement series for each material. For these three materials it was demonstrated that differences in the coefficients for the individual material are not significant. On the other hand, the differences between the materials are significant with the following average coefficients stated with the standard error in parentheses:

- Lightweight concrete: -1.37 (0.21)
- Brick: -1.87 (0.27)
- Wood: -0.99 (0.19)

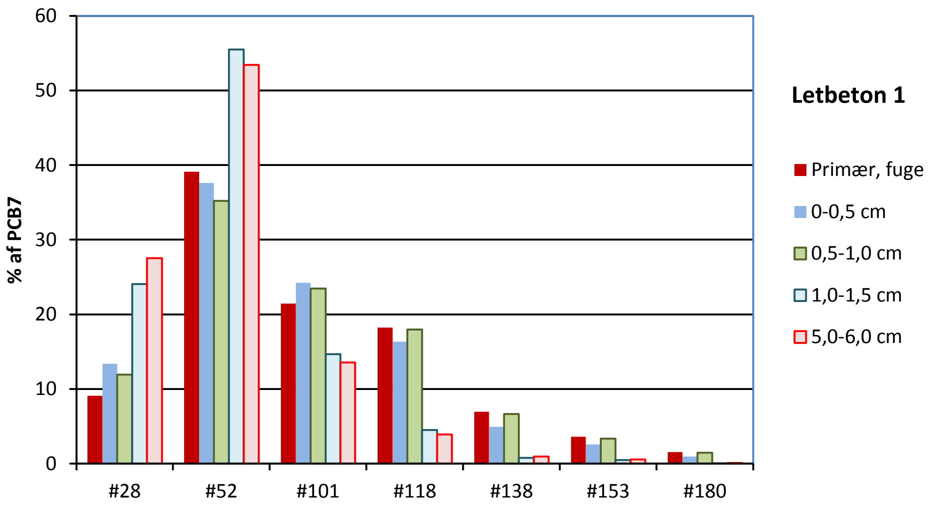
Statistical analysis has shown that there are significant differences between the diffusion coefficients for the three materials (details not described here).

Material penetration in relation to diffusion

Both the results shown here and the results of the literature study reveal that in individual cases sealant (primary source) has penetrated cracks in the adjoining material, and this has a major influence on how deep PCB penetrates into the adjoining material. The variation in penetration depth for the individual material thus appears to depend more on differences in penetration over the first 5 mm than on differences in diffusion coefficients.

Congener-specific differences in penetration

There is no evidence in the data to suggest there are significant congener-specific differences in the penetration of PCB in the materials. The congener compositions in the adjoining materials are obviously a reflection of the composition in the primary materials, as illustrated in the two figures below showing two distance profiles in lightweight concrete. The two sealants that act as primary source were low chlorinated and high chlorinated respectively, and this is reflected in all the samples from the adjoining materials. The results also provide a clear indication that the values found at 5–6 cm in actual fact originate from this primary source and are not due to a tertiary presence, for example, because the profiles are largely identical to the profiles at a distance of 1–1.5 cm. The assessment is that in all probability contamination did not occur during sampling since all precautions for avoiding contamination of the samples were taken at the time.



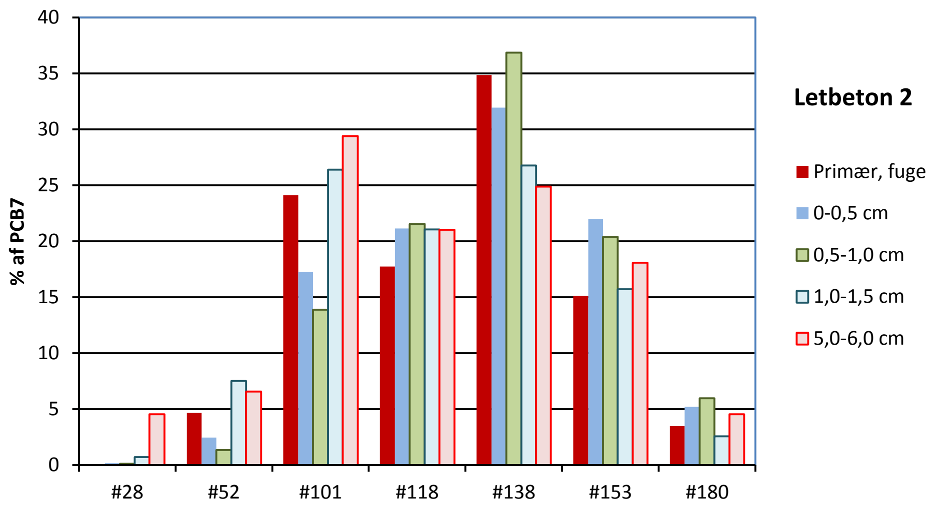


Figure 24 *Congener composition as a function of the distance to the primary source (sealant joint) in two samples of lightweight concrete with a different primary source.*

3.4.4 PCB amounts in secondary contaminated materials

Table 25 shows the following parameters for each sample series:

› Regression lines calculated on the basis of double logarithmic transformed data.

› Distance from sealant joint in which the calculated concentration in adjoining material is 50 mg/kg, 1 mg/kg and 0.1 mg/kg respectively.

› The amount of adjoining material that needs to be cut away per running metre of sealant in order to remove ≥50 mg/kg, 1–50 mg/kg and 0.1–1 mg/kg respectively.

› Amounts of PCB in the various fractions of cutaway material.

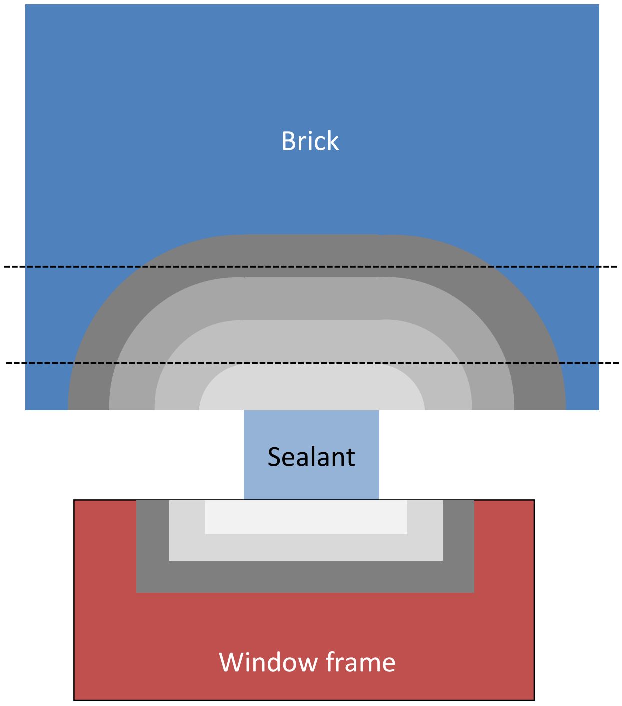
› Amount of PCB in the sealant. It is assumed that the sealant is 1 cm deep and 1 cm wide and has a density of 1.6 g/cm^3.

When calculating the amount of adjoining material that needs to be cut away per running metre of sealant, it is assumed that the sealant joint is 1 cm deep and the adjoining material is 12 cm thick (equivalent to a brick). The cut is made parallel to the surface facing the sealant and the concentrations are 50 mg/kg, 1 mg/kg and 0.1 mg/kg respectively at the point in the cut which is closest to the sealant (off the sealant joint). See the drawing below. Several of the materials will have thicknesses other than 12 cm, but this simplified calculation assumes that all materials have the same thickness.

PCB will spread out from the sealant into the adjoining material as illustrated on the brick in the drawing. If a cut is made at a distance of, for example, 0.5 cm from the sealant, where the concentration just off the sealant joint is 50 mg/kg, some parts of the cut will be further away from the sealant and these parts will therefore have a lower concentration.

The amount of PCB in the cutaway material was calculated in a simplified manner using a box model, as illustrated on the wood frame, and calculated using a numerical solution divided into sections of 0.05 cm (i.e. the material is divided into twenty sections for every centimetre). In materials with very deep penetration, 2mm sections are used in the calculation for distances over 5.5 cm.

The calculated regression lines are used when calculating total PCB amounts. The closest 0.05 cm to the source is not included because several of the curves, when approaching the distance 0 cm, give values far above the concentration in the primary source. By disregarding the first 0.05 cm, the calculated average concentrations in the interval 0–0.5 cm were the same size as the measured average at 0–0.5 cm (in some cases higher and in other cases lower, depending on the form of the regression lines in relation to the first measuring point).



As can be seen in the table below, there is very great variation within the individual materials; this is also illustrated in the previous figures. The discussion here will focus on the measurements taken in brick, lightweight concrete and pine wood.

The fact that the samples cannot be assumed to have the same representativeness (e.g. four lightweight concrete series from a school and one series from a nursery school, which are significantly different) means that it is believed that simple mean values of all measurement series are unrepresentative; for this reason no calculations have been made on the basis of mean values.

As regards brick, we can see that the distance from the primary source where the concentration reaches 50 mg/kg varies from 0.3 to 1.2 cm, while the concentration

0.1 mg/kg is reached at a distance of 12–35 cm from the primary source. In lightweight concrete, there is a single measurement series from a nursery school where 50 mg/kg is not reached until a depth of 14 cm, while the other measurement series taken at a school vary between 0.1 and 0.8 cm. For the four measurement series from the school, 0.1 mg/kg is reached at a distance of 7–35 cm from the primary source. In pine wood, it takes a distance of 0.6–12 cm from the source before the concentration falls to 50 mg/kg, while 0.1 mg/kg is reached at a distance of several metres. It should, however, be noted that it is very unreliable to extrapolate to a distance of several metres on the basis of measurements within the first 6 cm. In practice, this means that we cannot assume that the concentration is below 0.1 mg/kg in adjoining wood.

Material quantities and amounts of PCB are indicated on the right-hand side of the table in m^3 and mg respectively per running metre of sealant.

Calculations of material quantities to be removed if a cut is made parallel to the surface facing the sealant show that 5–10 times as much material needs to be removed if it needs to be stripped down to 0.1 mg/kg compared to stripping down to 50 mg/kg. Note that differences in material quantities are not as pronounced as differences in penetration, which is linked to the cuts being made parallel to the sealant, with larger amounts of material with concentrations below the concentration which was pivotal in the placing of the cut thereby being removed. In some series the difference is much more significant.

If we examine how much PCB is present in the adjoining materials compared to the primary source, much greater differences are seen; these are entirely dependent on how much of the primary source has penetrated into the closest part of the material. In many of the measurement series, the amounts in adjoining materials constitute 0.2–2% of the amount of PCB in primary materials, but some of the series stand out with 10–20% in the adjoining materials. This is the case for brick, lightweight concrete and wood.

In all profiles, the amount of PCB in the section covering the interval 0.1–1 mg/kg corresponds to less than 0.5% of the PCB in the primary source. For all three materials, there is a single measurement series in which the amount in the 1–50 mg/kg section corresponds to approx. 4% of the primary source, while the others are in the interval 0.1–2% of the primary source.

Table 25 Distance from sealant, material quantities and PCB amounts for different cuts (values have not been calculated for profiles which are not assumed to show actual penetration in the materials).

Sample	Regression line	Distance from sealant (cm)			Material (m^2/m sealant) for cut at distance from sealant corresponding to:				Amount of PCB (mg/m sealant) for cut at distance from sealant corresponding to:			PCB in sealant (mg/m)	Secondary as % of sealant
Brick		50 mg/kg	1 mg/kg	0.1 mg/kg	≥50 mg/kg	1–50 mg/kg	0.1–1 mg/kg	>0.1 mg/kg	≥50 mg/kg	1–50 mg/kg	0.1–1 mg/kg	mg	
Administration building, S	y = -1.509x +1.075	0.4	5.2	23.7	0.05	0.09	0.62	0.75	31	32	12	24,800	0.3%
Nursery school, 1	y = -1.62x +0.854	0.3	3.4	13.9	0.04	0.06	0.40	0.50	22	16	8	24,800	0.2%
Nursery school, 2	y = -2.55x +1.774	1.1	5.0	12.2	0.13	0.08	0.60	0.81	1,790	45	9	17,600	10.5%
Hospital	y = -1.828x +1.818	1.2	9.9	34.8	0.14	0.12	1.18	1.44	368	111	16	2,960	16.7%
Other, primary source: paint	y = -1.817x +1.122	0.5	4.1	14.7	0.06	0.07	0.50	0.63	65	26	9	Paint	Paint
Average coefficient	-1.88												
Lightweight concrete													
School, facade, N	y = -1.121x +0.733	0.1	4.5	35.1	0.02	0.08	0.54	0.64	4	5	8	8,800	0.2%
School, corridor 1	y = -1.360x +1.075	0.3	6.2	33.6	0.04	0.09	0.74	0.88	7	15	7	27,200	0.1%
School, temporary classroom, facade, W, 1	y = -1.724x +1.561	0.8	8.0	30.6	0.10	0.11	0.97	1.17	59	30	6	28,000	0.3%
School, corridor 2	y = -2.767x +1.457	0.8	3.4	7.7	0.10	0.06	0.40	0.56	591	9	2	32,000	1.9%
Nursery school, room, E	y = -1.061x +2.902	13.6	544	4,764	1.63	0.33	65.25	67.21	2,521	652	n/a	15,200	20.9%
Average coefficient	-1.61												
Softwood													
School, sports hall, 1	y = -0.81x +1.503	0.6	72	1,235	0.07	0.22	8.62	8.92	8	129	26	8,800	1.8%
School, sports hall, 2	y = -1.601x +1.587	0.9	10	41	0.10	0.12	1.18	1.40	36	26	6	24,800	0.3%
School, corridor 1	y = -0.671x +2.354	9.5	3,211	99,076	1.14	0.42	385.28	386.84	514	1,153	n/a	27,200	6.1%
School, temporary classroom, W facade	y = -1.645x +3.359	10.2	110	446	1.22	0.24	13.20	14.67	3,727	369	8	28,000	14.7%
School, corridor 2	y = -0.783x +2.096	3.2	477	9,048	0.39	0.32	57.27	57.98	109	568	n/a	32,000	2.1%
Nursery school, 1	y = -1.493x +2.497	3.4	47	220	0.41	0.20	5.65	6.27	362	174	22	24,800	2.2%

Sample	Regression line	Distance from sealant (cm)			Material (m^2/m sealant) for cut at distance from sealant corresponding to:				Amount of PCB (mg/m sealant) for cut at distance from sealant corresponding to:			PCB in sealant (mg/m)	Secondary as % of sealant
Brick		50 mg/kg	1 mg/kg	0.1 mg/kg	≥50 mg/kg	1–50 mg/kg	0.1–1 mg/kg	>0.1 mg/kg	≥50 mg/kg	1–50 mg/kg	0.1–1 mg/kg	mg	
Nursery school, 2	y = -0.892x +1.9	1.7	134	1,775	0.20	0.26	16.14	16.59	41	287	n/a	17,600	1.9%
Average coefficient	-1.13	0.6	72	1,235	0.07	0.22	8.62	8.92	8	129	26	8,800	1.8%
Mortar													
Mortar, administration building, S	y = -0.718x +1.242	0.2	54	1,327	0.03	0.21	6.45	6.68	7	321	125	24,800	2%
Mortar, nursery school, 1	y = -3.629x +1.194	0.7	2	4	0.09	0.04	0.26	0.38	10,379	13	2	24,800	42%
Mortar, nursery school, 2	y = -2.805x +1.692	1.0	4	9	0.12	0.07	0.48	0.67	3,230	39	6	17,600	19%
Average coefficient	-2.38	-	-	-	-	-	-	-	-	-	-	-	-
Concrete													
Concrete, administration building, W	y = 0.165x +0.124	-	-	-	-	-	-	-	-	-	-	-	-
Concrete, school	y = -1.338x +1.407	0.6	11.3	63	0.07	0.13	1.35	1.55	59	100	38	8,800	2%
Concrete, headteacher's residence, primary source: paint, 1	y = -0.13x +-0.198	-	-	-	-	-	-	-	-	-	-	-	-
Concrete, headteacher's residence, primary source: paint, 2	y = -0.887x +-1.106	-	-	-	-	-	-	-	-	-	-	-	-
Other materials													
Hardwood, administration building, S	y = 1.802x +0.13	-	-	-	-	-	-	-	-	-	-	-	-
Hardwood, administration building, W	y = -0.961x +0.69	-	-	-	-	-	-	-	-	-	-	-	-
Plastic, headteacher's residence	y = 0.144x +0.845	-	-	-	-	-	-	-	-	-	-	-	-
Glass cloth, headteacher's residence, primary source: paint	y = -0.126x +0.9394	-	-	-	-	-	-	-	-	-	-	-	-

3.4.5 Summary and partial conclusion

Power function versus exponential function

The penetration of PCB has previously been described in Swedish and Danish studies. A literature study published by the Danish Environmental Protection Agency this year discusses the best way to describe penetration of PCB from a primary source into adjoining materials. It is of great importance whether the penetration follows an exponential function (linear function in a simple logarithmic mapping) or a power function (linear function in a double logarithmic mapping). In the case of a power function, most of the PCB will penetrate deep into the material. According to the literature study, penetration in concrete is best described as a power function, while penetration in lightweight concrete is best described as an exponential function.

The results of this study show that penetration into pine, lightweight concrete and brick is best described as a power function, which means that PCB penetrates a relatively long way into the materials and that the concentration will not decrease to 0.1 mg/kg until a considerable distance from the source.

Differences within an individual material

The measurement series display considerable differences in concentrations in the materials within the first 0.5 cm from the source, which is primarily sealant. This is interpreted as indicating that some of the sealant penetrates inside holes and cracks in the adjoining materials in certain areas. For example, the concentrations in pine at a distance of 0–0.5 cm from a primary source with around 100,000 mg/kg vary from 200 to 20,000 mg/kg. At this distance, penetration is therefore determined not by the migration of PCB in the wood, but by the penetration of the sealant which contains PCB. Further into the material, additional penetration is determined by the migration of PCB into the wood, and relatively uniform migration coefficients are observed in the various measurement series. The considerable differences over the first 0–0.5 cm are thus propagated as substantial differences throughout the entire measurement series. This means that it is not possible to accurately predict how far PCB penetrates at a given point.

Differences between materials

The results show that PCB penetrates deeper into the pine than it does in the other materials, and at a distance of 4–5 cm from the source there was still ≥50 mg/kg in two out of seven measurement series, while it varied between 2 and 38 mg/kg in the others. Based on the calculated migration coefficients, it can be estimated that there will still be between 0.3 and 30 mg/kg at a distance of 20 cm from the source.

In lightweight concrete, the penetration is similarly deep. At a distance of 1 cm from the source, the concentration in all measurement series is close to <50 mg/kg, while for the measurement series with the highest penetration in the first 0.5–1 cm, the concentration would, based on the migration coefficient, not fall below 50 mg/kg until a distance of 12 cm from the source is reached. This is not because the migration coefficient is different in this measurement series, but simply because of the greater penetration at a distance of 0–0.5 cm from the primary source.

A statistical analysis has shown that there are significant differences between the diffusion coefficients for lightweight concrete, brick and paint, which are the three materials with enough profiles to generate statistics.

The results show that many samples need to be taken in order to come up with a detailed description of the penetration in adjoining materials in a building. Due to the great variation, it is not possible to predict with certainty how far PCB will penetrate in each case. It is therefore important to clarify whether the guidelines for removal of adjoining materials should be based on the deepest penetration or on average values. It would be useful to prepare some guidelines on the basis of the complete data from all studies on how a small number of depth profiles can be used to determine how much of the adjoining material needs to be removed and disposed of selectively.

Amount of PCB in adjoining materials

If we examine how much PCB is present in the adjoining materials compared to the primary source, much greater differences are seen; these are entirely dependent on how much of the primary source has penetrated into the closest part of the material. In many of the measurement series, the amounts in adjoining materials constitute 0.2–2% of the amount of PCB in primary materials, but some of the series stand out with 10–20% in the adjoining materials. This is the case for brick, lightweight concrete and wood.

In all profiles, the amount of PCB in the section covering the interval 0.1–1 mg/kg corresponds to less than 0.5% of the PCB in the primary source. The section covering 0.1–1 mg/kg typically weighs three to 10 times as much as the section covering concentrations down to 1 mg/kg.

4 Measurements of PCB in indoor air

4.1 Background

According to the tender documents for the survey, the indoor air measurements must lead to credible estimates for the following parameters in relation to the presence of PCB in indoor air:

› The proportion of Danish buildings with PCB in indoor air: in total and broken down by building type.

› The distribution of buildings with PCB in indoor air in concentration intervals based on the action values of the Danish Health and Medicines Authority.

› The composition of congeners in indoor air broken down by building type and compared to the identified sources of indoor air contamination.

› The correlation between the concentration of PCB in the materials examined (both primary and secondary sources) and the concentrations found in indoor air.

› Concentrations in indoor air broken down by building type.

› The building materials (and their location) that are of importance for the effect on indoor air.

4.1.1 Parameters that affect indoor air concentration

It is well known that the PCB concentration in indoor air varies over time and that taking a measurement at a single point in time does not provide a complete picture of the PCB concentration in a building. There is thus a need to repeat measurements over different time periods in order to establish the actual variation in the concentration in indoor air. Since this concerns indoor air measurements, this does not involve a single concentration; instead, the building's indoor air impact is described by indicating an interval in order to describe the extensive variation in all the factors of importance for the concentrations in indoor air (SBi, 2013).

The PCB concentration found in the indoor air of a room at a given time depends on a number of factors, as described in the table below. Several parameters have been measured in order to examine these factors.

A distinction is made between two types of parameters in the table:

1. Parameters which act through a change in the source strength – i.e. the rate at which PCB is released from materials to the indoor air.
2. Parameters which act in a different way – primarily through greater air exchange.

Table 26 Parameters which affect the PCB concentration in indoor air at a location at a given time.

Parameter	Description	Expected correlation (all other factors being equal)	Parameter that can be measured	Action via altered source strength
Concentration of PCB in materials	PCB is released into indoor air from materials containing PCB. The concentration in the surface of the materials is presumably lower than it is deeper in the material, but the total concentration in the material is presumed to affect the PCB concentration in the indoor air.	Higher concentration in materials > higher concentration in indoor air.	PCB_{total} in materials	Yes
Composition of PCB in materials	Migration of PCB to the surface of the materials, and the release into the air, differs for the individual congeners; the total emissions will therefore depend on the composition in the materials, which will be different in sealants than in paint for example.	Materials with a high content of low chlorinated PCB will lead to higher concentrations in indoor air.	Primary source: sealant/paint/flo or compound/emis sions from capacitors.	Yes
Surface of materials containing PCB	The larger the surface, the greater the emissions and PCB concentrations in the air for materials with the same PCB concentration.	Larger surface > higher concentrations in indoor air.	Total surface area of material containing PCB.	Yes
Presence of sealed glazing units containing PCB	PCB in sealed glazing units in which frames and sills contain PCB from sealant tape and Termokit window putty may release PCB into the indoor air.	Sealed glazing units facing east, west and south will release PCB when the temperature of the units rises, e.g. due to solar heat gain.	The number of sealed glazing units containing PCB with sills and frames.	Yes
Presence of PCB capacitors	PCB capacitors in fluorescent lamps, and particularly leaking capacitors, could release PCB into the indoor air.	Illuminated fluorescent lamps (with PCB) > higher concentrations in indoor air. Several fluorescent lamps (with PCB) > higher concentrations in indoor air.	The number of light fittings containing PCB (removed if necessary in a measuring situation).	Yes
Location of materials.	All other factors being equal, materials containing PCB that are located indoors will release larger amounts of PCB into the indoor air than materials located outdoors. As regards buildings which only have materials containing PCB located outdoors, it is still uncertain whether the PCB concentration in indoor air could in exceptional circumstances reach the Danish Health and Medicines Authority's lowest recommended action value or if it would be significantly lower under all circumstances.	An indoor location results in higher concentrations in indoor air than an outdoor location.	Location: outdoors/indoor s	Yes

Parameter	Description	Expected correlation (all other factors being equal)	Parameter that can be measured	Action via altered source strength
Air temperature, indoors	A higher temperature results in higher emissions of PCB, as demonstrated in numerous studies. Depending on the location of the materials in the structure, both indoor and outdoor temperatures may affect the concentrations. This could also lead to heterogeneous emissions of PCB into the indoor air, e.g. solar heat gain or a PCB source being placed behind a radiator that is in use.	Higher temperature outdoors and indoors > higher concentrations in indoor air.	Indoor temperature Outdoor temperature	Yes
Temperature of the materials	The deviation rate from primary source must be expected to depend more on the temperature of the material than the temperature of the room. In winter, for instance, sealant on internal joints around windows has a significantly lower temperature than the air in the room.	Higher temperature > higher concentrations in indoor air.	Surface temperature of materials	Yes
Outdoor temperature	If the largest primary source consists of materials containing PCB which are located outdoors, the temperature would be expected to affect the evaporation from the source.	Higher temperature > higher concentrations in indoor air.	Outdoor temperature	Yes
Air humidity	Air humidity may affect the emissions of PCB, but this has not been examined in detail and the effects are presumably limited. Air humidity normally falls as temperature rises. When air humidity is high, this may affect the amount of dust in the room in which measurements are being taken, as well as the adsorption to tertiary sources for example.	Not known	Indoor air humidity	Yes
Air exchange	During air exchange, the PCB released to the indoor air from the PCB sources is diluted. At a given source strength (emission), a higher rate of air exchange normally produces a lower PCB concentration in the room. The effect will depend on whether there is PCB in the air which is drawn into the room. In addition to sources inside the room, PCB could be brought in from adjacent rooms, with higher concentration – and the concentration in the individual room will therefore depend on the PCB concentration in adjacent rooms and the direction of the air exchange.	Higher rate of air exchange > lower concentrations in indoor air: - provided that the concentration is not greater in adjacent rooms and there is air exchange with uncontaminated air.	Total air exchange between room and surroundings possibly broken down into: - outdoor air exchange - air exchange with adjacent rooms - concentration in adjoining rooms Measurement of air exchange	No (see discussion below)

Parameter	Description	Expected correlation (all other factors being equal)	Parameter that can be measured	Action via altered source strength
Air exchange between the room examined and cavities in the building.	In addition to sources inside the room, PCB could be brought in from sources located in cavities or on the exterior of the building. PCB can for example reach high concentrations in cavities in the building and the air containing PCB can under exceptional wind and pressure conditions move from cavities into living rooms. Until now the issue has not been examined in detail; it is very complex and specific to each individual building.	Relationships will depend on the presence of cavities, the presence of sources touching cavities and the direction of the air exchange.	The measurement of differential pressure can presumably only be used to determine the variation in the individual building and between building types.	No
Other air exchange in the building	PCB can also be transferred through air supply if the ventilation system involves recirculation and a rotary heat exchanger. The transfer of PCB can furthermore take place from one room to another whenever the external transfer of air occurs between the ventilation's outlet and intake vents outside the building.	When there is no clear relationship, the action will depend on a large number of factors in the building in question.	Measurement of mechanical air exchange and the PCB concentration in injected air will be required.	No
Concentration of dust in air	PCB sticks to dust. When a lot of air circulates and the room is in use, dust will be stirred up and this can result in higher PCB concentrations in the air. However, existing measurements show that dust makes only a very modest contribution to the total amount of PCB in the air; they also show that variations in the amount of dust on the surface and the extent to which it is stirred up presumably have a very limited effect on the variation in PCB concentrations in indoor air.	More dust in the air > higher concentrations in indoor air.	PCB in dust and gaseous form respectively. The method used does not distinguish between the forms of PCB that are found. It is apparent that indoor air concentrations are composed of PCB in both dust and gaseous form.	No

The relationships between PCB in indoor air and the parameters are complicated by the fact there can be several feedback mechanisms that affect the source strength and the adsorption of PCB onto surfaces in the room:

› Theoretically, the concentration of PCB in indoor air will affect the release from the primary sources; it is however uncertain whether the actual air concentrations and high concentrations in the primary sources are of any importance.

› The concentration of PCB in the air affects the equilibrium between PCB in the air and materials with a relatively low PCB content – i.e. at times of high PCB concentration, there will be a tendency for PCB to adsorb onto surfaces and be absorbed into the materials, while the equilibrium will be displaced so that the tertiary sources act as sources when the PCB concentration in the air is relatively low.

It must be expected that these feedback mechanisms will be reflected in a non-linearity between PCB concentration in the air and the air exchange, but so far this relationship has not been described in detail.

Variations in the factors mentioned above will result in variations over time in the PCB concentrations in the individual room in the building.

When discussing variations, it is important to distinguish between:

› The variation in primary parameters which directly affect the PCB concentration in the air.

› Variations in physical factors which affect the variation in the primary parameters (e.g. wind conditions that might affect air exchange, temperature, pressure difference in the building and several other parameters).

4.1.2 Variations within the individual building and between buildings and building types

It is well-known that there may be significant differences between the PCB concentration measured in the same room at, for example, monthly intervals and between day/night, and that there are significant variations between PCB concentrations in the individual rooms within the same building.

The local and temporal variations are generally determined by environmental changes and the use of the building. The variation can be described for the separate buildings, but in order to extract more general information across the buildings, it will be necessary to define some general conditions that can affect the PCB concentration.

Local variation (within an individual building) can be related to:

› Orientation in relation to compass points. Wind action (the prevailing wind is from the west) and solar heat gain (higher temperatures on the south side than on the north side) will have an effect. In individual buildings, the effect will however be determined by the location of primary sources and this may mask a general pattern.

› Horizontal location in the building. All other factors being equal, higher PCB concentrations will be expected in the upper floors compared to the bottom floors due to air flows and temperature conditions.

› The location of primary sources and ventilation conditions. These factors will be totally different from building to building and a general pattern cannot really be expected.

Variation as a function of the use of the building:

› In many buildings, significant differences in PCB concentrations must be expected between the situations in which the building (or the room in which measurement is taken) is in use. Depending on the ventilation conditions (active or passive ventilation), a significantly higher rate of air exchange is expected when the building is in use than when it is not.

- The use of the building may also result in greater air circulation, which may lead to higher dust content.

Temporal variation:

- Use of the building. Significant differences must particularly be expected while a building/room is in use, depending on variations in the use of the building/room, which first and foremost occur as a result of differences in air exchange.

- Climatic conditions – temperature and wind. These will give a temporal variation both when a room is in use and when it is not.

The potential difficulty in explaining the variation is illustrated by a recent study of radon concentration in 200 new-build houses in Denmark, where the radon concentration was related to municipality, building age, floor area, floor level and whether there was a basement as well as wall and roof construction. Based on a multivariate analysis, it was possible to explain 9% of the variation in radon concentration using these parameters, while the relationship with single parameters was not statistically significant for any of the parameters (Bräuner et al., 2012). The same was deemed to be true for PCB in indoor air, although PCB does behave differently; there will also be an effect from the adsorption/desorption from both secondary and tertiary sources.

4.2 Sampling and analysis

Based on the results of the ENS survey of PCB in building materials (phase 2 of the survey) and a structural review, a total of 67 buildings was selected within the three building categories intended for inclusion in the indoor air studies; see section 2.3.5 for a more detailed description.

Two rooms were selected in each building, room A and room B respectively, in which the studies of indoor air were carried out. The rooms were chosen on the basis of the highest concentrations in the building materials. A room was deemed unsuitable for sampling if nothing would be gained by taking a measurement there, e.g. in a stairwell where there would naturally be a very high rate of air exchange, in a very large room that cannot be closed off or if renovation work was taking place in the room. Furthermore, it should have been possible to identify a period of time in the day when there was no activity in the building, so that stable conditions could be achieved in the adjacent rooms in that building. Measurements were therefore taken during periods of time when the building was not in use and when it was possible to take indoor air measurements in the two rooms without interruption or disturbance.

The following studies were carried out in two rooms in each building in connection with the study of PCB in indoor air:

- PCB in air: two PCB air samples in each room in which significant concentrations of PCB in building materials had been found previously.

- Quantity of PCB sources: surface areas and the volume of the PCB sources are measured and described in the rooms from which air samples were collected.

› PCB in material: in 12 selected buildings, supplementary samples were taken of building materials and fixtures and fittings. The 12 buildings were selected before the indoor air measurements were taken, based on where primary sources of PCB in paint, sealant and flooring were found previously.

While PCB in the air was being collected, the following were logged:

› Temperature

› Air humidity

› Differential pressure

In addition to this, the injected and extracted volume flow rate and the temperature were measured in test rooms with mechanical ventilation. Air exchange was measured in one of the two test rooms in each building, defined as room A, by measuring the decay of the tracer gas hydrogen.

Before the air sample was taken, the room was ventilated for 10–15 minutes. Doors and windows were closed during the indoor air measurement process, while the heating system and any ventilation system were run as normal. Any small fresh air valves mounted in window frames were closed.

No people or animals were present in the rooms while sampling was taking place. The sample takers tried to avoid moving around near the rooms or opening and closing doors and windows near the rooms while sampling was taking place. Both the indoor air measurement and air exchange measurement were initiated using timers, providing a time delay with the aim of stabilising the air volume in room A in order to ensure the best possible air sampling/air exchange measurement.

The methods used for taking samples, measuring air exchange and ventilation, etc. are described in Annexes 1 and 2.

To examine the presence of PCB congeners other than the seven PCB congeners included in standard analyses, measurements for the following 27 congeners were taken for the indoor air studies:

› The six indicator congeners that constitute PCB_6: PCB nos. 28, 52, 101, 138, 153 and 180.

› The 12 dioxin-like congeners: PCB nos. 77, 81, 105, 114, 118 (included in PCB_7), 123, 126, 156, 157, 167, 169 and 189.

› Another nine non-dioxin-like congeners: PCB nos. 66, 74, 99, 170, 178, 182, 183, 187 and 190.

The samples were analysed in a laboratory using the GC-MSD-SIM method. Total PCB was calculated as five times the sum of the seven congeners.

The study programme followed does not enable the following to be examined:

› **Variation over time**. By only taking the measurements on a single day it was not possible to examine the variation that exists over time, nor was it possible to obtain a complete picture of the average PCB concentration in the buildings. It is well-known that PCB concentration varies depending on a number of parameters, but little is known about this variation. There is thus significant uncertainty when individual measurements are checked against the Danish Health and Medicines Authority's action levels; there is also no consensus about how this variation should be taken into account.

› **Measuring conditions**. Taking the measurements in rooms which are not in use means that a true picture of the PCB concentration in the indoor air while the room is in use is not obtained. Use of the room could for example result in greater air circulation, stir up more dust into the air and affect the air exchange inside the building and between the building and its surroundings. It is, however, uncertain how much the use of a room affects the PCB concentration in the indoor air. Section 4.3.1 makes reference to studies carried out as an extension to these studies which show the variation during and outside the period of use of the building.

› **Congeners that are measured**. The studies include the analysis of 27 congeners, which is more congeners than are covered by standard measurements of PCB_7. It is well-known that low chlorinated PCBs (with a low congener number) are released from the materials to a greater extent. The demarcation for PCB_{27} can therefore provide some limits in relation to clarifying the congener-specific relationship between PCB in the materials and in the indoor air in terms of low chlorinated PCBs.

› **Air exchange measurements**. The air exchange measurements are carried out as decay measurements without any activity in the room and without any normal passive or mechanical ventilation. This means that the air exchange measured as part of these studies may be lower than that which occurs during normal use of the building. This may be of relevance when describing the correlation between the concentration of PCB in the materials examined (primary, secondary and tertiary sources) and the concentrations found in indoor air.

4.3 Results of the study

4.3.1 PCB in indoor air

The results of measurements of PCB in indoor air in 67 buildings are shown in the table below. Measurements were only taken in two rooms in each building, and the table is based on the highest value measured in each building.

As can be seen, a concentration ≥300 ng/m^3 was found in one of the detached and semi-detached houses surveyed and in one of the blocks of flats surveyed. In none of the buildings surveyed in these two building types was a concentration ≥2,000 ng/m^3 found. Concentrations of less than 30 ng/m^3 were found in 71% and 75% respectively of the buildings in which indoor air measurements were taken; this level is close to the detection limit.

There was a significantly higher frequency of private office buildings and public institutions with ≥300 ng/m^3. In 12 of the 33 buildings surveyed (36%), at least one room with a concentration ≥300 ng/m^3 was found and a concentration ≥3,000 ng/m^3 was found in one building. The results correlate well with the results of the survey of materials, which concluded that the extensive presence of indoor materials with a high concentration of PCB was most widespread in office buildings and public institutions. As with the results of the survey of PCB in materials, it can be stated that blocks of flats with extensive PCB contamination, such as the examples that have been highlighted in recent years, are not a widespread phenomenon.

The results are undermined by the fact that some owners of buildings which were selected did not wish to participate in this part of the study. As can be seen in the table, ≥300 ng/m^3 was only found in one of the 14 bungalows surveyed, but five owners of buildings with relatively high concentrations of PCB in materials did not wish to participate in the study. When preparing the study, it was assumed that there was a very small chance of finding ≥300 ng/m^3 in the other buildings in which there were no materials with indoor PCB concentrations above 50 mg/kg. The validity of this assumption is discussed in more detail in the following sections and in connection with the estimates of the number of buildings in Denmark with PCB in the indoor air at various concentration levels.

Table 27 Highest measured value for buildings selected for PCB in indoor air study.

PCB_{total} in indoor air, ng/m^3	Highest measured value per building							
	All buildings		Detached and semi-detached houses		Blocks of flats		Office buildings and public institutions	
	Number	Frequency of total	Number	Frequency of total	Number	Frequency of total	Number	Frequency of total, indoor air
<30	32	48%	10	71%	15	75%	7	21%
≥30	35	52%	4	29%	5	25%	26	79%
≥100	23	34%	1	7%	3	15%	19	58%
≥300	**14**	**21%**	**1**	**7%**	**1**	**5%**	**12**	**36%**
≥2,000	1	1%	0	0%	0	0%	1	3%
≥3,000	1	1.5%	0	0%	0	0%	1	3%
300–2,000	13	19%	1	7%	1	5%	11	33%
2,000–3,000	0	0%	0	0%	0	0%	0	0%
Total number of buildings surveyed for PCB in indoor air	67	100%	14	100%	20	100%	33	100%
Total number of buildings surveyed for PCB in materials *1	352		154		105		93	
Selected but did not wish to participate in indoor air study *2	17		5		11 (one housing ass.)		1	

*1 Indicates the total number of buildings surveyed for PCB in materials, from which buildings with materials with the highest concentrations were selected for the study of PCB in indoor air.

*2 Indicates the number of buildings selected for the study of PCB in indoor air on the basis of high concentrations of PCB in materials, but whose owners did not wish to participate in the study.

If the office buildings and public institutions category is broken down further, it can be seen that a relatively high frequency of buildings with ≥300 ng/m^3 was found in both private office buildings and public buildings. However, the total number of private office buildings surveyed is quite low because, as mentioned previously, it was difficult to find building owners that were willing to participate in the study.

The table presents a comparison of the results of the municipal surveys of PCB in indoor air in municipal properties and those of the ENS survey. Assuming that none of the buildings in which measurements were taken contain concentrations ≥300 ng/m^3 in indoor air, the frequency of buildings containing concentrations ≥300 ng/m^3 in the ENS survey is 12% of all buildings, compared with 7% (5–9% confidence interval) observed in the municipal authorities' surveys. As the municipal authorities' surveys cover 507 randomly selected buildings, these results are more robust than those relating to municipal properties in the ENS survey. However, the results of the ENS survey confirm that those of the municipal authorities' surveys barely overestimate the presence of PCB in public buildings.

In addition, the study shows clearly that high concentrations of PCB in indoor air are more widespread in public buildings and office buildings than in blocks of flats and detached and semi-detached houses.

Table 28 Highest measured values for office buildings and public buildings compared with the results of measurements concerning PCB in indoor air obtained by the municipal authorities.

PCB_{total} in indoor air, ng/m^3	Highest measured value per building						
	Office buildings		Public buildings			Survey of municipal buildings in the municipalities	
	Number	Frequen-cy of total	Number	Frequen-cy of total	Frequency of total surveyed (OBS)	Number	Frequency of total
<30	1	8%	6	29%		372	73%
≥30	11	92%	15	71%		135	27%
≥100	7	58%	12	57%		74	15%
≥300	**5**	**42%**	**7**	**33%**	**12%**	**35**	**7%**
≥2,000	0	0%	1	5%	2%	7	1%
≥3,000	0	0%	1	5%	2%	2	0.4%
300–2,000	5	42%	6	29%		28	6%
2,000–3,000	0	0%	0	0%		5	1%
Total number of buildings surveyed for PCB in indoor air	12	100%	21	100%		507	100%
Total number of buildings surveyed for PCB in materials *1	36		57				
Selected but did not wish to participate in the indoor air study *2	1		0				

*1 Indicates the total number of buildings surveyed for PCB in materials, from which buildings with materials with the highest concentrations were selected for the study of PCB in indoor air.

*2 Indicates the number of buildings selected for the study of PCB in indoor air on the basis of high concentrations of PCB in materials, but whose owners did not wish to participate in the study.

4.3.2 Relationships between primary, secondary and tertiary sources of PCB

A large number of supplementary measurements were taken during the measurement programme described in section 4.2. The measurements taken all form the basis for the assessment of indoor air measurements.

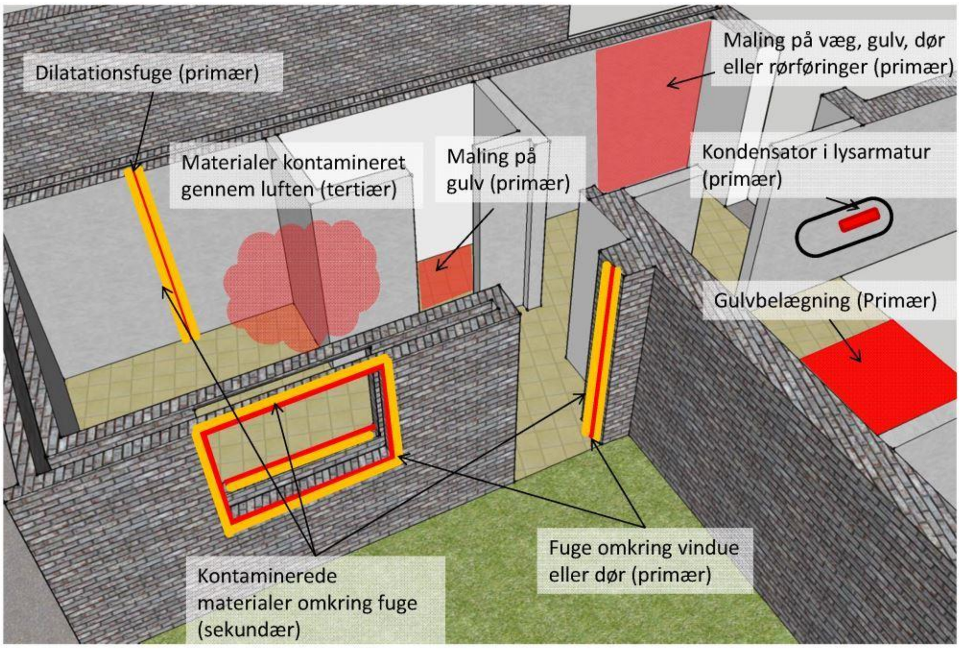


Figure 25 Outline diagram showing primary, secondary and tertiary sources in a building.

The PCB sources in a building shown have varying distributions, surfaces and extent. They will therefore have different impacts on the indoor air concentration observed in the room in a building in which they occur.

The typical relationship between demonstrated sources of PCB in a room in detached and semi-detached houses, blocks of flats and public buildings and institutions is presented in three cases, which are summarised below. See Annex 3 for a detailed description.

Case: Detached house

The detached house case shows a building where the primary source is floor paint in the basement of the house. No other primary sources were observed in the building which could have had a material impact on the indoor air.

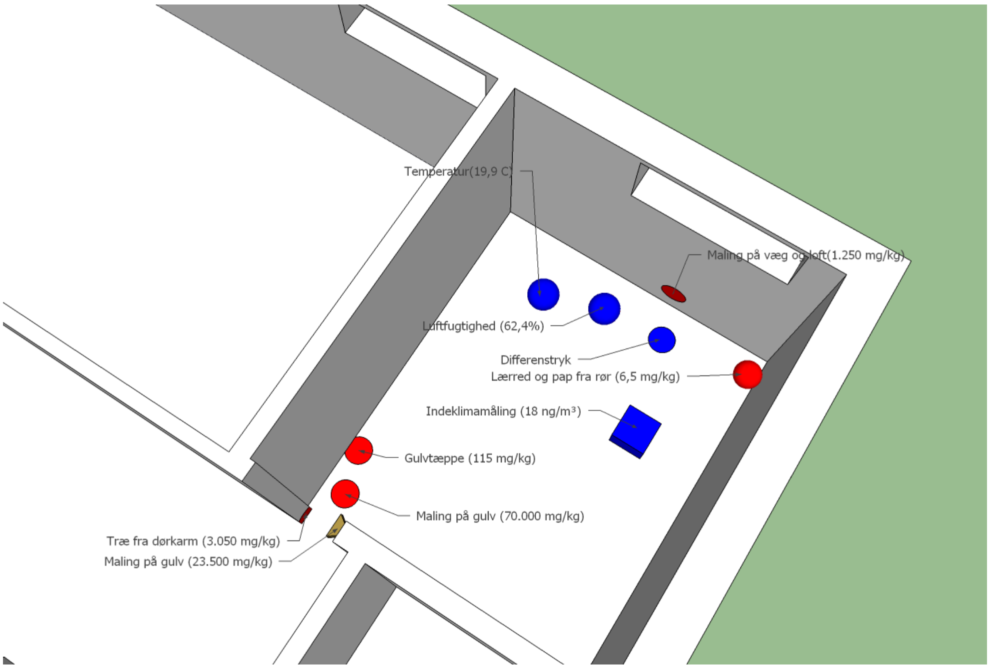


Figure 26 *Case: Detached house. Measuring points for building materials, indoor air, differential pressure, temperature and air humidity, and statement of results of measurements in room A. The primary source at this location is floor paint. Paint on the wall may be a secondary or primary source. Other building materials are considered to be secondary or tertiary PCB sources.*

A concentration of 18 ng/m^3 was demonstrated in indoor air in the basement, which is therefore below the lowest action level of 300 ng/m^3. A PCB concentration in indoor air of 7 ng/m^3 was demonstrated on the ground floor of the house. As in the case of room A presented in Figure 26, where tertiary sources with concentrations of up to 115 mg/kg were detected in a carpet, the presence of PCB from the demonstrated primary source would be expected in fixtures and fittings etc. on the ground floor of the house, partly because of air exchange between the building and the basement and partly because of migration of materials containing secondary or tertiary PCB contamination between the basement and ground floor of the building.

The concentration level detected in indoor air in this detached house was low. However, experience gained from the measurements taken during the survey indicates that there may be important primary sources in parts of the building that are not used frequently which may be of importance in respect of other parts of the building that are used frequently.

Case: Block of flats

The block of flats case shows a building where the primary source is an interior sealant joint around a window on the ground floor of the building. No other primary sources were demonstrated in the building which could have had a material impact on the indoor air.

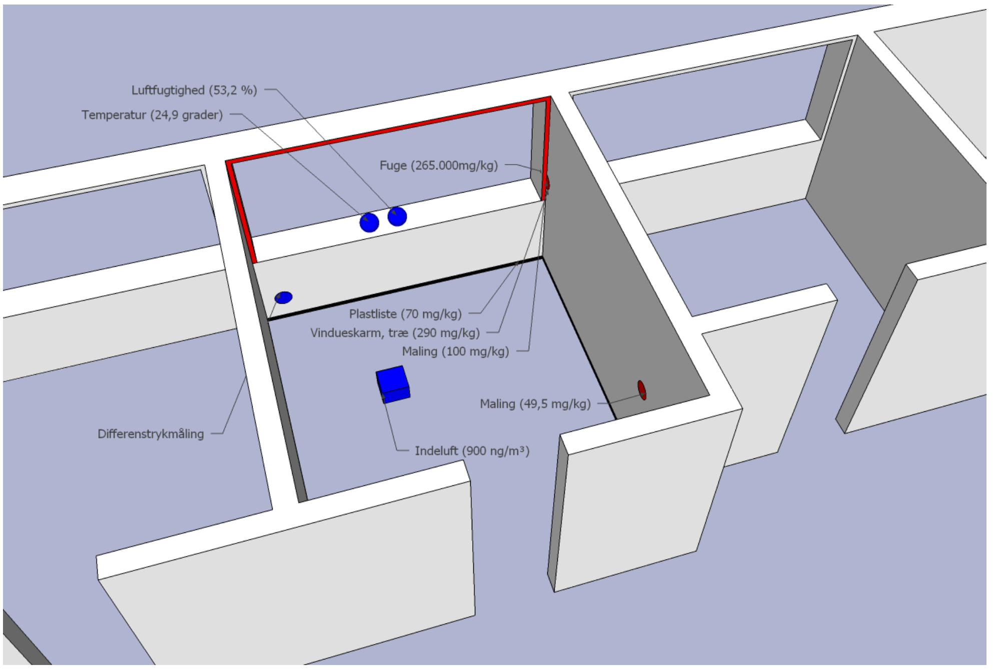


Figure 27 *Case: Block of flats. Measuring points for building materials, indoor air temperature and humidity, and statement of measurement results. The primary source at this location consists of interior sealant materials in the form of sealant joints around windows. The window frame is considered to be a secondary source. Paint and plastic strips are considered to be tertiary sources.*

A concentration in indoor air of 900 ng/m^3 on the ground floor was detected in a meeting room. The concentration thus exceeds the Danish Health and Medicines Authority's lower action level of 300 ng/m^3, but is below the Danish Working Environment Authority's requirement of 1,200 ng/m^3 for an eight-hour stay in the room. In another room on the ground floor, a PCB concentration in indoor air of 1,100 ng/m^3 was detected. Tertiary sources containing concentrations of up to 100 mg/kg can be demonstrated in paints in the room, and the presence of PCB in fixtures and fittings etc. would therefore be expected in other rooms which contain tertiary contamination from the demonstrated primary source.

Case: School

The school case shows a building where the primary source is an interior sealant joint between concrete elements (expansion joints) which are widespread on the ground floor of the building. No other primary sources were demonstrated in the building which could have had a material impact on the indoor air.

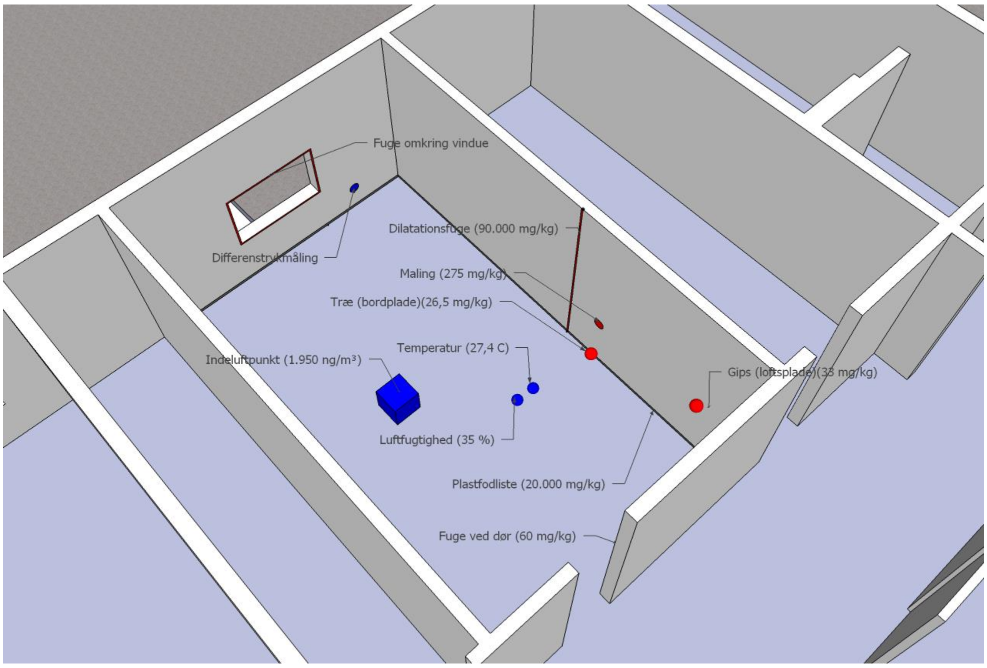


Figure 28 *Case: School. Measuring points for building materials, indoor air, temperature and humidity, and statement of measurement results. The primary source at this location is interior sealant materials in the form of expansion joints. Plastic skirting board is considered to be a secondary/tertiary source. Other building materials are considered to be secondary or tertiary PCB sources.*

A concentration of 1,950 ng/m^3 was detected in indoor air on the ground floor in a teaching room. The concentration thus exceeds the Danish Health and Medicines Authority's lower action level of 300 ng/m^3 and the Danish Working Environment Authority's requirement of 1,200 ng/m^3 for an eight-hour stay in the room by staff at the school. In another room on the ground floor, a PCB concentration in indoor air of 1,800 ng/m^3 was detected. Tertiary sources containing concentrations of up to 275 mg/kg can be demonstrated in paints, and the presence of PCB in fixtures and fittings etc. would therefore be expected in other rooms containing tertiary contamination from the demonstrated primary source. This is because of air exchange with the rest of the building, as well as the migration of materials containing tertiary contamination between the ground floor and the rest of the building which contains secondary or tertiary PCB contamination. To reduce the concentration levels in indoor air, it is necessary to maintain a constant temperature of between 20–22°C, implement preventive measures in the form of cleaning and increased ventilation and also improve the ventilation in the building.

An action plan should therefore be prepared to reduce indoor air concentrations with the aim of achieving a stable impact on the indoor air which does not vary as the temperature rises during the summer or in the event of changes in management, use or general maintenance of the building. A number of documents must be prepared with the aim of ensuring that employees and employers receive sufficient information concerning works in and around a building which contains PCB. For more information, visit PCB-guiden.dk.

4.3.3 Relationship between PCB concentration, building use and temperature

The indoor air measurements were repeated in 11 buildings with the aim of assessing the variation in indoor air over time. In these buildings, indoor air measurements were taken using the same method as that used in the survey. However, the repeat measurements were taken while the building was in use; hence air exchange in the building is considered to be higher as a result of the building being in use.

As regards the 11 buildings, it was possible to use the measurements to assess the variation in indoor air concentration in connection with temperature variations and differences between measurements taken while the building was either in use or not in use.

Table 29 PCB in indoor air measured in the same building and room at two different times, when the other rooms in the building were either in use or not in use.

Building type	First indoor air measurement Other rooms in the building	First indoor air measure-ment	Second indoor air measure-ment Other rooms in the building	Second indoor air measure-ment	Difference between first and second indoor air measure-ments
Office buildings and public institutions	Applicable	1,950	Not applicable	3,100	1.6
Office buildings and public institutions	Applicable	1,800	Not applicable	3,750	2.1
Block of flats	Not applicable	900	Applicable	240	3.8
Block of flats	Not applicable	1,100	Applicable	490	2.2
Office buildings and public institutions	Not applicable	410	Applicable	600	1.5
Office buildings and public institutions	Applicable	290	Not applicable	475	1.6
Office buildings and public institutions	Not applicable	750	Applicable	900	1.2
Office buildings and public institutions	Applicable	550	Applicable	500	1.1
Office buildings and public institutions	Applicable	335	Applicable	245	1.4

Dependency of indoor air concentrations on use

Table 29 shows that the PCB concentration in the air while blocks of flats, offices and public buildings are in use varies by a factor of 1.1–3.8, depending on whether the measurements were taken with or without users present in other rooms.

The indoor air measurements taken while the buildings were in use generally show that the concentrations are about 1.8 times lower than concentrations measured while the building was not in use. This applies even though very different building types are involved and even though the measurements were taken at different temperatures and under very different air exchange conditions in the buildings concerned.

Dependency of indoor air concentrations on temperature

If the measured indoor concentrations are corrected for temperature using a model from SBi Guidelines no. 242, it can be calculated that a difference of between two and five times would be expected between measurements taken with users present and without users present.

The figures below show the temperature correction for a block of flats relative to the corresponding temperature-corrected data for Farum Midtpunkt. The curves from Farum are based on a large number of measuring points, while the curves from this survey are based on two measuring points.

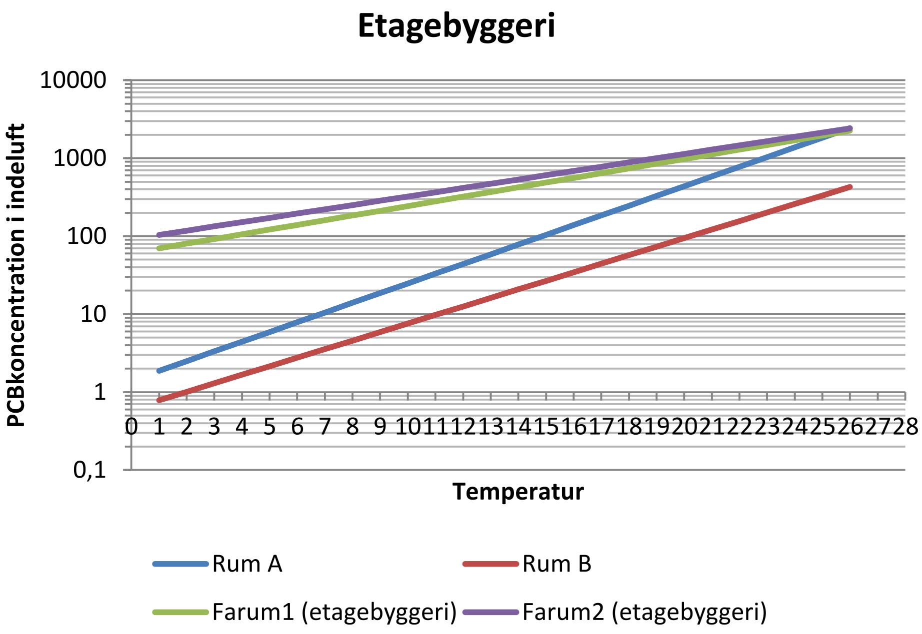


Figure 29 *Indoor air concentration as a function of temperature for blocks of flats with a basement. The two curves for rooms A and B are based on two measuring points, whereas the curves for Farum 1 and 2 are based on extensive data from the studies carried out in Farum Midtpunkt (Lundsgaard et al., 2010; SBMI, 2011).*

The examples from the three cases show that the indoor air concentration will change significantly in the event of the temperature changing or being maintained at 21°C, for example.

To maintain a good indoor climate, temperatures of 20–22°C are recommended.

If the building contains elevated indoor air concentrations of PCB, it may therefore be an advantage to maintain a low temperature of 20°C, for example.

Conditioning of the room was carried out before the indoor air measurements were taken. For this study, the rooms were ventilated for 15 minutes before sampling was commenced. If the room was equipped with a ventilation system, the room was conditioned for at least two hours prior to the commencement of sampling.

On the basis of the temperature measurements that were taken, it is believed that a general stabilisation of the room can be observed after less than 0.5 hours, provided that there is no solar heat gain in the room or other external influences. Figure 30 shows the temperature data logs for the 15 highest indoor air concentrations.

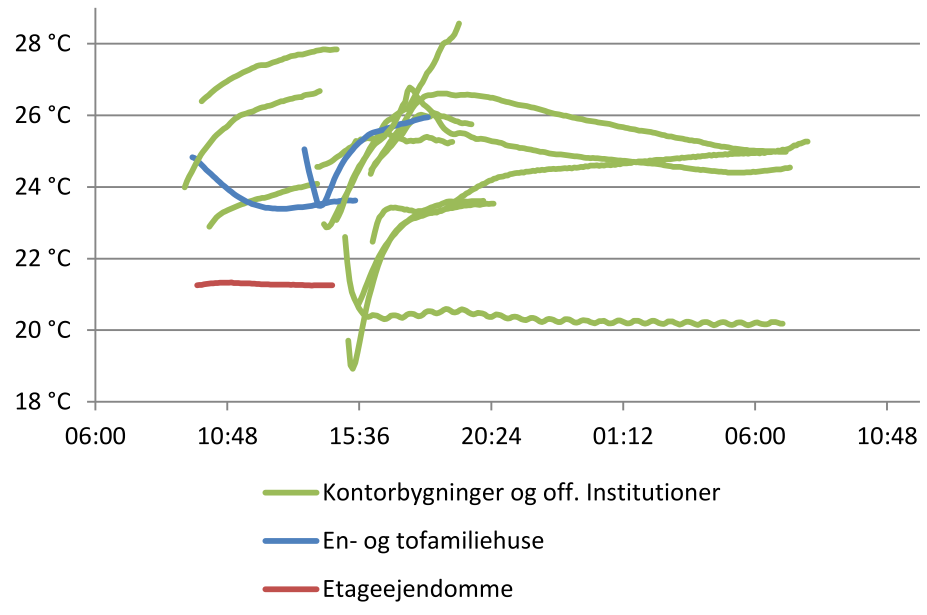


Figure 30 *Data log of temperature in room A for the 15 highest indoor concentrations.*

4.3.4 Ventilation in surveyed buildings

The ventilation was measured in one room in 15 detached houses, 20 blocks of flats and 32 offices and public buildings in which indoor air measurements of PCB were taken. The ventilation was measured as:

- Air exchange through measurement of the decay of tracer gas
- Mechanically supplied and exhausted air flow in rooms equipped with mechanical ventilation.

A detailed description of the measurement method and measurement criteria is presented in section 4.2 and Annex 2.

Of the 15 measurements taken in detached houses, 14 could be used. In the case of the measurement which could not be used, the number of tracer gas concentrations measured was too low to enable an acceptable level of accuracy to be achieved. The measurements that were taken all fell in the interval 0.029–1.01 h^{-1}, equivalent to a mean of 0.32 h^{-1}. Only in one building was a value of over 0.5 h^{-1} measured.

In 20 blocks of flats, all the measurements that were taken are considered to be usable. The measurements that were taken all fell in the interval 0.033–1.13 h^{-1}, equivalent to a mean of 0.32 h^{-1}. Three of the 20 measurements taken in blocks of flats fell in the interval 0.58–1.13 h^{-1}; i.e. over 0.5 h^{-1}, which approximates to the current requirement of 0.3 l/s per m^2 floor space.

In the 32 office and public institutional buildings which were surveyed, air exchanges in the interval 0.016–3.68 h^{-1} were measured. Two of the measurements taken were over 2.5 h^{-1}, which is the estimated requirement for schools. A total of 22 buildings had air exchanges of between 0.016 and 0.5 h^{-1}, while eight buildings had air exchanges of between 0.5 and 2.5 h^{-1}.

Very low air exchanges were generally measured in all surveyed buildings. The surveys were carried out while the rooms were not in use, i.e. windows and doors were not opened, forced extraction from extractor hoods and bathrooms etc. did not take place. In the rooms in which the outdoor air vents were located in the window frame as a sliding vent, this vent was closed before the measurements were taken. As a result of the reduction in scope to inject outdoor air, the air exchange will be greater than in the situation where the rooms are being used by people.

In the 67 buildings surveyed, a total of 10 mechanical ventilation systems were identified. These systems were split between eight public office or institutional buildings and two privately owned office buildings. It was not possible to take measurements in the case of two of the systems because of a lack of access or the fact that the system was not connected.

There was recirculation in the case of four out of eight ventilation systems, where PCB in the exhaust air from the test room and any other rooms connected to the system is returned to the test room after being diluted with outdoor air.

The results of measurements taken in the three building categories are shown in the table below.

Table 30 Mean, minimum and maximum values etc. for the measured air exchanges.

Building type	Number (quantity)	Mean (h^{-1})	Median (h^{-1})	Min. (h^{-1})	Max. (h^{-1})
Detached and semi-detached houses	15	0.32	0.10	0.029	1.79
Blocks of flats	20	0.23	0.13	0.032	1.13
Offices and public institutions	32	0.60	0.32	0.016	3.68

For all building categories, it can be seen that many rooms experienced remarkably little air exchange during the measurements, as the median values for a detached/semi-detached house, block of flats and offices and public institutions were 0.10 h^{-1}, 0.23 h^{-1} and 0.32 h^{-1} respectively.

The mean is higher than the median in relative terms in detached and semi-detached houses, as some air exchanges were relatively high, e.g. a single test room in the form of a garage in detached and semi-detached houses had an air exchange of 1.79 h^{-1}. The measurement of an air exchange of 0.47 h^{-1} in another room in the same building category is associated with substantial uncertainty, so these two air exchanges were omitted. The mean for the detached and semi-detached houses is therefore considered to be 0.19 h^{-1}.

The cumulative relative distribution of air exchanges in the test rooms is shown in Figure 31.

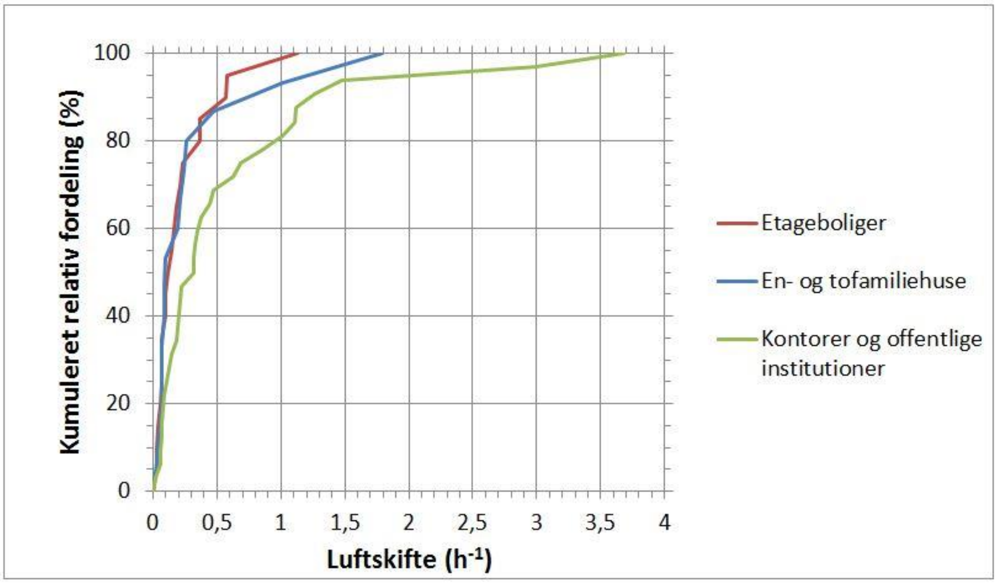


Figure 31 *Accumulated relative distribution of air exchanges in the three building categories.*

The figure shows that approx. 40% of all test rooms in the homes were measured with an air exchange of less than 0.10 h^{-1}, and approx. 60% of the test rooms had an air exchange of less than 0.20 h^{-1}. In relation to the requirement laid down in the Danish building regulations for a minimum basic outdoor air exchange of 0.5 h^{-1}, the PCB measurements were carried out under relatively low air exchanges. If the entire air exchange is considered to consist of outdoor air, only around 10% of the test rooms fulfilled the requirement imposed in the building regulations at the time the rooms were measured.

A proportion of the air inflow measured will also originate from rooms through walls or through the floor from below the structural floor and cannot be considered to constitute outdoor air, so the outdoor air exchange is less than the air exchange which was previously observed in studies conducted by Bergsøe, 1991.

However, it is possible that some of the low air exchanges observed reveal the true picture of air exchange in the rooms concerned while the rooms are in normal use, e.g. if the room’s door and windows are normally kept closed.

If the air exchanges for the detached and semi-detached houses are considered in relation to the measured air exchanges and the *normal* use of bedrooms (see Bergsøe, 1994-1), the measured air exchanges can be estimated at between four and 17 times greater than those measured as part of the studies. In reality, the figures will be even higher, as the measured air exchanges also include air which has entered from other rooms.

If the same considerations as described above for blocks of flats are assumed as regards the measured air exchanges relative to the mean outdoor air exchanges for bedrooms (see Bergsøe, 1994-2), the mean measured air exchange for an outdoor air exchange can be estimated at approx. seven times greater. As above, the air exchange will in reality also be even greater during normal use in this case.

The inflow of outdoor air required to ensure an acceptable air quality in offices and public institutions in accordance with DS 447:2013 and Class II, with a room height of 2.5 m, corresponds to an air exchange of 2.0 h^{-1}. If all “offices and public institutions" are considered to be offices and the measured air exchange is assumed to be an outdoor air exchange, 93% of the measured air exchanges were below 2.0 h^{-1}, and in reality a greater proportion will be lower. See the enclosed Annex 3 and the three cases.

4.3.5 Congener composition of PCB_{27} in indoor air

To determine the presence of more PCB congeners than the seven PCB congeners included in standard analyses, measurements were taken during the indoor air studies which covered the same 27 congeners as those included in the Danish Health and Medicines Authority's study in Farum (Mayer et al., 2012).

With the exception of PCB 118, the dioxin-like PCBs occur in relatively small concentrations compared to the congeners in PCB_7, and they will often be below the detection limit for standard analyses, as a lower detection limit is necessary in order to include these congeners.

Tests were performed for all 27 congeners in all indoor air samples and in selected material samples. However, the results indicated that, with the exception of PCB 118, the dioxin-like PCBs were below the detection limit in virtually all the indoor air samples. A selection of the samples from the indoor air measurements were therefore subsequently concentrated, so that a detection limit of less than 0.1 ng/m^3 per congener could be achieved. As relatively high concentrations are required in order to measure the dioxin-like congeners, even with this detection limit, it was decided to only perform new analyses of the 20 samples with the highest concentration (in addition to these 20 samples, there were a number of samples containing high concentrations where insufficient extract was obtained from the XAD-2 tube to achieve a better detection limit, as well as a single sample where interference problems were experienced).

The increase in concentration was carried out by carefully evaporating 1,000 µl of extract at 40°C to desiccation. The substances were then re-dissolved in 100 µl of extract. By comparing congener profiles for PCB_7 between the original and new results, it was established that no significant shift in the profile had occurred. Determined as PCB_7, the new analyses varied by ±40% relative to the original analyses, but they were not systematically higher or lower. It was therefore concluded that the congener profiles for the 27 congeners had not been significantly affected by the increase in concentration.

On average amongst the 20 measurements, the dioxin-like PCBs amounted to 3% of PCB_{27} and approx. 1% of PCB_{total}. Measurements below the detection limit were set to half the detection limit. This had no significant impact on the contribution from the dioxin-like PCBs, for which measurements below the detection limit were set to 0. In the Danish Health and Medicines Authority's study of Farum, where the source consisted of interior sealant joints, the dioxin-like PCBs averaged 1.1% of PCB_{27} (Mayer et al., 2012).

Of the dioxin-like PCBs, PCB 118 (which is included in PCB_7) constituted on average 58%, varying from 26% to 72% (average of 75% and up to 100% if values below the detection limit were set to 0). Other dioxin-like PCB congeners present above the detection limit in many of the samples were PCB 77, PCB 81, PCB 105, PCB 114 and PCB 123. In the Farum study, PCB 118 comprised 56% of the dioxin-like PCBs on average. In foreign studies, it has previously been demonstrated that PCB 118 can be used as an indicator for the total content of dioxin-like PCBs (Kieper and Hemminghaus, 2005). A good correspondence between the total quantity of dioxin-like PCBs and PCB 118 was also observed in this study. It should be noted that no similar relationship can be observed between the dioxin-like PCBs and, for example, PCB 101 or PCB 138. In the figure which shows the concentration of PCB 118 against the sum of the other dioxin-like PCBs, measurements below the detection limit are considered to be half the detection limit, which impacts on the relationship at the lowest concentrations to some extent.

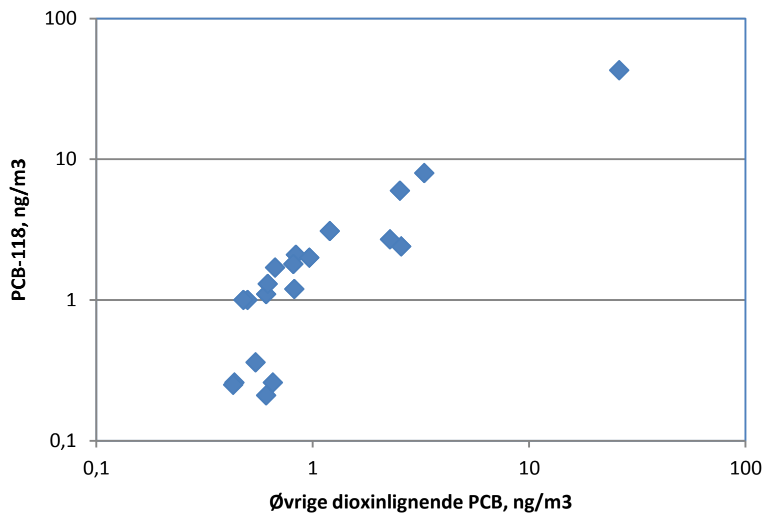


Figure 32 *Relationship between total concentration of PCB 118 and the other dioxin-like PCBs and in indoor air. Measurements below the detection limit were set to half the detection limit.*

In order to calculate total dioxin toxicity (expressed as PCB-TEQ), the concentrations of the individual congeners must be multiplied by equivalence factors for dioxin toxicity, which was not done here. The contribution from PCB 118 will probably be slightly less if it is specified in terms of dioxin equivalents. In the event that the results are subsequently converted to dioxin equivalents, it is worth noting that the most toxic congener (PCB 126) is 10,000 times more potent than the least toxic dioxin-like PCBs. The contribution to PCB-TEQ from a PCB 118 concentration of 1 ng/m^3 corresponds to the contribution from a PCB 126 concentration of 0.002 ng/m^3. This is well below the detection limit used here, and other, more refined analysis methods will be necessary if PCB 126 is to be measured. A German study found that PCB 118 constituted around 40% of the total PCB-TEQ in all samples irrespective of the PCB source (Kieper and Hemminghaus, 2005). In indoor air in rooms contaminated with sealants and paint containing PCB, PCB 126 was the second most important congener, while this role was played by PCB 156 when the source of PCB in indoor air was ceiling panels. As noted previously, the very important contribution to PCB-TEQ from PCB 126 could not be included on the basis of the results of the ENS survey and the Farum study.

Three examples of congener profiles from the ENS survey and an average profile from the Farum study are shown in Figure 33.

One of the profiles differs markedly in that the dioxin-like PCBs comprised 20% of PCB_{27} (room 5A). The material with the highest concentration was paint, but the congener profile of the paint did not differ from other materials (see room 5A on Figure 35). It is known from the inspection and subsequent assessment of sources that PCB in air in the building may have been caused by the effect of indoor air originating from leaking capacitors. The capacitors have now been removed. The room was used for storing light fittings and contained one light fitting where the capacitor appeared slightly corroded. Other possible sources are known to be present at the location, but sealant joints that have been replaced do not contain significant quantities of PCB. Type A40 capacitors contain particularly large amounts of PCB 118, but the same also applies to some types of sealant. It cannot be determined unequivocally whether or not the source is a capacitor.

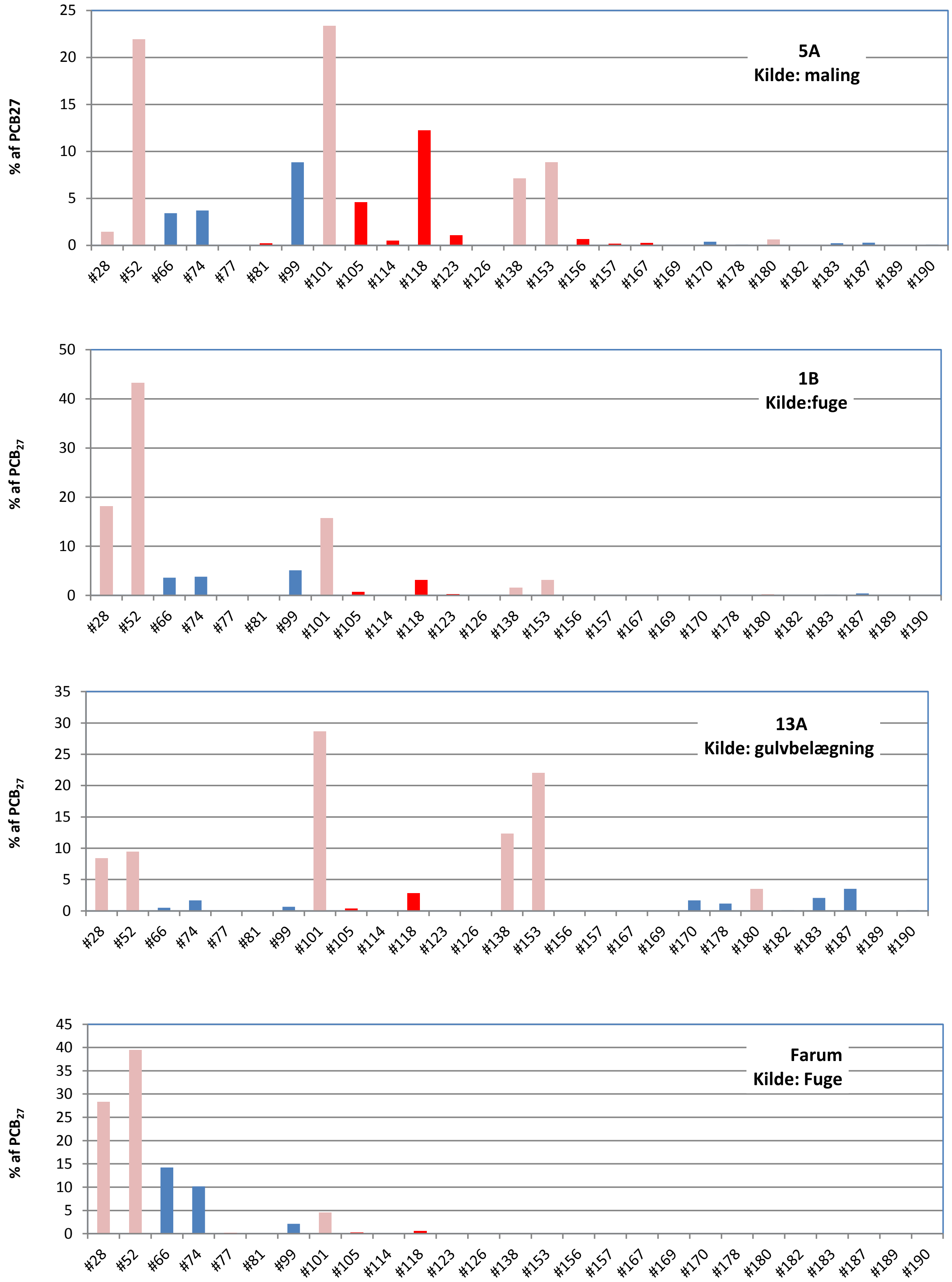


Figure 33 Three examples of PCB_{27} congener profiles from the ENS survey and an average profile from the Farum study (Mayer et al., 2012). The indicator congeners in PCB_7 are indicated in pink, the dioxin-like PCBs in dark red and the other congeners in blue.

The congener profile for indoor air in the room where flooring was assumed to be the primary source also differs from most others, but a similar profile has been observed in another building where flooring was assumed to be the primary source (room 14 in Figure 35). Similar profiles shifted towards the most highly chlorinated PCBs and with a characteristic pattern between PCB 101 and PCB 153 have been observed in Swiss surveys, where the source was ceiling panels treated with a fire retardant consisting of the highly chlorinated Clophen 60 (Kohler et al., 2002). As shown previously, floor coverings with a high PCB concentration have a profile similar to Clophen 60.

As the figure shows, the profile which most closely resembles the average profile from the Farum study came from a measurement of indoor air in a room in which the primary source was sealant, as in the Farum study.

There is considerable variation as regards which of the non-dioxin-like PCBs contribute the most. In the room in which the source was sealant, PCB 66, PCB 79 and PCB 94 are the main contributors, while in the room in which the source is assumed to be flooring, the highly chlorinated PCB 170, PCB 178, PCB 183 and PCB 187 provided a substantial contribution.

This study thus gives a very fragmented picture, which corresponds well with what has been observed in foreign studies. Relationships between the congener profiles in the materials and indoor air are discussed further in the next section with a focus on PCB_7, but with a brief discussion of other congeners.

4.3.6 Relationships between congener profiles in materials and indoor air

For 47 buildings from the ENS survey, an analysis was carried out of the relationships between the PCB congener profile in indoor air and that in materials from the same room which are assumed to be the primary source of PCB in indoor air.

A fragmented picture is also apparent here. Figure 25 shows 20 associated measurements where the PCB concentration in the room is relatively high. These are the same indoor air measurements on which analyses of PCB_{27} were conducted with an improved detection limit.

Materials with a profile shifted towards the lower chlorinated congeners generally also show a displacement in indoor air towards the same congeners, as can be seen for example in the six measurements where the source is assumed to be sealant (on the left of the figure). As noted in the previous section, the highly chlorinated congeners contribute considerably more to PCB in indoor air when the presumed source is flooring (right-hand side).

Four measurements (from three buildings) stand out and are of particular interest: rooms 8, 10, 12A and 12B. In the combined data covering 67 buildings, such measurements were observed in four buildings. In these buildings, an overlap was observed between markedly high contributions from PCB 28 in indoor air (>70% of PCB_7) and markedly high concentrations of PCB 28 in the materials that are presumed to be the source (>59% of PCB_7). In the rooms which were measured, relatively high concentrations are also observed in indoor air relative to the levels of PCB in the materials, which are below 150 mg/kg. The data contain no examples of markedly high contributions of PCB 28 in indoor air where a high contribution from the materials was not observed.

The pattern of a high contribution of PCB 28 is compatible with the source being low chlorinated PCB from capacitors. This is the only known primary source that will give this pattern. If this is the explanation, the materials contain tertiary PCB contamination from the capacitors via indoor air. This explains why high concentrations can be found in indoor air even if concentrations in the materials are low.

Studies have been carried out of materials containing tertiary PCB contamination in 12 buildings, which are discussed in section 3.1.9, but none of these contained examples of sources with such unusually high PCB 28 contributions as those observed in the above examples. This also suggests a source other than sealant or paint.

To examine the effect of capacitors further, Figure 34 shows associated profiles for capacitors and indoor air in a school classroom which is known to have been contaminated by the capacitor (unpublished data provided by a municipal authority). As is apparent, the capacitor is of the low chlorinated type, which produces a characteristic pattern with an unusually high proportion of PCB 28. This is reflected in the concentration in the materials, and a pattern is apparent which is virtually identical to that which can be observed in the four examples discussed above. The congener pattern in virtually all materials follows that of the indoor air (not all shown here), but a single sample of wooden flooring containing 105 mg/kg did differ markedly, which may indicate that this material also contains PCB from varnish, for example.

The concentration in the school classroom varied between 1,000 and 3,400 ng/m^3 before it became clear that the capacitors were the source and were removed. There were eight light fittings in the room. Upon their removal, PCB oil leaked out from several capacitors, but all the fittings worked until the time of their removal. Based on currently available knowledge, the congener profile for indoor air would immediately have directed attention towards the capacitors in the room.

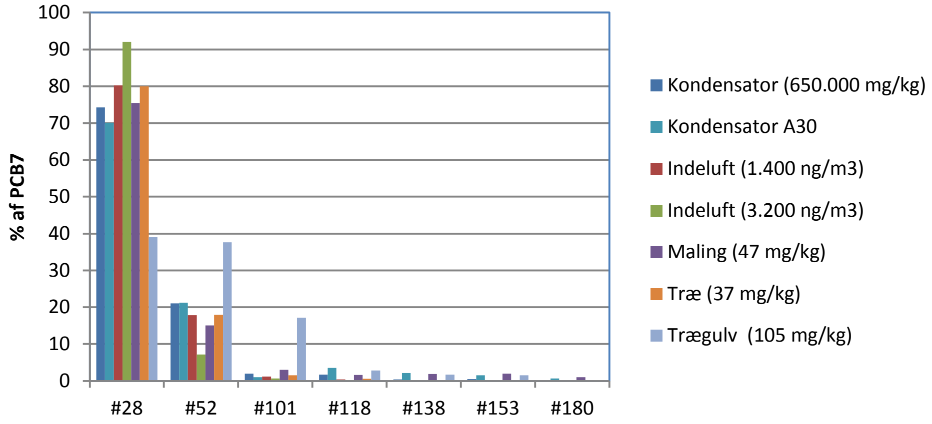


Figure 34 *Congener profiles from capacitors and indoor air in a school classroom known to be contaminated by capacitors. The profile for the capacitor concerned was compared with the average for the group, which is designated capacitor A30 here. Concentrations in the room prior to the removal of the capacitors varied from 1,400 to 3,400 ng/m^3. The concentration in the indoor air was more than halved immediately after removal of the capacitors. Data provided by a municipal authority.*

The results underline the difficulty in predicting the indoor air concentration on the basis of concentrations in materials. While a clearer pattern is apparent in the case of sealant, a more complex picture can be seen as regards paint and flooring materials, which can act as important primary and tertiary sources.

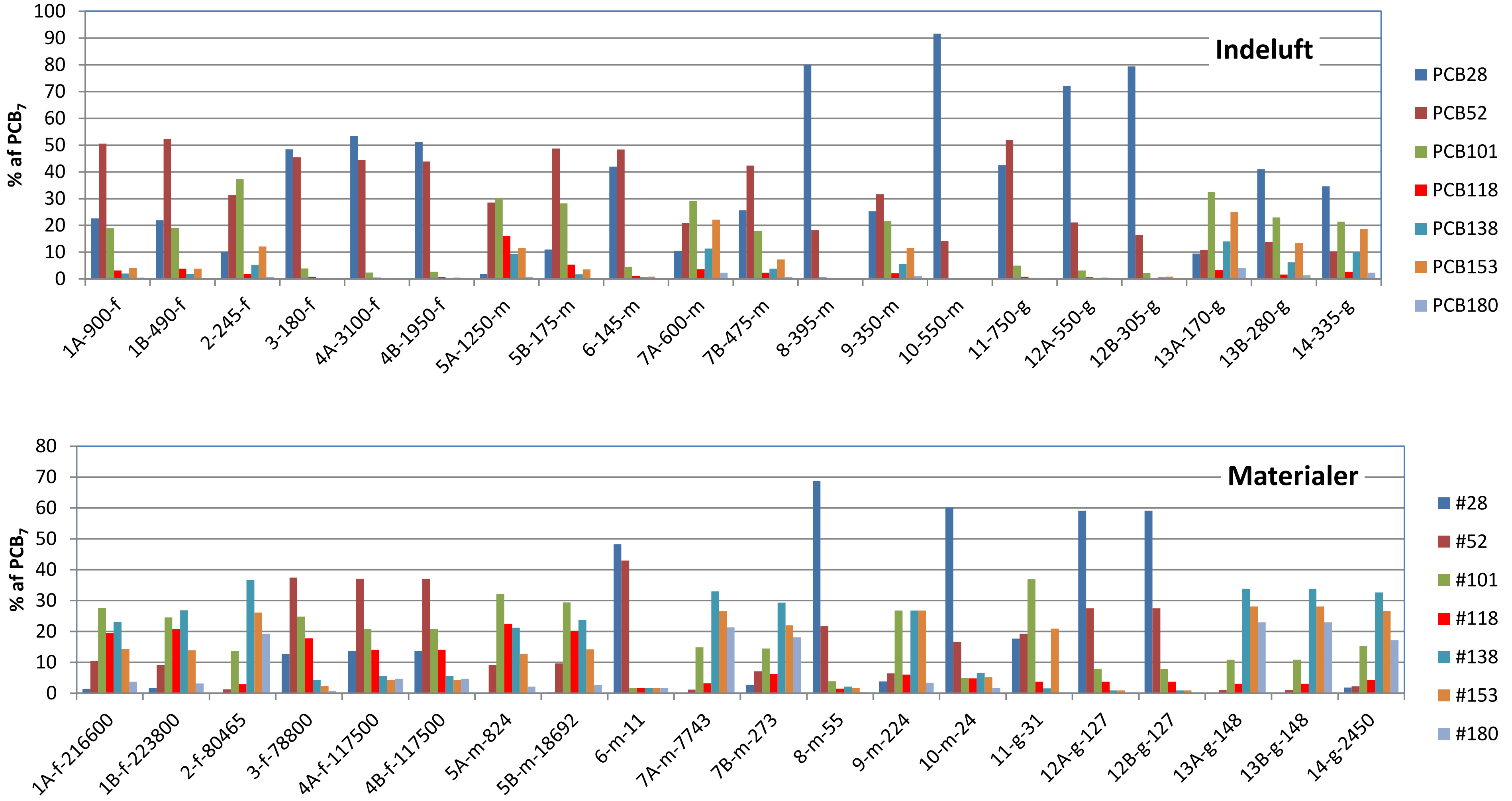


Figure 35 *Associated congener profiles for indoor air and the material in the same room containing the highest PCB concentration. In the case of indoor air, a room ID (rooms specified as A and B are in the same building), the PCB concentration (in ng/m^3) and the associated material: sealant (f), paint (m) and floor covering (g) are specified for each profile. For materials, a room ID, the material type and PCB concentration (in mg/kg) are specified.*

4.3.7 Other factors

A more detailed review of the results of indoor air measurements and the prevailing conditions in the surveyed buildings indicates that there has generally been a relatively low air exchange and high temperatures in the rooms in which high levels of PCB were found in indoor air.

As discussed in section 4.3.3, there is a general link between the concentration in the presumed primary source and the concentration in indoor air. However, as discussed elsewhere in the report, there are many cases where high concentrations have not been observed in the presumed primary source where a high concentration of PCB has still been found in the indoor air.

Table 31 shows the highest detected indoor air concentrations together with a number of other factors which could have an impact on the PCB concentrations measured in indoor air. Only results where air exchange was also measured are shown.

The rooms can roughly be divided into:

› Rooms containing >100,000 mg/kg in interior sealant joints (1, 3, 4, 7 and 10). High concentrations are often observed in indoor air in connection with high concentrations in sealant joints.

› Rooms with relatively high PCB concentrations (>5,000 mg/kg) in paint (8, 14). None of the rooms contained fluorescent lamp fittings.

› One room with a relatively high PCB concentration in flooring materials (>2,000 mg/kg) in paint (9).

› Rooms with relatively low PCB concentrations in paint or flooring:

  › with light fittings present (2, 6, 11, 12, 13, 15 and 16)

  › without any light fittings (5 and 17).

The two examples with low concentrations in materials and no light fittings show how difficult it is to predict the concentration in indoor air based on our knowledge of potential sources. In the detached and semi-detached houses in which high PCB concentrations were found in one room, the presumed source was paint containing PCB, but sealed glazing units dating from the PCB period are known to be present. In many other cases, this will not result in such high concentrations, but at this location, an elevated PCB concentration was observed in the indoor air.

Many different parameters appear to impact on the concentration of PCB in indoor air, but only some of these were measured in this study.

The presence of capacitors containing PCB in light fittings from fluorescent tubes appears to be one of the parameters which may complicate the picture considerably. As discussed in section 4.3.6, there are examples where light fittings can give rise to very high PCB concentrations in indoor air, and it can be demonstrated in many cases that the primary source is capacitors. However, it must be anticipated that capacitors may also contribute in many other cases where it is not possible to demonstrate clearly that the capacitors are the source.

In the 17 rooms shown in Table 31, there were light fittings in 13 of them and in all these 13 rooms the capacitors could potentially contribute to PCB in indoor air and could be a contributory factor in masking the true picture. As discussed in section 4.3.6, it will particularly be in rooms in which PCB 28 constitutes a high proportion of the PCB in indoor air that capacitors must be expected to be a possible contributory source.

Contributions from sealed glazing units containing PCB have not been investigated, but like the contribution from capacitors these contributions will be a contributory factor in masking the true picture.

At a general level, it is noted that, for the time of year, the temperatures were relatively high while the measurements were being taken.

As also discussed in section 4.3.4, it is also apparent that relatively low air exchanges were measured in the buildings in which elevated indoor air concentrations were observed. However, two buildings differ markedly, with air exchanges of 1.12 h^{-1} and 1.26 h^{-1} respectively. In these two buildings, concentrations of 899 and 906 ng/m^3 were observed, in both cases at relatively high temperatures of 25.2 and 24.9ºC respectively. Both cases involve a primary source in the form of sealant materials which have been used internally within the building.

As discussed in section 4.3.3, correcting for air exchange and temperature does not result in a significantly better relationship between the PCB concentration in the presumed primary sources and that in the indoor air. Temperature and air exchange can only explain a small part of the differences in indoor concentrations that have been observed. However, this does not mean that temperature and air exchange do not affect the concentration in an individual room – this has clearly been demonstrated in many studies.

On the basis of the measured concentrations and air exchange rates, it is believed that the indoor air concentrations can be reduced further by altering the temperature to the recommended 20–22ºC and, in many cases, by increasing the air exchange to 0.5 h^{-1}. In many cases, this can be done cost-effectively and could reduce indoor air concentrations by a factor of between two and five (see Haven and Langeland, 2011).

Table 31 Concentrations of PCB in indoor air and materials, and numerous parameters which may have an effect on PCB concentrations in indoor air.

	Building type	Function of room	Indoor air				Building material					Sealed glazing units	Number of light fittings
			PCB ng/m^3	PCB 28 /PCB_7	Air exchange, per hour	Tempera-ture, ºC	Material	Is it a general material type in the building	Function of material	PCB mg/kg	PCB 28 /PCB_7		
1	Office buildings and public institutions	Classroom	1,873	32%	0.21	22.9	Sealant	Yes, the sealant is widespread throughout the building	Expansion joints between concrete elements	205,000	2.0%	No	12
2	Office buildings and public institutions	Store (Basement), corresponds to the rest of the building, which is used frequently	1,237	1%	0.44	24.4	Paint	Paint and this type of fitting only present in this basement room and the neighbouring room. There are different types of fittings in the rest of the building	Paint on floor.	830	0.1%	No	8
3	Office buildings and public institutions	Classroom (IT)	906	22%	1.12	25.2	Sealant	Yes, the sealant is widespread throughout the building	Expansion joints between concrete elements	140,000	0.0%	No	9
4	Office buildings and public institutions	Office	899	20%	1.26	24.9	Sealant	Yes, the sealant is present around all windows	Sealant around windows	265,000	1.7%	Yes	1
5	Detached and semi-detached houses	Room – frequently used	602	51%	0.07	23.7	Paint	Assumed not to be widespread. Probably only paint in the basement	Paint on downpipe in basement.	225	3.8%	Yes	None
6	Blocks of flats	Basement room. Laundry room	550	80%	0.57	21.3	Paint	The paints can be found across the entire basement	Wall paints and paint on door frames	55	70%	Yes	2
7	Office buildings and public institutions	Classroom (subject teaching room)	499	27%	0.63	25.5	Sealant	Yes. The sealant is widespread along the entire length of the building	Expansion joints between concrete elements	310,000	2.1%	Yes	12

Table 31 Concentrations of PCB in indoor air and materials, and numerous parameters which may have an effect on PCB concentrations in indoor air.

	Building type	Function of room	Indoor air				Building material					Sealed glazing units	Number of light fittings
			PCB ng/m^3	PCB 28 /PCB$_7$	Air exchange, per hour	Tempera-ture, ºC	Material	Is it a general material type in the building	Function of material	PCB mg/kg	PCB 28 /PCB$_7$		
8	Office buildings and public institutions	Store (Basement), corresponds to teaching rooms in the rest of the basement	409	10%	0.22	20.4	Paint	Yes. The paint is present throughout the room and the rest of the basement	Floor paint	8,000	0.04%	Yes	None
9	Office buildings and public institutions	Store (Basement)	335	40%	0.06	24.7	Flooring	The entire room has this type of flooring. Extent elsewhere in the building unknown	Flooring	2,450	1.8%	Yes	7
10	Office buildings and public institutions	Classroom	325	37%	0.07	25.4	Sealant	Yes, the sealants are presumably present throughout the building	Expansion joints between concrete elements	190,000	2.9%	Yes	8
11	Office buildings and public institutions	Store (Basement), corresponds to teaching rooms elsewhere in the basement	170	6%	0.07	19.9	Flooring	Yes. The flooring is present in many places in the basement	Flooring	150	0.2%	Yes	2
12	Office buildings and public institutions	Store associated with teaching rooms	155	39%	0.32	22.6	Paint	Yes. The paint is present throughout the building	Wall paint	11	50%	Yes	3
13	Office buildings and public institutions	Store, equipment room, meeting rooms and office (basement)	132	38%	0.14	29.1	Paint	Yes, paint in a number of locations in the basement. A number of areas have been painted over.	Wall and ceiling paint	20	13%	Yes	2
14	Blocks of flats	Room – in frequent use	112	58%	0.37	25	Paint	The paint is present on radiators around the building	Paint on radiators	12,000	0.03%	Yes	None

Table 31 Concentrations of PCB in indoor air and materials, and numerous parameters which may have an effect on PCB concentrations in indoor air.

	Building type	Function of room	Indoor air				Building material					Sealed glazing units	Number of light fittings
			PCB ng/m^3	PCB 28 /PCB_7	Air exchange, per hour	Tempera-ture, ºC	Material	Is it a general material type in the building	Function of material	PCB mg/kg	PCB 28 /PCB_7		
15	Office buildings and public institutions	Classroom, home economics storeroom	78	77%	0.68	24.2	Paint	May also be present in the rest of the basement. The paint is on a downpipe	Paint	55	72%	No	Yes, the room is lit by light fittings
16	Detached and semi-detached houses	Store/workshop (basement)	72	37%	0.26	20.1	Flooring	May also be present in the rest of the basement. There is however no description of it	Flooring	70	36%	No	2 or 3
17	Office buildings and public institutions	Corridor (Basement)	56	33%	0.38	22.0	Flooring	Yes, the flooring is present throughout the basement	Flooring	31	18%	Yes	None

4.4 Relationships between the concentration of PCB in materials and indoor air

As part of phase 2 of the survey, existing information was collected concerning associated measurements of PCB in indoor air and in materials. The aim was to determine which criteria should be used to select buildings for the studies of PCB in indoor air in the ENS survey.

The figure below was produced using data taken from the municipal authorities' screenings and covers buildings for which there is an associated data set of PCB measurements in both materials and indoor air. These were compared with results from the Danish Health and Medicines Authority's study in Farum in 2011 (Mayer et al., 2012), data presented in the mitigation project for EBST (Haven and Langeland, 2011) and data from the health assessment of building sealant joints containing PCB entitled "Sundhedsmæssig vurdering af PCB-holdige bygningsfuger (Gunnarsen et al., 2009).

For each building from the municipal authorities' studies, the highest measured concentration in indoor air is shown compared with the highest measured concentration in materials which are located indoors in the same building. Note the logarithmic scales. In many cases, the screenings were not carried out in the same rooms in the buildings as those from which indoor air and material samples were taken, so the comparison may only provide an indication of the relationship between concentrations in materials and indoor air for a building. In relation to the large number of measurements concerning materials and indoor air (discussed in other sections), the municipal authorities' screenings only cover a limited number of locations where there are associated measurements, due to the two different survey strategies used in the studies. In some cases, follow-up measurements were taken, e.g. of PCB in materials in places where PCB was observed in indoor air, but this data, which could have provided additional associated measurements, has not been included.

There is a considerable amount of data which indicates a clear relationship between PCB concentrations in interior building sealant (red dots) and in indoor air. In a very high proportion of the buildings where high concentrations were observed in sealant, concentrations above the lowest action value were observed in indoor air. These lead to clusters of dots in the top right-hand corner of the figure. Low concentrations in sealant, linked to low concentrations in indoor air, produce a cluster of red dots in the bottom left-hand corner.

The interesting part of the figure is the bottom right-hand corner, where there are many examples where high concentrations were found in indoor air, yet only paint and floor coverings containing relatively low concentrations were found. This may of course be due to the fact that the primary source was overlooked when the indoor air measurements were taken in different rooms to the material samples, but it is striking that such a high proportion of the dots represent materials with a large surface area. Whether the PCB in indoor air is caused by the presence of paint and/or flooring as a primary source or whether there has been a different primary source in the past is unclear.

The existing data indicate that interior PCB sources may have a substantial effect on indoor air, even though the concentration level is well below the levels at which any effect from PCB in sealants has been demonstrated (regardless of whether it is a primary or a tertiary source). The fact that this study has demonstrated the more widespread presence of PCB in paint and flooring than had previously been assumed raises the question as to what extent the observed levels could give rise to PCB in indoor air.

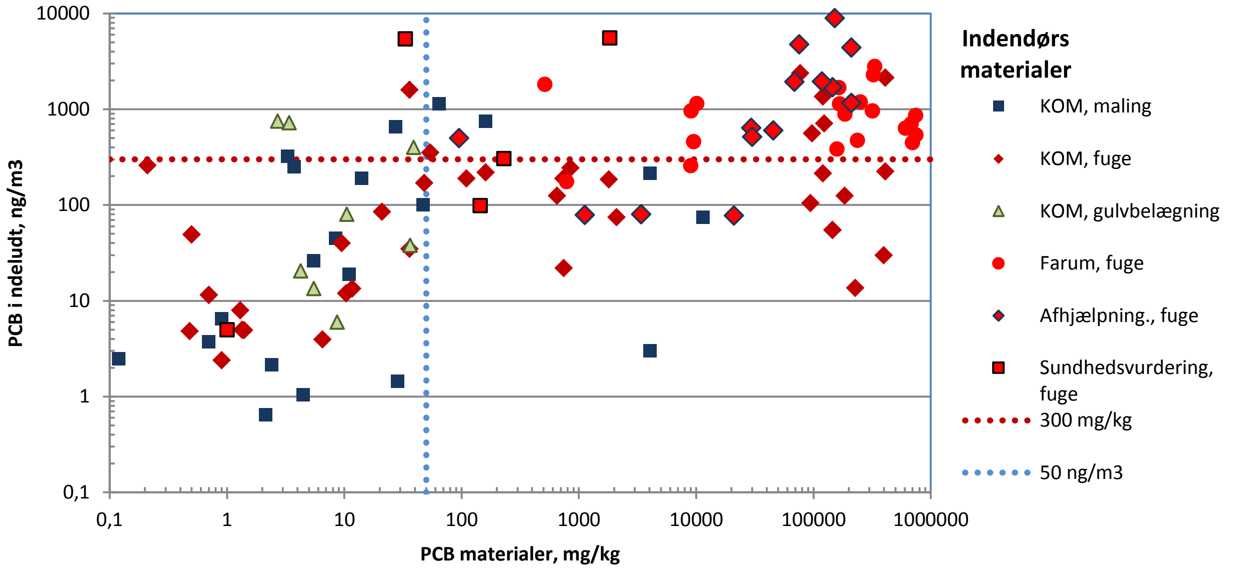


Figure 36 *Associated values from screenings of PCB in indoor air and interior materials from the municipal authorities' surveys (KOM), compared with results from previous studies.*

Notes: Paint, sealant and flooring originate from data collected by municipal authorities. Highest concentrations for indoor air and materials located indoors in the building. Only data sets where the concentrations in both indoor air and materials are above the detection limit are shown.

Farum, sealant: Data from the Danish Health and Medicines Authority's study in Farum in 2011 (Mayer et al., 2012).

Mitigation project, sealant: Data presented in the mitigation project for EBST (Haven and Langeland, 2011)

Health assessment, sealant: Data presented in the health assessment of building sealant joints containing PCB entitled "Sundhedsmæssig vurdering af PCB-holdige bygningsfuger" (Gunnarsen et al., 2009).

Results from the ENS survey and the survey of Danish Defence buildings (FBE) are shown in Figure 37. Measurements where the concentration in indoor air is below the detection limit are specified as being half the detection limit. Results are only shown for measurements where the concentration of materials in the room is known, or where it was believed at the time of sampling that there has been a material corresponding to one of the surveyed materials in the past. In the case of paint, some uncertainty is introduced, as it is difficult to say whether paint containing PCB, which is often present under several other layers of paint, is also present.

As measurements were taken in two rooms in each building, a number of measurements were taken where the concentrations in materials were below 50 mg/kg because the material which triggered the selection of the building was located in another room.

As in the previous figure, in the case of sealant, a clear relationship can be seen between high concentrations in interior sealant joints and high concentrations in indoor air. A similar tendency can be seen as regards paint and floor compounds, but with much greater variation.

Many examples can be seen where paint and flooring produce concentrations ≥300 ng/m^3. As is apparent, in the vast majority of cases, concentrations in materials of less than 50 mg/kg (which was the cut-off value used in the selection of buildings) result in concentrations in indoor air <300 ng/m^3.

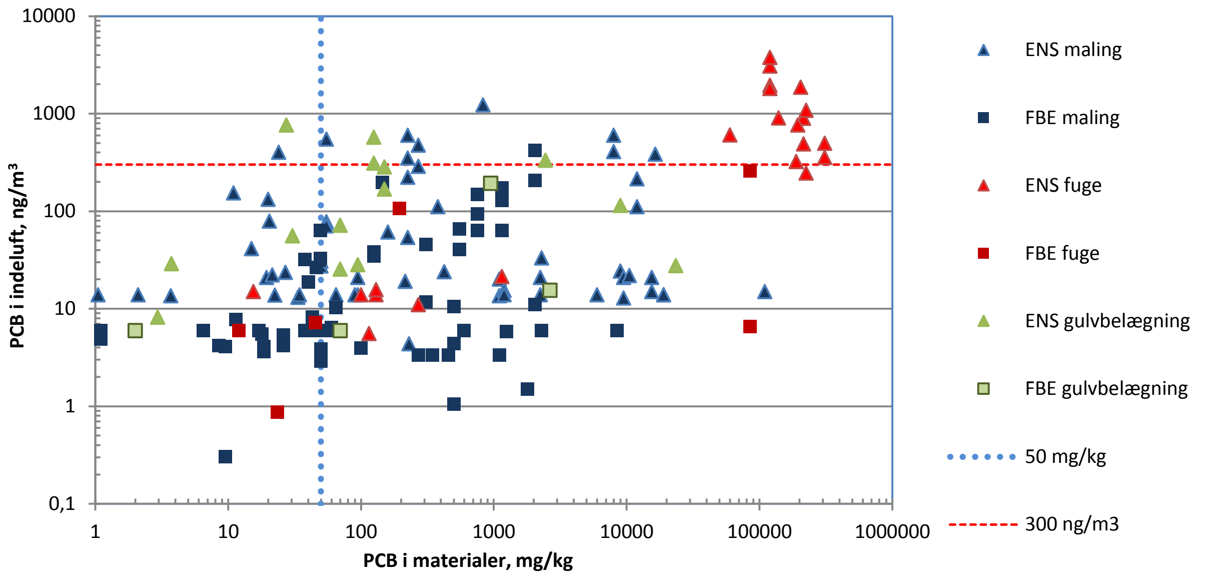


Figure 37 *Associated values of PCB in indoor air and materials from the ENS and FBE surveys. Values below the detection limit are specified as 1 ng/m^3, so that they can be shown on the figure.*

However, there are some exceptions which are important as regards the interpretation of the results in relation to the buildings where no indoor air measurements were taken. There are three measurements in the surveys where the concentration in air exceeds 300 ng/m^3, even though the concentration in the materials is below 50 mg/kg. These are identical to the measurements which were discussed in the previous section.

In one case, concentrations of 550 and 395 ng/m^3 were measured in two adjacent basement rooms, while the highest concentrations measured in paint in the two rooms were 55 and 24 mg/kg. It was noted during the sampling that there were capacitors in the room. The congener composition with a proportion of PCB 28 in excess of 80% of PCB_7 in both materials and indoor air gives a clear indication that this is the result of contamination from capacitors of the low chlorinated type, which was the only primary source with such a high proportion of PCB 28 to be found.

In another case where flooring is stated as being the source, the following was noted during the sampling: "*No primary source in room – PCB found in paint on adjacent staircase, adhesive under the floor may be a source, it is the same as on* *the staircase*." Paint on the adjoining staircase was measured at 95 mg/kg and triggered the selection of the building, but no measurements of PCB in indoor air were taken from the staircase, as it was not possible to close the room during sampling. No paint samples were taken from the room. There is therefore some doubt as to whether there could actually have been a larger source in the surveyed room or whether there has been a different primary source in the past.

In the third case from the FBE survey, high values were found in indoor air in the adjoining room, along with paint containing 1,150 mg/kg. It is therefore very likely that it is the PCB source in the adjoining room which produces the high values in the room concerned.

A characteristic pattern can be seen in the material, with relatively high concentrations in indoor air relative to the concentration in paint correlating with PCB 28 constituting a high proportion of PCB_7. The fact that materials were found with relatively low concentrations and a proportion of PCB 28 significantly above that observed in sealants and paints with higher concentrations (where they are assumed to be the primary source) gives a clear indication that the materials found are not the original primary source. In the case of the very high proportions of PCB 28, there is an obvious possibility that capacitors are the source, or that the primary source was for example a sealant joint that has now been removed.

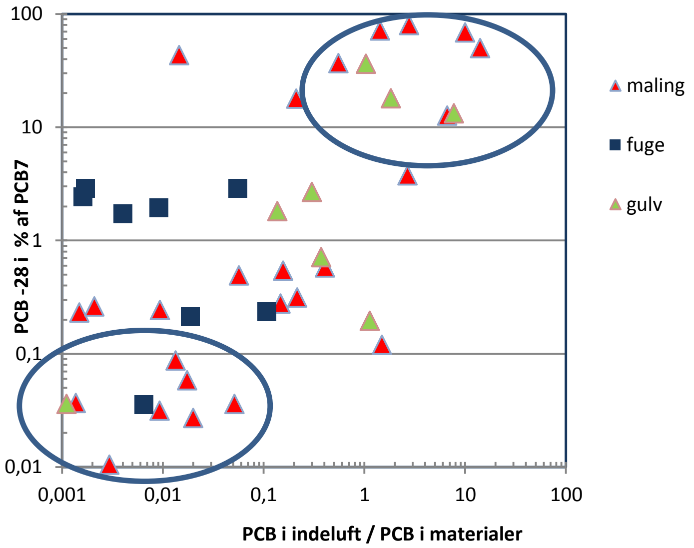


Figure 38 *Proportion of PCB 28 plotted against the ratio between PCB in indoor air (in ng/m^3) and PCB in the material which is assumed to be the main source.*

In the 12 buildings which were surveyed for primary, secondary and tertiary sources, discussed in section 4.3.6, the PCB 28 proportions in paints containing secondary and tertiary contamination in the 12 buildings varied from 0 to 28% (the high values occurred where the primary source consists of sealant joints), with a mean of 7%. The proportions shown in the figure above which give rise to relatively high indoor air concentrations are thus significantly higher than those found in the 12 buildings in which the primary source was either paint or sealant.

The results strongly indicate that capacitors may also be the source of the elevated levels. This complicates the description of relationships, but ensures that the extrapolation of the results also takes account of this source.

The considerable uncertainty relating to whether the materials that were found actually are primary sources results in a substantial variation in the relationship between PCB in indoor air and materials.

Thus it cannot be assumed that buildings with concentrations <50 mg/kg in materials do not have PCB concentrations above 300 ng/m^3 in indoor air, as assumed in the proposed method. It is therefore also necessary to estimate how many of the other buildings could contain PCB concentrations in indoor air above the relevant levels.

In order to investigate the extent to which many other parameters impact on the relationship, various calculations were performed using the data sets containing air exchange measurements, in order to determine whether this produced a better correlation between the concentrations in materials and indoor air.

Air exchange. All measured concentrations were normalised to an air exchange of once per hour. It was assumed that the outflowing air has the same concentration as that in the room, while the inflowing air is clean air. With the air exchange method that was used, it is not possible to estimate how much of the inflowing air actually originates from the outside or how much originates from other rooms or cavities in the building.

Temperature. Normalisation to 21ºC was carried out on the basis of an empirical relationship determined for contaminated apartments in Farum (SBMI, 2011). On this basis, the correction factor was calculated as y = 60.68* exp(0.1389x), where x is the temperature at which the measurement was taken and y is the correction factor.

Material surfaces. The total surface area of the material which is assumed to be the main source was calculated, and a source potential was determined by multiplying the concentration in the material by the surface area. This should take account of differences between, for example, painted floors with a large surface area and a single water pipe that had been painted.

Source strength. A source strength was calculated which expresses how much PCB disappears from the room per hour. This was calculated as the product of the concentration in indoor air normalised in relation to temperature and air exchange (once per hour) and the volume of the room. This source strength was then compared with the calculated source potential.

The degree of correlation was determined as the correlation coefficient R^2 for the double-logarithmically transformed data (as shown in the above figures). Correlations were produced for PCB_{total}, PCB 28 and the sum of PCB 28 and PCB 54.

Somewhat unexpectedly, normalising the data or comparing the source strength against the source potential, as shown in the table below, did not produce a better correlation. An attempt was made to create other correlations, which did not produce any better results. These are not shown.

The correlation coefficients for PCB_{total} of 0.14 indicate a very weak relationship between the various parameters. The correlation for PCB 28 was considerably better, partly because PCB 28 evaporates rapidly into the indoor air and partly because of the circumstances described above. However, in order to use the data to extrapolate the results to the buildings where no indoor air measurements were taken, the correlation for PCB 28 is of no great use, as no clear conversion back to PCB_{total} can be performed.

Table 32 Correlation coefficients, R^2 for double-logarithmically transformed data.

	Non-normalised indoor air concentration versus PCB in materials	Normalised indoor air concentration versus PCB in materials	Source strength versus source potential	Non-normalised indoor air versus source potential
PCB_{total}	0.14	0.10	0.12	0.14
PCB 28+ PCB 54	0.29	0.30	0.30	0.30
PCB 28	0.40	0.39	0.35	0.39

In order to create a basis for extrapolation, it was therefore decided to look at the relationship between the variables in a more advanced way, by calculating uncertainties for each variable. This means that, instead of looking at confidence limits around a linear regression line, confidence ellipses were calculated in a two-dimensional outcome space.

The confidence ellipses shown for the same data set as that shown in Figure 37 are shown in the figure below. The ellipses were calculated by considering all materials together. It is possible that there are differences between the materials and considering them collectively may have weakened the model. There is insufficient data to perform an estimation for each material separately. In the case of floor materials, the relationship is less clear than that observed for the other materials, which is presumably linked to the fact that in many cases the floor materials are not the primary source. The presence of capacitors as a primary source and uncertainties relating to whether there has previously been a primary source make a significant contribution to the variation that can be seen.

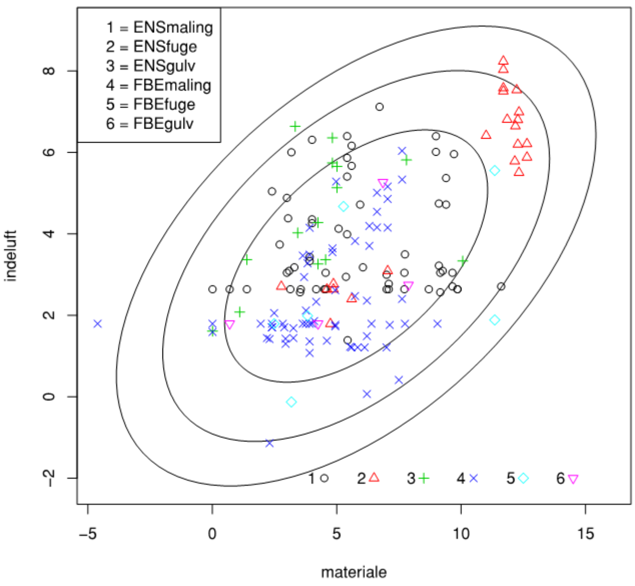


Figure 39 *Associated log(PCB) in materials and indoor air. 99%, 95% and 75% confidence ellipses. Same data as in Figure 37.*

Based on the two-dimensional distribution, relationships were determined between PCB in materials located indoors and outdoors, as illustrated in the figures below, which show the probability of finding the specified intervals in indoor air as a function of the highest concentration of PCB in materials in the room. The figure shows 90% confidence intervals.

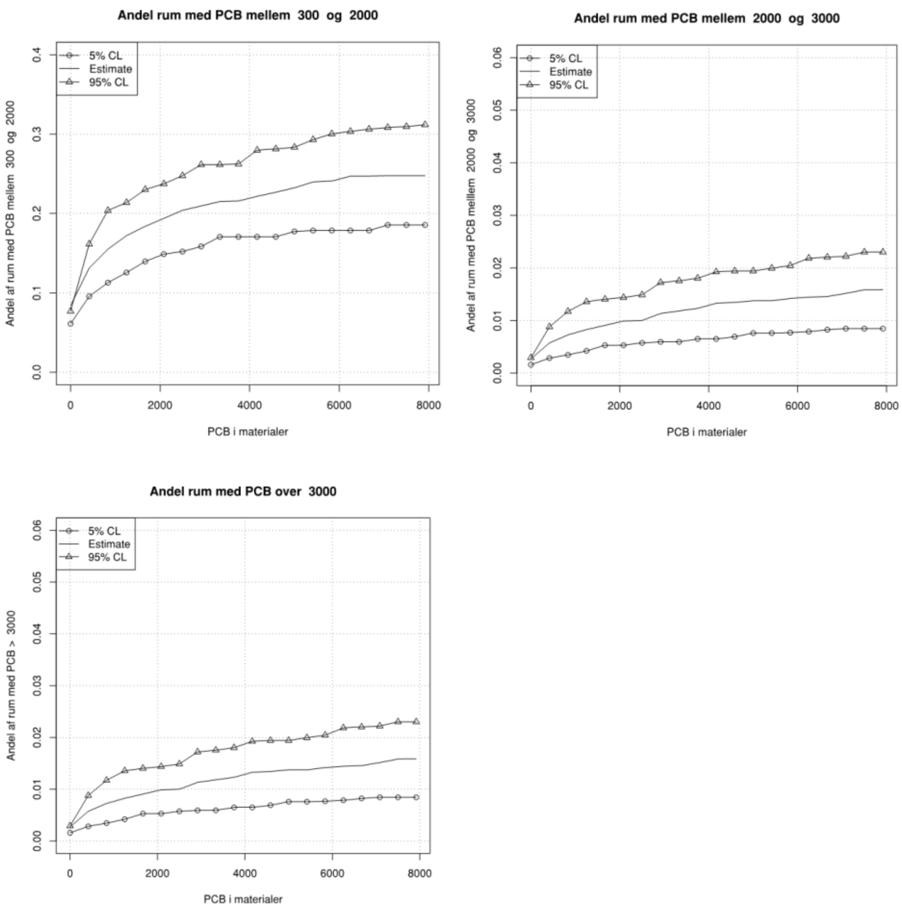


Figure 40 *Estimated probabilities of finding PCB in indoor air in the specified intervals as a function of PCB in materials. In the figure, probabilities are only shown up to materials containing 8,000 mg/kg, but calculated up to the highest values found in the materials (approx. 300,000 mg/kg).*

Materials located outdoors

In none of the buildings surveyed in either the ENS or the FEB surveys were concentrations ≥300 ng/m^3 found in indoor air where high concentrations were found in sealant joints outdoors without any obvious interior sources.

In screenings carried out by municipal authorities, there are a number of examples of ≥300 ng/m^3 being found in indoor air where only measurements of outdoor sealant joints were available or no other sources were found. As many of the screenings carried out by the municipal authorities only investigated PCB in paint and flooring to a limited extent, sources which are entirely obvious in cases where very low concentrations were found in the sealant may well have been overlooked.

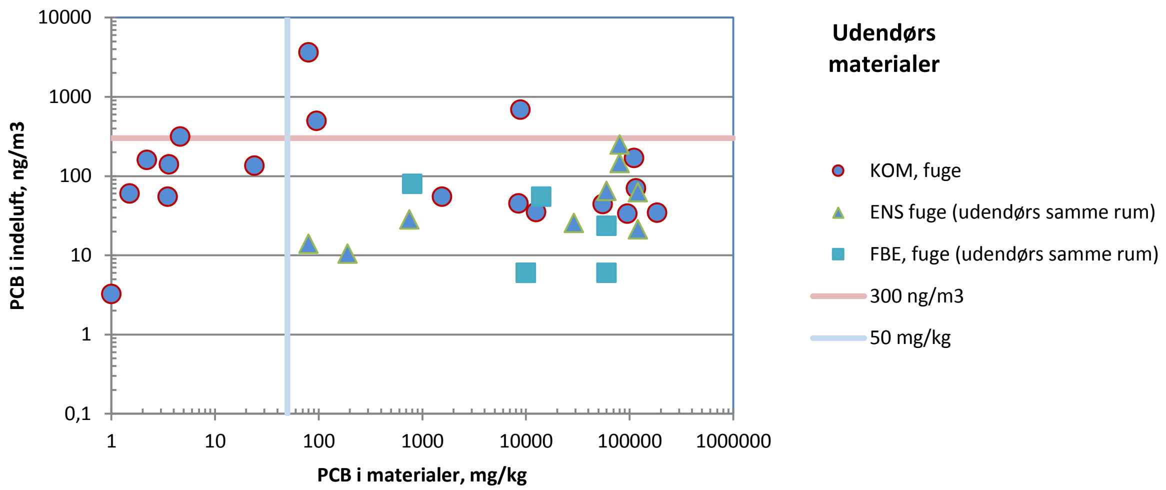


Figure 41 *Associated values from screenings for PCB in indoor air and materials from the ENS, FBE and municipal authority (KOM) surveys. From the municipal authorities' screenings, the data shown concern cases where concentrations over 10 mg/kg were not found in indoor measurements in the same building. Values below the detection limit are specified as 1 ng/m^3, so that they can be shown in the figure.*

From the report on the mitigation measures to address elevated PCB levels in the indoor climate ("Afhjælpningstiltag ved forhøjede PCB-niveauer i indeklimaet") by Haven and Langeland (2011), associated data were also collected concerning PCB in indoor air and solid substances, and some cases indicated that there may be a significant impact on the indoor air if concentrations over 10,000 mg/kg are demonstrated in solid substances outdoors as the only identified sources.

As the underlying data are very limited and the ENS and FBE surveys did not find examples where outdoor sealants gave rise to levels above 300 ng/m^3 in indoor air, no consideration will be given in the estimates to the outdoor sources which are considered under all circumstances to only represent a small proportion of the cases where concentrations over 300 ng/m^3 may be present in indoor air.

4.5 Summary and partial conclusion

Based on a structural review and PCB concentration levels in building materials, a total of 67 buildings were selected within the three building categories in which PCB measurements were taken in indoor air. The buildings were selected on the basis of the criteria that there should either be indoor materials containing more than 50 mg/kg PCB or outdoor materials containing more than 5,000 mg/kg PCB. However, a number of owners of the selected buildings did not wish to take part in the survey, and this has compromised the results of the study and rendered extrapolating them to the entire building stock more difficult.

Detached and semi-detached houses

PCB in indoor air was measured in 15 of the 20 detached and semi-detached houses surveyed, while five building owners did not wish to participate. A concentration ≥300 ng/m^3 was found in one of the detached and semi-detached houses surveyed. In none of the surveyed houses was a concentration ≥2,000 ng/m^3 found. Concentrations of less than 30 ng/m^3 were found in 71% of the buildings in which indoor air measurements were taken.

Blocks of flats

Of the selected 31 blocks of flats, PCB was measured in indoor air in 20 of them, while one housing association with 11 selected properties did not wish to take part. A concentration ≥300 ng/m^3 was found in one of the blocks of flats surveyed. In none of the blocks of flats surveyed was a concentration ≥2,000 ng/m^3 found. Concentrations of less than 30 ng/m^3 were found in 75% of the buildings in which indoor air measurements were taken. As with the results of the study of PCB in materials, it can be stated that blocks of flats with extensive PCB contamination, such as the examples that have been highlighted in recent years, are not a widespread phenomenon.

Office buildings and public institutions

There was a markedly higher frequency of both private office buildings and public institutions with ≥300 ng/m^3. In 12 of the 33 buildings surveyed (36%), at least one room with a concentration ≥300 ng/m^3 was found, and a concentration ≥3,000 ng/m^3 was found in one building. The frequencies of buildings containing ≥300 ng/m^3 were 42% and 33% of the office buildings and public institutions surveyed respectively. The results correlate well with the results of the survey of materials, which concluded that the extensive presence of indoor materials with a high concentration of PCB was most widespread in office buildings and public institutions.

When consideration is given to the prior selection of buildings with a high concentration of PCB in materials, the results for public sector offices and institutions correspond well with the results of surveys carried out by municipal authorities.

The results of 1,377 indoor air measurements at 507 locations (schools, nursery schools, town halls, etc.) in 16 municipalities are summarised in this survey. The overwhelming majority of the data set is represented by surveys where measurements were taken at all locations (where appropriate within a sub-category of buildings only) or a random sample without any prior selection based on measurements of PCB in materials. As measurements from 507 locations provide an excellent statistical basis, the results of these surveys were used to estimate PCB in indoor air in all Danish public sector offices and institutions.

The summary shows that concentrations ≥300 ng/m^3 were found in 7% of the locations surveyed. Concentrations of ≥3,000 ng/m^3 were found in two locations, equivalent to 0.4% of the locations surveyed.

Relationship between congener composition in materials and indoor air

In respect of 47 buildings, an analysis was carried out of the relationships between the PCB congener profile in indoor air and that in the material from the location which is assumed to be the primary source of PCB in indoor air.

As a general rule, materials with a profile displaced towards lower chlorinated congeners also result in a displacement in indoor air towards lower chlorinated congeners, as can be seen for example in measurements where the source is assumed to be sealants, compared with profiles where the primary source is paint or flooring.

Dioxin-like PCBs

On average, the dioxin-like PCBs comprised 3% of PCB_{27} and approx. 1% of PCB_{total}. In the Danish Health and Medicines Authority's study of Farum, where the source consisted of interior sealant joints, the dioxin-like PCBs averaged 1.1%

of PCB_{27} (Mayer et al., 2012). The results of the ENS survey thus correspond closely with the results obtained in Farum. One of the profiles differed markedly, in that the dioxin-like PCBs constituted 20% of PCB_{27}. This may point to capacitors being the source, but the source may also be sealant which is no longer present in the room.

Of the dioxin-like PCBs, PCB 118 (which is included in PCB_7) constituted 58% on average, and there was generally a good link between the content of PCB 118 and the total content of dioxin-like PCBs, a finding which has also been observed in foreign studies.

Capacitors as a source of PCB in indoor air

Some of the buildings stand out as a result of a very high proportion of PCB 28 in both materials (in which the concentrations of total PCB are low) and indoor air. This points to capacitors as a possible primary source, or may alternatively indicate that the primary source has been removed and that in these cases the PCB in indoor air is due to the fact that all materials in the room contain tertiary contamination. Analyses of relationships between primary sources and materials containing secondary and tertiary contaminants show that some displacement takes place towards lower chlorinated congeners in the materials containing tertiary contaminants, but this would not give rise to PCB 28 ratios as high as those seen in four buildings in which the above phenomenon has been observed. The results indicate that capacitors are responsible for at least four of the cases (approx. 12% of all cases) where more than 300 ng/m^3 has been found in indoor air. The type of capacitor that stands out and can be identified as a primary source accounts for only around half of the capacitors, and the total number of cases where capacitors are responsible for the high levels in indoor air may well be higher. In connection with this, it should be noted that capacitors could legally contain PCB until 1986, and buildings constructed right up to this year may therefore have this source of PCB in indoor air.

Relationships between concentrations in materials and indoor air

A detailed analysis has been carried out of the connection between PCB concentrations in materials and indoor air. A summary has also been prepared based on the municipal surveys and other studies, along with a collective summary of the ENS and FBE surveys. In the latter summary, there is considerable certainty that the materials were found in rooms in which PCB was measured in indoor air.

Both summaries show that there is some connection between high concentrations in materials and high concentrations in indoor air, but there is considerable variation and the relationship is not particularly clear. This particularly applies to paint and flooring. In order to investigate the importance of air exchange, temperature, surface area, etc., various normalisations were carried out and source strengths and source potentials were calculated. However, it has not been possible to describe relationships more clearly in this way. The analysis shows that a considerably better correlation can be achieved if only PCB 28 is considered, rather than looking at PCB_{total}. However, as the results cannot subsequently be converted unequivocally to PCB_{total}, such a correlation cannot be used to predict the PCB concentration in indoor air on the basis of PCB 28 concentration in materials. In numerous cases, concentrations of more than 300 ng/m^3 were found in rooms in which the highest measured value in materials did not exceed 50 mg/kg, yet there are also many examples of the presence of large painted surfaces with PCB concentrations of several thousand mg/kg not giving rise to such high indoor air concentrations. Much evidence suggests that paint and floor coverings in particular are not the actual primary source. In the case of a significant proportion of the measurements over 300 ng/m^3, it has been shown that capacitors are probably the primary source, and the capacitors will probably also contribute to PCB in materials and indoor air in many of the measurements with lower values and therefore mask the relationships between materials and indoor air.

In order to use these relationships between materials and indoor air to extrapolate to buildings where only materials were measured, so-called confidence ellipses were calculated which describe the relationships between materials and indoor air. In the model, all values for materials have been merged, as there are insufficient values for the individual materials. In particular, it is a weakness that no clear relationship is apparent between concentrations in materials and indoor air for flooring, presumably because the flooring is not actually the primary source in most cases. The probability of a room containing a material with a given concentration in materials having indoor air containing more than 300 ng/m^3, for example, was calculated on this basis. These probabilities are specified with a confidence interval. By calculating a probability for all surveyed buildings, the numbers of buildings that would be expected to contain PCB at concentrations ≥300 ng/m^3, ≥300–2,000 ng/m^3, ≥2,000–3,000 ng/m^3 and ≥3,000 ng/m^3 were calculated. These have been calculated using what is known as a prediction interval. Using this method, it was calculated that, of the total of 352 buildings, 15 buildings would be expected to contain concentrations ≥300 ng/m^3, which corresponds well with the fact that concentrations ≥300 ng/m^3 were found in 15 of the buildings surveyed. This confirms the expectation that buildings with less than 50 mg/kg will make a very modest contribution to the total number. However, as regards individual buildings types, there is a significant difference between the expected number and the actual number measured, which is primarily due to the fact that there will be a substantial variation in the number of actual measurements above 300 ng/m^3 as a result of the modest number of measurements of indoor air for each building type. As regards office buildings, the estimated expected number is low relative to the number of actual measurements, which may be linked to the fact that concentrations ≥300 ng/m^3 were found in many of the buildings, whilst at the same time the concentrations in materials were low.

Although the relationship between PCB concentrations in materials and indoor air in a specific building is not particularly clear, the relationship can be used to estimate the number of buildings within an individual building type which may contain PCB above a given concentration when the PCB concentration in materials is known for many buildings.

The results indicate that surveys which are intended to investigate the presence of PCB in indoor air are best carried out by first investigating PCB in indoor air, and then investigating the presence of PCB in materials if the concentration in indoor air is too high. This may also help to reveal whether there have previously been any primary sources, or whether capacitors are giving rise to excessively high PCB levels in the indoor air.

Ventilation in surveyed buildings

For all building categories, it can be seen that many rooms experienced remarkably little air exchange during the measurements, as the median values for a detached/semi-detached house, block of flats and offices and public institutions were 0.10 h^{-1}, 0.23 h^{-1} and 0.32 h^{-1} respectively. Approx. 40% of all test rooms in the homes were measured with an air exchange of less than 0.10 h^{-1}, and approx. 60% of the test rooms had an air exchange of less than 0.20 h^{-1}. In relation to the requirement laid down in the Danish building regulations for a minimum basic outdoor air exchange of 0.5 h^{-1}, the PCB measurements were therefore carried out under relatively low air exchanges.

The surveys were carried out while the rooms were not in use, i.e. windows and doors were not opened, forced extraction from extractor hoods and bathrooms etc. did not take place. If the air exchanges for the detached and semi-detached houses are considered in relation to the measured outdoor air supply and the normal use of a bedroom, as shown in previous studies, the measured air exchanges can be estimated at between four and 17 times higher than those measured during the surveys. In reality, the figures will be even higher, as the measured air exchanges also include air which has entered from other rooms.

The measurements taken while the respective buildings were in use generally show that PCB concentrations are lower by a factor of around 1.8 when the building was in use compared with when the building was not in use. Higher concentrations of PCB in indoor air can similarly be seen at higher temperatures. The results confirm that higher temperatures and air exchange impact on PCB concentrations, as has been observed in other studies.

The results show that maintaining a low temperature, such as 20˚C, and increasing the air exchange can have benefits if the building has elevated concentrations of PCB in indoor air, which can reduce overall indoor air concentrations by a factor of between two and five.

A detailed review of the results with the highest demonstrated indoor air concentrations suggests that there are many factors which could impact on the outcome of an indoor measurement, but the most commonly occurring of these factors are considered to be interior sealant joints, painted surfaces with durable paints and capacitors. It is also considered that sealed glazing units containing PCB may be of significance to PCB concentrations in indoor air.

Some of the rooms in which high PCB concentrations were found are storage rooms in basements, teaching rooms and corridors, but as illustrated in the above example, PCB from these rooms could migrate to other rooms in the buildings. It is particularly important to focus on basements which are used for teaching purposes, as wall and floor paint will often contain PCB which could have an effect on the indoor air.

5 Results of other studies of PCB in materials and indoor air

5.1 Surveys carried out in municipalities

As of 1 February 2013, the results of surveys from 20 municipalities had been received. Of these, the following 17 municipalities have submitted detailed data which were used in the statistical basis for the detailed analyses: Albertslund, Billund, Brøndby, Esbjerg, Faxe, Fredericia, Greve, Holbæk (in addition to those surveyed as part of the ENS survey), Copenhagen, Mariagerfjord, Norddjurs, Nordfyn, Randers, Rebild, Slagelse, Vesthimmerland and Aabenraa. The surveys conducted in the other municipalities only covered a few locations.

The results of these surveys are summarised in Table 33. Alongside these surveys, many of the municipal authorities have carried out surveys in connection with renovations, and more locations have therefore been investigated, but only the results of the screening studies are used here.

In many municipalities, surveys have been carried out on all the buildings in the municipality, whereas in others random samples have been taken and a spotlight then placed on institutions for children and young people. In some of the municipalities, random samples were taken based on a risk profile, i.e. where it was assumed that there was a strong probability of finding PCB in buildings or where the users comprised a special risk group.

The municipal authorities have generally used three different approaches:

- Associated measurements of indoor air and materials.
- Screening of indoor air and subsequent material samples where PCB was found in indoor air above a given value.
- Screening of materials and subsequent indoor air samples where PCB was found in materials.

There were some differences in the method used to specify locations and buildings, as well as differences in the method used to select buildings. In most of the reports on the surveys, only locations have been specified, e.g. “Nordgård school”, without any detailed information indicating the number of buildings at the location or the buildings in which PCB was found. In the case of many of the municipalities, data were obtained from the detailed reports for each location, but again it is often difficult to identify precisely how the various samples were distributed between the buildings, as the sampling location was for example simply stated as being the “woodwork room”. For each location, major detective work would therefore be necessary in order to determine precisely how many of the buildings contain PCB.

When processing data from the surveys, only locations for all the municipalities were considered in order to homogenise the material. The material was also sorted so that buildings from before the PCB period were considered separately. In one municipality, all buildings where the windows had been replaced were considered not to contain PCB without any inspection being carried out, even though this assumption cannot be considered to be 100% certain.

The importance of determining the frequency of PCB at location level rather than building level was investigated on the basis of data from two large surveys which reported at building level. At building level, the average frequency of buildings with materials containing concentrations ≥50 mg/kg PCB in the two municipalities was 7.5%, while the frequency is 9.3% when considered at location level. The same picture is apparent with indoor air measurements. Schools in particular contributed more buildings per location, and in these cases PCB is often only found in some of the buildings. When determined at location level, the frequency must therefore be considered to be around 20% higher than when determined at building level. This is taken into account in the extrapolation of data in order to calculate the number of buildings which contain PCB above a given level at national level. The presentation and discussion of data in this section are based entirely on location level, because the results of the surveys are comparable at this level.

Table 33 Differences in frequencies determined at building and location level.

	Locations			Buildings		
Materials	Num-ber	≥50 mg/kg	Frequency	Num-ber	≥50 mg/kg	Frequency
Nordfyn Municipality	39	3	7.7%	65	4	6.2%
Aabenraa Municipality	90	9	10.0%	108	9	8.3%
Total	129	12	9.3%	173	13	7.5%
Indoor air	Num-ber	≥300 ng/m^3	Frequency	Num-ber	≥300 ng/m^3	Frequency
Nordfyn Municipality	51	4	7.8%	58	4	6.9%
Aabenraa Municipality	94	4	4.3%	140	4	2.9%
Total	145	8	5.5%	198	8	4.0%

After this sorting, 1,639 primary samples of PCB in materials taken from 670 locations (including locations where samples were not taken because of the absence of relevant materials), along with 1,377 individual measurements of PCB in indoor air at 507 locations, were included in the analysis. The municipalities are evenly distributed across the country, as shown in the map below, which shows the municipalities from which surveys have been used and the municipalities which are included in the ENS survey.

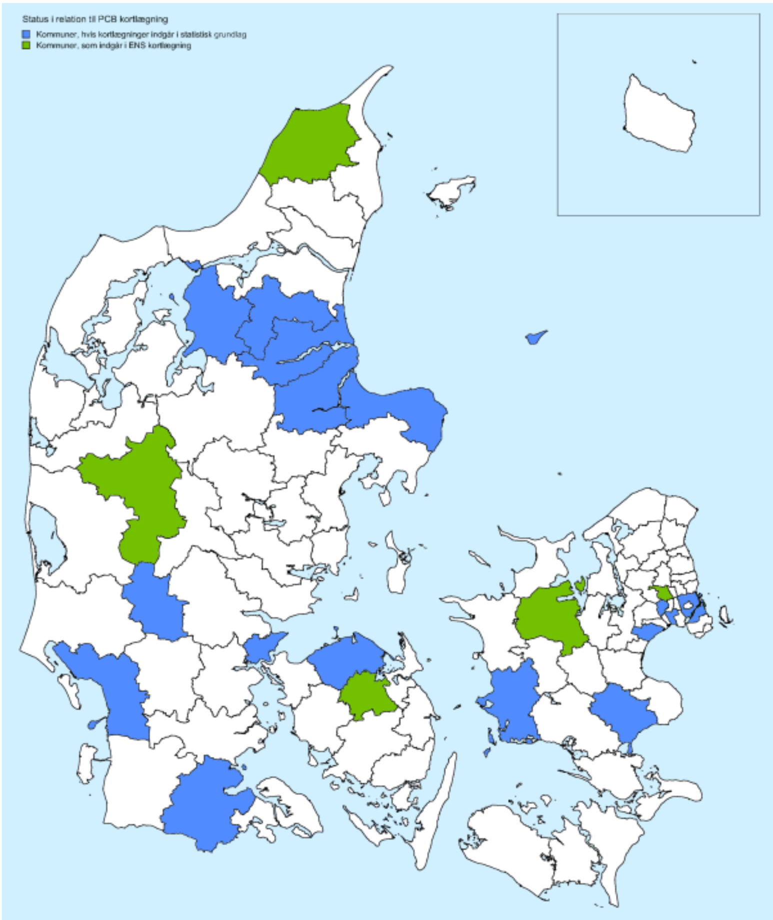


Figure 42 *Municipalities whose surveys are included in the statistical basis. Municipalities marked in blue contributed existing data to the survey. Municipalities marked in green contributed buildings which were analysed in connection with the ENS survey.*

Detailed data were entered with seven PCB congeners for 914 individual analyses of materials and 1,070 indoor air measurements, while only PCB_7 and PCB_{total} were entered for the others. The detailed congener analyses were generally taken from the individual laboratory reports, and it is considered that around 1,000 individual analyses will provide an adequate basis for the analyses for which the detailed information on congeners was used.

Only sealant materials were sampled in most of the municipalities, and given the widespread presence of PCB in paint and flooring materials observed in the ENS survey, the surveys from these municipalities are only considered to be valid for sealant materials. As regards paint and floor compounds, data from the municipal authorities will therefore only be presented as a percentage of the buildings from which paint and floor compound samples were taken.

The municipal authorities which took random samples based on a risk profile represent a small proportion of the total material, but there is a possibility that these could result in a slight overestimation of the frequencies in relation to the combined building stock.

Table 34 *Results from screening studies of municipal properties included in the statistical basis for the survey. Only includes locations where one or more buildings were erected during the PCB period.*

Municipality *1	Building categories	Method of selection	Number of buildings/locations surveyed		Number of buildings/locations where PCB has been demonstrated		Proportion of surveyed buildings/locations	
			Where materials were surveyed	Where indoor air was surveyed	In materials (≥50 mg/kg)	In indoor air (≥300 ng/m^3)	In materials (≥50 mg/kg)	In indoor air (≥300 ng/m3)
Albertslund Municipality	Public buildings, all types	All buildings, PCB period	70	70	15	3	21%	4%
Billund Municipality	Public buildings, all types	All buildings from the PCB period	38	10	4	0	11%	0%
Brøndby Municipality	Public buildings, all types	Random sample, PCB period	7	5	2	0	29%	0%
Esbjerg Municipality	Public buildings, all types	Random sample, PCB period	3	34	3 (where only PCB in indoor air has been demonstrated)	3	100%	9%
Faxe Municipality	Public buildings, all types	Random sample based on risk profile	0	17	-	1	-	6%
Fredericia Municipality	Institutions for children and young people	All buildings from the PCB period	24	24	8	4	33%	17%
Greve Municipality	Public buildings, all types	Random sample, PCB period	38	40	12	5	32%	13%
Holbæk Municipality (data prior to national survey)	Institutions for children and young people	Buildings with special risk exposure	8	8	3	1	38%	133%

City of Copenhagen	Institutions for children and young people	Random sample, PCB period	127	3 (in available data)	8	1	6%	33%
Mariagerfjord Municipality	Public buildings, all types	All buildings from the PCB period	70	68	10	4	14%	6%
Norddjurs Municipality	Institutions for children and young people	All buildings from the PCB period	57	56	4	1	7%	2%
Nordfyn Municipality	Public buildings, all types	All buildings from the PCB period	65	58	4	5	6%	9%
Randers Municipality	Public buildings, all types	All buildings from the PCB period	112	0	9	-	8%	-
Rebild Municipality	Public buildings, all types	Random sample based on risk profile	0	5	-	0	-	0%
Slagelse Municipality	Institutions for children and young people	All buildings from the PCB period	87	84	8	2	9%	2%
Vesthimmerland Municipality	Public buildings, all types	Random sample, PCB period	13	4	4	0	31%	-
Aabenraa Municipality	Public buildings, all types	All buildings from the PCB period	90	146	9	4	10%	3%
In total			788	634	101	39	13%	6%

*1 For some of the municipalities, information is only available on locations, and the data have not been broken down between the individual buildings.

5.1.1 PCB in materials

The results of the surveys broken down between concentration intervals for locations and individual measurements in 15 municipalities are presented in the table below (two of the municipalities only screened for PCB in indoor air). A total of 1,619 measurements and 670 surveyed locations are included.

It is estimated that around 16% of the locations contain one or more materials with PCB concentrations ≥50 mg/kg.

Materials containing concentrations ≥5,000 mg/kg were found at 9% of the locations.

Compared to the results of the ENS survey, there is a lower occurrence of buildings with PCB concentrations above 50 or 5,000 mg/kg, for example, and PCB concentrations ≥0.1 mg/kg were only found at 46% of the locations.

Table 35 Results of measurements of PCB in materials in institutions and public office buildings in 15 municipalities broken down according to concentration interval.

PCB_{total} in material, mg/kg *1	Locations (highest measured value)		Individual measurements *2	
	Number	% of total number of locations	Number	% of total number of measurements
<0.1	401	60%	924	57%
0.1–50	160	24%	392	24%
50–500	24	4%	82	5%
500–5,000	25	4%	55	3%
≥5,000	59	9%	166	10%
≥50	108	16%	695	43%
≥0.1	268	40%	303	19%
Total number	669		1,619	

*1 PCB_{total} is calculated as $5*PCB_7$.

*2 Locations where there were no relevant materials count as a single measurement with the concentration 0.

The lower frequencies compared to the ENS survey are largely due to the fact that surveys in many of the municipalities focused on sealants and in some cases did not screen the buildings if there were no flexible sealant joints or the windows had been replaced.

Sealants

The two data sets are thus only comparable as regards sealants.

Table 36 Results of measurements of PCB in sealants in institutions and public office buildings at 448 locations in 15 municipalities broken down according to concentration interval.

PCB_{total} in material, mg/kg *1	Locations (highest measured value per location)		Individual measurements *2	
	Number	Frequency of total number of locations *1	Number	Frequency of total number of measurements
<0.1	302	57%	694	54%
0.1–50	135	23%	309	24%
50–500	16	3%	60	5%
500–5,000	21	4%	48	4%
≥5,000	58	11%	164	13%
≥50	95	18%	272	21%
≥0.1	230	43%	581	46%
Total number	532		1,275	

*1 As % of all locations, including those where no sealant samples were taken (588 locations).

*2 Locations where there were no relevant materials count as a single measurement with the concentration 0.

Overall, the frequency of public institutions and offices with PCB concentrations ≥50 mg/kg in sealant was 14% (12–16% specified at 90% confidence interval).

The frequencies specified with 90% confidence intervals broken down between Jutland/Funen and Zealand are shown in the table below in order to indicate whether there are marked differences between the regions. The frequencies of buildings with sealants containing concentrations of ≥50 mg/kg were 12% for Jutland/Funen and 18% for Zealand. In the case of Zealand, two large data sets from Greve and Albertslund in particular drag the average up. A significance test of the difference gives a p value of 0.058, indicating that there is no significant difference between the regions.

As mentioned previously, the frequency of locations with PCB concentrations ≥50 mg/kg will be approx. 20% higher than when specified at building level, so the frequency at building level can be estimated at around 11%. It is not possible to convert the confidence intervals using exact statistical methods, but the error introduced when reducing the values by 20% is considered to lie within the rounding to whole numbers. On this basis, it is estimated that the frequency at building level of PCB ≥50 mg/kg will be 11% (9–13%).

Table 37 Comparison of the frequency of locations with PCB concentrations ≥50 and ≥5,000 mg/kg in sealants and across regions.

	Jutland/Funen (North Denmark Region, Central Denmark Region and Region of Southern Denmark)			Zealand (Region Zealand and Capital Region of Denmark)			Entire country		
	Number of locations	%	90% CI *1	Number of locations	%	90% CI	Number of locations	%	90% CI
Number of locations	363			306			669		
PCB ≥0.1 mg/kg	94	26%	22–30%	108	35%	31–40%	202	30%	27–33%
PCB ≥50 mg/kg	42	12%	9–15%	54	18%	14–22%	96	14%	12–17%
PCB ≥5,000 mg/kg	30	8%	6–11%	28	9%	7–12%	58	9%	7–11%

*1 90% confidence intervals (CI) calculated on the basis of a binomial distribution.

Paint

A total of just 111 paint samples were extracted from the surveys conducted by the municipal authorities. The data set cannot be expected to give a representative picture of the presence of PCB in paint in the buildings, and it was therefore decided in Table 38 to specify percentages as frequencies of locations where paint samples were taken, rather than the total number of locations.

It is apparent that concentrations ≥50 mg/kg were found in paint at 16% of the locations where samples were taken. By way of comparison, in the ENS survey, paint containing concentrations ≥50 mg/kg was found in 21% of the buildings from which paint samples were taken (in total for all building categories) and in 17% of all buildings surveyed. Thus, virtually the same frequency was found in the municipal authorities' surveys if studies where samples were taken are compared. Concentrations of ≥5,000 mg/kg were found in 3%, compared with 5% in the ENS survey. The results therefore confirm the widespread presence of PCB in paint. Concentrations ≥0.1 mg/kg were found in 52% of the primary samples, compared with 73% in the ENS survey, but as discussed under the cumulative distribution functions, this difference may well be due to the interval 0.1–0.5 mg/kg, as a higher detection limit was used in many of the surveys, and considerably more samples per building were taken in the ENS survey.

Table 38 Results of measurements of PCB in paint in institutions and public office buildings at 70 locations broken down according to concentration interval.

PCB_{total} in materials, mg/kg *1	Locations (highest measured value)		Individual measurements *2	
	Number	Frequency of total number of locations where paint samples were taken *1	Number	Frequency of total number of measurements
<0.1	28	40%	53	48%
0.1–50	28	40%	40	36%
50–500	8	11%	11	10%
500–5,000	4	6%	5	5%
≥5,000	2	3%	2	2%
≥50	14	20%	18	16%
≥0.1	42	60%	58	52%
Total number	70		111	

*1 Note that the percentages given here indicate the percentage of locations where paint samples were taken, and not the total number of locations.

*2 Locations where there were no relevant materials count as a single measurement with the concentration 0.

Flooring

As with paint, the data set from the municipal authorities cannot be considered to be adequate as regards flooring. PCB was measured in 85 samples of flooring from 54 locations. PCB concentrations ≥50 mg/kg were found at 13% of the locations from which samples were taken. The same frequency of 13% was observed for individual measurements in the ENS survey, where the frequency of buildings with PCB concentrations ≥50 mg/kg in flooring was 3%.

Table 39 Results of measurements of PCB in flooring in institutions and public office buildings at 70 locations broken down according to concentration interval.

PCB_{total} in material, mg/kg *1	Locations (highest measured value)		Individual measurements	
	Number	Frequency of total number of locations where paint samples were taken *1	Number	Frequency of total number of measurements
<0.1	26	48%	44	52%
0.1–50	21	39%	33	39%
50–500	5	9%	6	7%
500–5,000	2	4%	2	2%
≥5,000	0	0%	0	0%
≥50	7	13%	8	9%
≥0.1	28	52%	41	48%
Total number	54		85	

*1 Note that the percentages given here indicate the percentage of locations where floor material samples were taken, and not the total number of locations.

Schools

The data set from the municipal authorities contains data for material samples from 87 schools distributed across the country. In the 87 schools, sealant joints containing ≥5,000 mg/kg were found in 26 schools, corresponding to 31% of the schools surveyed. The concentrations in this category are typically ≥100,000 mg/kg. Sealant joints containing ≥5,000 mg/kg were found indoors in 11 schools, equivalent to 13% of the schools surveyed. In many of the schools, high values were found in all surveyed buildings, while at other schools, only one or a limited number of the buildings contained sealant joints with high PCB concentrations. Compared to the national total in the BBR register (extracted via OIS), more schools were constructed during the period 1965–1969, when the use of PCB appears to have reached its peak. However, this cannot entirely explain the high frequencies compared with other municipal institutions.

It should be noted that the data set includes data from major screenings in the municipalities and not individual cases where surveys were carried out because of specific suspicions. The data set must therefore be considered to be reasonably representative of the schools in the country constructed during the PCB period.

Table 40 shows data for the highest measured value at each school and the results of all measurements. At 29% of the schools, sealants containing ≥5,000 mg/kg PCB were found in one or more sealant samples, while the frequency is only 27% if all sealant measurements are included (an average of five samples per school were taken).

On the basis of the data set, it is not possible to say what proportion of all buildings at the schools contains sealants with ≥5,000 mg/kg PCB. There are some municipalities for which data are available at both location level (institution level) and building level, but the number of schools surveyed in these municipalities is too low to say anything about the conversion from location level to building level with any certainty.

Table 40 Frequency of schools with PCB in sealants.

PCB_{total} in materials, mg/kg *1	Locations (highest measured value)		Sealant measurements	
	Number of schools	Frequency of total number of schools surveyed	Number of measurements	Frequency of all measurements
≥0.1	59	68%	257	62%
≥50	35	40%	158	38%
≥5,000	26	29%	112	27%
Total number	87		417	

For all public institutions, the frequency specified at location level is around 20% higher than when specified at building level (see section 6.1), but the difference may well be higher for schools, which often have many buildings which have been constructed at different times.

In the national survey (the ENS survey), which is summarised in Table 1, 27 buildings from 23 schools were surveyed. In most cases, samples were only taken from a single building. At schools where a number of buildings were surveyed, the buildings concerned were constructed in different years. Of the 27 buildings surveyed, materials containing ≥5,000 mg/kg were found in five (19% of the buildings). Sealant joints containing more than 100,000 mg/kg were found in three buildings (11%), while paint containing ≥5,000 mg/kg was found in two buildings (7%). Interior sealant joints containing more than 100,000 mg/kg were found in two of the buildings (7%).

In the national survey, the frequency of school buildings with materials containing ≥5,000 mg/kg was only slightly higher than the total frequency of materials containing ≥5,000 mg/kg in public buildings of 16%. The higher occurrence of sealant joints containing ≥5,000 mg/kg in schools which were found in the municipal authorities' surveys is thus not confirmed in the ENS survey.

Due to the lower number of school buildings in the ENS survey, the uncertainty associated with this survey is significantly greater than that associated with the combined data from the municipal authorities' surveys, and as materials containing ≥5,000 mg/kg were only found in five buildings, the uncertainty is so great that it is not possible to say that this is significantly less than the result of the municipal authorities' surveys.

Table 41 Frequency of school buildings with PCB in sealants in the ENS survey.

PCB_{total} in materials, mg/kg *1	Buildings (highest measured value)			
	School buildings		All public institutions and office buildings (incl. school buildings)	
	Number	Frequency of total number of school buildings	Number	Frequency of total number of school buildings
≥0.1	21	78%	47	82%
≥50	8	30%	20	35%
≥5,000	5	19%	9	16%
Total number	27		57	

The presence of PCB in indoor air in 126 schools, distributed across the country, is shown in
Table 42. Again, the data are taken from screenings, and only a few of the schools were specifically selected on the basis of PCB having previously been found in materials. Concentrations ≥300 ng/m^3 were observed in at least one measurement at 13% of the schools, which is more than twice the average frequency for all municipal buildings surveyed. Of all 578 indoor air measurements taken at the 126 schools, concentrations ≥300 ng/m^3 were observed in 12% of the measurements. Schools represent half of the municipal buildings where concentrations ≥300 ng/m^3 were found during the screenings.

In the municipal authorities' screenings, methods were generally used which correspond to the guidelines for the measurement of PCB in indoor air published by the Danish Enterprise and Construction Authority in November 2010. The results are therefore considered to reflect the actual situation.

Table 42 PCB in indoor air at the schools surveyed.

PCB_{total} in indoor air, ng/m^3 *1	Locations (highest measured value)		All indoor air measurements	
	Number of schools	Frequency of total number of schools surveyed	Number of measurements	Frequency of total number of schools surveyed
<30	72	57%	400	69%
≥30	54	43%	178	31%
≥100	29	23%	115	20%
≥300	17	13%	71	12%
≥2,000	6	5%	10	2%
≥3,000	2	1.6%	3	0.5%
100–300	12	10%	44	8%
300–3,000	15	12%	68	12%
Total number	126		578	

*1 Calculated as 5 x PCB_7.

In order to investigate whether there are marked differences between the municipalities, Table 43 presents data for each individual municipality. The names of the municipalities are not given, as permission to disclose detailed data was not obtained from the municipal authorities concerned. The municipalities are therefore only specified as a region.

In the eight municipalities where PCB in indoor air was measured in more than five schools, the frequency of schools with measurements ≥300 ng/m^3 PCB varies between 7% and 31%. In all eight municipalities, concentrations ≥300 ng/m^3 were thus found in at least one school, and in all the municipalities, concentrations ≥300 ng/m^3 were found in less than one third of the schools. The distribution is therefore relatively even and corresponds with the results of the ENS survey, which shows that building materials containing PCB have been used to some extent across the country. The vast majority of schools with concentrations ≥300 ng/m^3 were found in connection with broad screenings of municipal buildings and were not selected as a result of PCB being demonstrated in materials.

In two of the municipalities where PCB in sealant was measured in more than five schools, no concentrations >5,000 mg/kg were found in sealant. However, in both municipalities, PCB was found in indoor air in more than one school. This may be because the primary source is a material other than sealant, but it may also be due to the fact that the material samples were not taken from the same rooms and/or buildings as the indoor air samples.

Table 43 Frequency of schools with PCB in sealants and indoor air in the individual municipalities.

Region	Sealant			Indoor air		
	Number surveyed	Number with ≥5,000 mg/kg	Frequency % of total	Number surveyed	Number with ≥300 ng/m3	Frequency % of total
Zealand	5	2	40%	3	1	33%
Zealand	1	1	100%	1	0	0%
Zealand	-	-	-	4	0	0%
Zealand	7	4	57%	7	1	14%
Zealand	7	2	29%	1	0	0%
Zealand	4	1	25%	8	1	13%
Jutland & Funen	5	2	40%	5	0	0%
Jutland & Funen	1	1	100%	16	2	13%
Jutland & Funen	10	5	50%	13	4	31%
Jutland & Funen	7	0	0%	13	2	15%
Jutland & Funen	13	2	15%	12	2	17%
Jutland & Funen	6	2	33%	14	1	7%
Jutland & Funen	4	1	25%	-	-	-
Jutland & Funen	-	-	-	3	0	0%
Jutland & Funen	7	3	43%	3	0	0%
Jutland & Funen	10	0	0%	27	3	11%
Total	87	26	30%	126	17	13%

Temporal distribution

The temporal distribution of the 65 buildings with concentrations ≥50 mg/kg, compared with the distribution of surveyed buildings and the national total from the OIS database, indicates that PCB was used throughout the period, but particularly during the period 1965–1974, whereas use since 1974 has been limited. For some of the locations, several years of construction are specified, without any specific statement of which years the surveyed buildings were constructed in. In these cases, the lowest of the specified years during the PCB period was used, which may displace the distribution slightly towards the lowest years, with the result that the true difference between the period 1965–1974 and the preceding years is actually even more pronounced.

It is to be expected that buildings constructed at the start of the PCB period may have been painted and fitted with flooring later during the period and that the buildings' year of construction does not therefore give a clear indication of when the materials containing PCB were used.

In the case of sealant containing ≥5,000 mg/kg, 77% of all the buildings were constructed during the period 1965–1974.

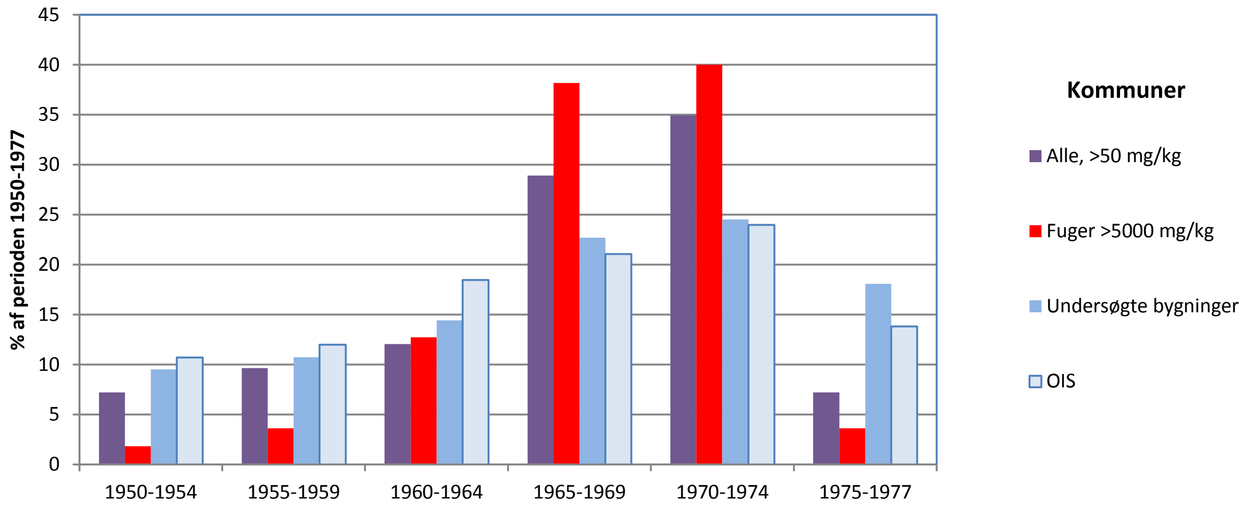


Figure 43 *Temporal distribution of buildings with PCB concentrations ≥50 mg/kg in materials and ≥5,000 mg/kg in sealant, compared to the temporal distribution of all buildings surveyed and the distribution of all municipal institutions and office buildings in Denmark from the OIS database.*

If the frequencies for the individual sub-periods are compared, the figure below clearly shows a markedly higher frequency in the presence of sealant containing PCB in buildings dating from the period 1965–1974.

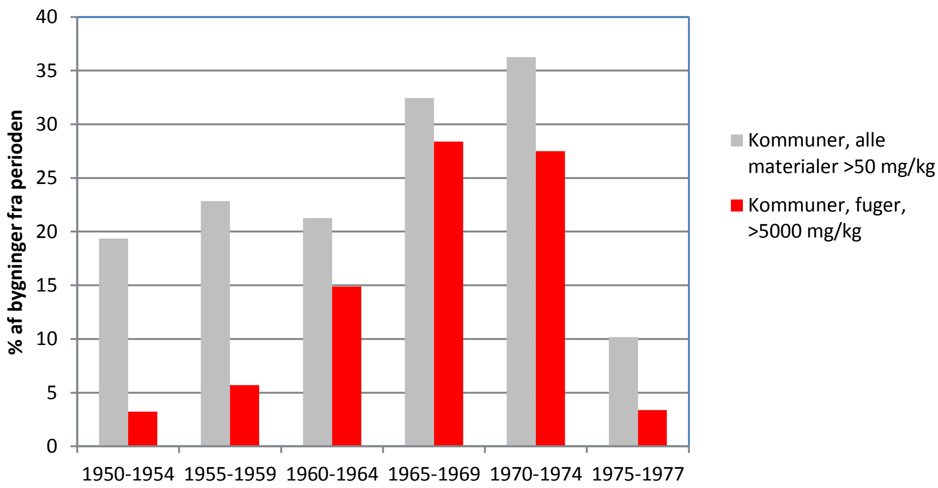


Figure 44 *Frequency of surveyed buildings with PCB concentrations ≥50 mg/kg and ≥5,000 mg/kg respectively in sealant as a function of year of construction.*

5.1.2 PCB in indoor air

In connection with the ENS survey, results were also collected concerning PCB in indoor air from the municipal authorities' surveys. These results were used in the planning of studies of PCB in indoor air in the ENS survey.

The results of 1,377 indoor air measurements at 507 locations in 16 municipalities are shown in the table below (some municipal authorities only investigated PCB in materials). The overwhelming majority of the data set is represented by surveys where measurements were taken at all locations (where appropriate within a sub-category of buildings only) or a random sample without any prior selection based on measurements of PCB in materials. This applies to Albertslund, Aabenraa, Esbjerg, Faxe, Fredericia, Norddjurs, Nordfyn, Slagelse, Greve and Mariagerfjord, which collectively represent around 95% of the data set. As regards the other municipalities, there may have been a prior selection process, which means that the frequency may be overestimated.

The results of the municipal authorities' surveys only concern municipal office and institutional buildings, and as the surveyed buildings match the temporal distribution of public institutions and office buildings in the OIS database, the data set is considered to be representative of public buildings in Denmark. All buildings are owned by municipal authorities, but it is not believed that there is any reason to assume that buildings owned by the State (excluding Danish Defence, which was covered in a separate survey) or the regions have used building materials which differ significantly from those used in municipal buildings. By specifying locations instead of buildings, there will as mentioned above be a slight tendency to see higher frequencies than if only buildings are considered, but the vast majority of the locations only consist of a single building or a group of buildings constructed during the same period.

As is apparent, concentrations ≥300 ng/m^3 were found at 7% of the surveyed locations, while concentrations in the interval 100–300 ng/m^3 were found at a further 8% of the locations. As described above, sealant containing ≥5,000 mg/kg were identified indoors at 22 locations, equivalent to 5% of all locations. There is therefore an overlap between the frequency of locations with ≥5,000 mg/kg in sealant and the frequency of locations with ≥300 ng/m^3 in indoor air. It should also be noted that indoor paint was generally not covered in these studies.

Table 44 Results of measurements of PCB in indoor air in institutions and public office buildings in 16 municipalities broken down according to concentration interval.

PCB_{total} in indoor air, ng/m³ *1	Locations (highest measured value per location)		Individual measurements (entire data set)	
	Number	Frequency of total	Number	Frequency of total
<30	372	73%	1,054	77%
≥30	135	27%	323	23%
≥100	74	15%	184	13%
≥300	35	7%	95	7%
≥2,000	7	1%	10	1%
≥3,000	2	0.4%	3	0.2%
100–300	39	8%	89	6%
300–3,000	33	7%	92	7%
Total number of locations	507		1,377	

*1 PCB_{total} is calculated as $5*PCB_7$ here, but it was calculated differently in some of the studies.

A statistical analysis shows that the frequency of buildings with PCB concentrations ≥300 ng/m³ was 7% (90% confidence interval: 5–9%), while the frequency of buildings with ≥3,000 ng/m³ was 0.4% (90% confidence interval: 0.1–1.2%). An analysis of possible regional differences shows that there is no statistically significant difference between the regions (*n* value of 0.58).

As noted previously, the frequency of buildings with ≥300 ng/m³ PCB in indoor air specified at location level will be around 20% higher than when specified at building level, so the frequency at building level can be estimated at around 5.8%. It is not possible to convert the confidence intervals using exact statistical methods, but the error introduced when reducing the values by 20% is considered to lie within the rounding to whole numbers. On this basis, it is estimated that the frequency at building level will be 6% (4–8%).

Table 45 Comparison of frequency of PCB in indoor air in ng/m³ at location level across regions.

PCB$_{total}$ in indoor air, ng/m³	Jutland/Funen (North Denmark Region, Central Denmark Region and Region of Southern Denmark)			Zealand (Region Zealand and Capital Region of Denmark)			Entire country		
	Numb-er	Frequen-cy, %	90% CI, % *1	Numb-er	Frequen cy, %	90% CI, %	Num-ber	Frequen cy, %	90% CI, %
Total number of locations	304	100		203	100		507	100	
≥100	43	14.1	11–18	31	15.3	11–20	74	145	12–17
≥300	22	7.2	5–10	13	6.4	4–10	35	7	5–9
≥2,000	6	2.0	0.9–3.9	1	0.5	0.0–2.3	7	1.4	0.6–2.6
≥3,000	2	0.7	0.1–2.1	0	0.0	0.0–1.5	2	0.4	0.1–1.2

*1 90% confidence intervals (CI) calculated on the basis of a binomial distribution.

If one considers the temporal distribution of the buildings where concentrations ≥300 ng/m³ were found in indoor air, the same pattern can be observed as with the material samples with a significantly higher representativeness of buildings with ≥300 mg/kg during the period 1965–1975, as shown in the figure below. The distribution of locations surveyed for indoor air largely follows that of public institutions and office buildings in the OIS database. Note that the list of buildings covered is not identical to the list of buildings from which material samples were taken, as there is a significant number where only either material samples or indoor air samples were taken.

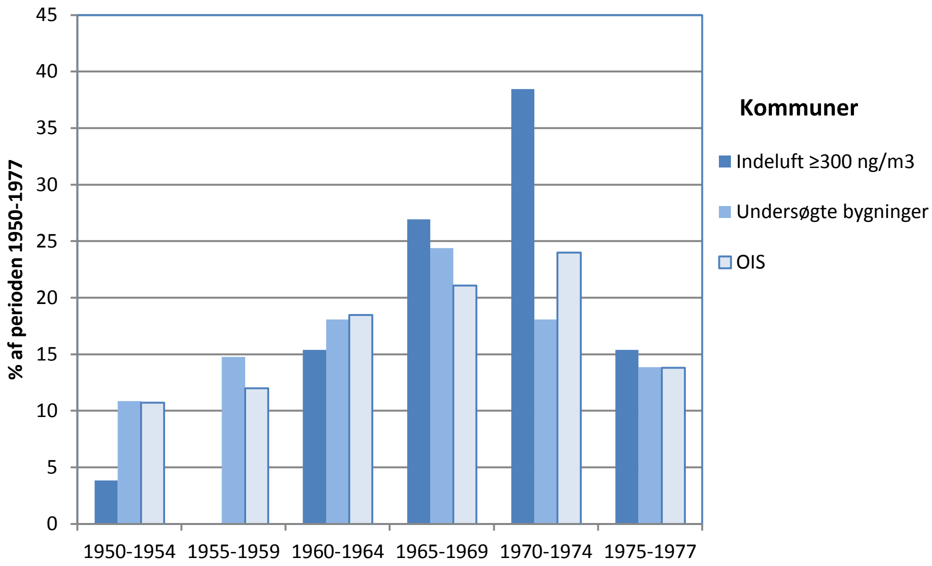


Figure 45 Proportion of surveyed buildings with >300 ng/m³ in indoor air as a function of year of construction (23 locations with >300 ng/m³ and specified year of construction).

The distribution is not identical to that of material samples, possibly as a result of the size of the data sets, but exactly the same tendency can be seen, with a significantly higher frequency of buildings dating from the period 1965–1974.

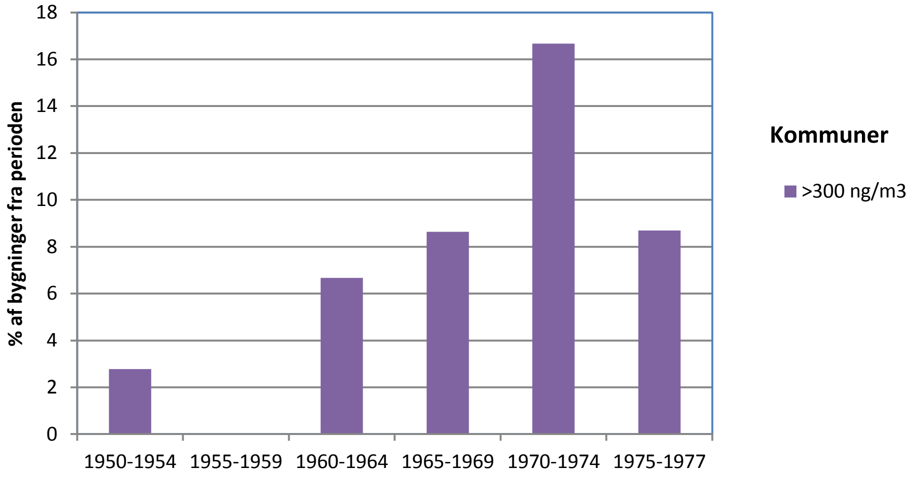


Figure 46 Proportion of surveyed buildings with ≥300 ng/m³ in indoor air as a function of year of construction.

Schools

The presence of PCB in indoor air in 126 schools, distributed across the country, is shown in
Table 46. Again, the data are taken from screenings, and only a few of the schools were specifically selected on the basis of PCB having previously been found in materials. Concentrations ≥300 ng/m^3 were observed in at least one measurement at 13% of the schools, which is more than twice the average frequency for all municipal buildings surveyed. Of all 578 indoor air measurements taken at the 126 schools, concentrations ≥300 ng/m^3 were observed in 12% of the measurements. Schools represent half of the municipal buildings where concentrations ≥300 ng/m^3 were found during the screenings.

In the municipal authorities’ screenings, methods were generally used which correspond to the guidelines for the measurement of PCB in indoor air published by the Danish Enterprise and Construction Authority in November 2010. The results are therefore considered to reflect the actual situation.

Table 46 PCB in indoor air at the schools surveyed.

PCB_{total} in indoor air, ng/m³ *1	Locations (highest measured value)		All indoor air measurements	
	Number of schools	Frequency of total number of schools surveyed	Number of measurements	Frequency of total number of schools surveyed
<30	72	57%	400	69%
≥30	54	43%	178	31%
≥100	29	23%	115	20%
≥300	17	13%	71	12%
≥2,000	6	5%	10	2%
≥3,000	2	1.6%	3	0.5%
100–300	12	10%	44	8%
300–3,000	15	12%	68	12%
Total number	126		578	

*1 Calculated as 5 x PCB_7.

In order to investigate whether there is a marked difference between the municipalities, Table 47 presents data for each individual municipality. The names of the municipalities are not given, as permission to disclose detailed data was not obtained from the municipal authorities concerned. The municipalities are therefore only specified as a region.

In the eight municipalities where PCB in indoor air was measured in more than five schools, the frequency of schools with measurements ≥300 ng/m³ PCB varies between 7% and 31%. In all eight municipalities, concentrations ≥300 ng/m³ were thus found in at least one school, and in all the municipalities, concentrations ≥300 ng/m³ were found in less than one third of the schools. The distribution is therefore relatively even and corresponds with the results of the ENS survey, which shows that building materials containing PCB have been used to some extent across the country. The vast majority of schools with concentrations ≥300 ng/m³ were found in connection with broad screenings of municipal buildings and were not selected as a result of PCB being demonstrated in materials.

In two of the municipalities where PCB in sealant was measured in more than five schools, no concentrations >5,000 mg/kg were found in sealant. However, in both municipalities, PCB was found in indoor air in more than one school. This may be because the primary source is a material other than sealant, but it may also be due to the fact that the material samples were not taken from the same rooms and/or buildings as the indoor air samples.

Table 47 Frequency of schools with PCB in indoor air in the individual municipalities.

Region	Indoor air		
	Number surveyed	Number with ≥300 ng/m^3	Frequency % of total
Zealand	3	1	33%
Zealand	1	0	0%
Zealand	4	0	0%
Zealand	7	1	14%
Zealand	1	0	0%
Zealand	8	1	13%
Jutland & Funen	5	0	0%
Jutland & Funen	16	2	13%
Jutland & Funen	13	4	31%
Jutland & Funen	13	2	15%
Jutland & Funen	12	2	17%
Jutland & Funen	14	1	7%
Jutland & Funen	-	-	-
Jutland & Funen	3	0	0%
Jutland & Funen	3	0	0%
Jutland & Funen	27	3	11%
Total	126	17	13%

5.1.3 Buildings erected before the PCB period

The surveys included a total of 57 buildings which were constructed before the PCB period. The buildings were included in seven of the municipal authorities' surveys. The municipal authorities' surveys do not specifically state that the buildings have been altered or renovated during the period. However, it generally seems to be common for it to be largely buildings that are known to have been constructed or renovated during the PCB period that are selected for the survey. The results show that only one of the 57 buildings contained a material with ≥50 mg/kg. The material concerned was flooring. A total of six paint samples were taken from the 57 buildings, and the results cannot therefore be considered to be adequate for paint.

Table 48 Results of surveys of PCB in materials in buildings constructed before the PCB period.

PCB_{total} in materials, mg/kg *1	Locations (highest measured value)	
	Number of schools	Frequency of total number of schools surveyed
<0.1	43	75%
0.1–50	13	23%
50–500	1	2%
500–5,000	0	0%
>=5,000	0	0%
>=50	1	2%
>=0.1	14	25%
Total number of locations	57	

In a systematic screening carried out in Mariagerfjord Municipality of 70 buildings constructed before the PCB period which are not included in the table above, one building with materials containing ≥50 mg/kg was found, while three buildings contained materials with PCB concentrations in the interval 0.1–50 mg/kg.

5.2 PCB in Danish Defence buildings

Alongside the ENS survey, a survey of Danish Defence buildings was also carried out. The survey is described in a special report produced for the Danish Defence Estates and Infrastructure Organisation, but the general results of the survey are reproduced in this section.

5.2.1 PCB in materials in Danish Defence buildings

The subdivision of building categories used for Danish Defence buildings differs from that used in the ENS survey. The distribution of Danish Defence buildings according to building age also differs from that of building types in the ENS survey, as a greater proportion of the buildings were constructed during the early part of the period prior to 1965, when the relative frequency of PCB in buildings at national level is lower. In addition, different materials may have been used during the construction of Danish Defence buildings. Thus, the surveys cannot be considered to be comparable, which means that the results of the two surveys cannot be merged without further consideration. It was instead decided to examine similarities and differences between the results of the two surveys. The distribution of the surveyed buildings between the three building categories that were used is shown in the table below.

A different survey method was used in the survey than that used in the ENS survey, with random samples being taken by surveying all buildings in a selection of all the establishments. Where the buildings at establishments were identical, samples were only taken from some of the buildings, on the assumption that the other identical buildings had similar PCB concentrations in the materials as those from which samples were taken. All buildings at the surveyed establishments were therefore included.

Table 49 Distribution in relation to the three building categories.

		Depots/-workshops	Office/frequently used buildings	Accomm-odation	Total
Total list *1	Number	431	269	370	1,070
	%	40%	25%	35%	100
Surveyed	Number	115	81	104	300
	%	38%	27%	35%	100
Sampled	Number	107	78	103	288
Inspected, no relevant materials	Number	18	5	30	53
Inspected, identical to sampled building	Number	8	3	1	12

*1 The list only covers buildings in Denmark (excluding Greenland and the Faroe Islands).
*2 Sampled includes identical buildings.

The distribution of results between the three building categories is shown in Table 50. For each building category, the table shows how many of the surveyed buildings contain PCB in each concentration interval.

The concentration intervals indicate the highest measured value for each building, regardless of material type. As the table shows, materials containing more than 50 mg/kg were found in 46% of the surveyed depots/workshops, 16% of the buildings used for accommodation purposes and 49% of the office buildings/frequently used buildings. For both office/frequently used buildings and depots/workshops, higher frequencies of buildings with materials containing ≥50 mg/kg are observed than were found in the three building types covered by the ENS survey. On the other hand, the frequencies of buildings with materials containing ≥5,000 mg/kg is lower or at the same level as in the ENS survey. The FBE survey shows a markedly higher frequency of buildings with materials containing concentrations ≥5,000 mg/kg in office/frequently used buildings compared with buildings used for accommodation purposes. It was not investigated whether this is due to different age profiles for the two building categories.

As with the results of the ENS survey, more than 75% of the buildings within all building categories contain materials with concentrations ≥0.1 mg/kg.

Table 50 Buildings with PCB in one or more samples, highest measured value.

	Number of buildings					
	Depots/workshops		Accommodation		Office/frequently used buildings	
Number surveyed	115		104		81	
Number sampled	107 (106) *2		103		78 (76) *2	
PCB_{total}, mg/kg	Number	% of total *1	Number	% of total *1	Number	% of total *1
All materials located outdoors or indoors	107		103		76	
<0.1	10	9%	25	24%	0	0%
0.1–50	43	37%	61	59%	36	44%
50–500	31	27%	9	9%	12	15%
500–5,000	16	14%	7	7%	15	19%
≥5,000	6	5%	1	1%	13	16%
Total ≥0.1	96	83%	78	75%	76	94%
Total ≥50	53	46%	17	16%	40	49%
Materials located indoors	96		96		73	
<0.1	10	9%	25	24%	2	2%
0.1–50	43	37%	55	53%	36	44%
50–500	30	26%	9	9%	19	23%
500–5,000	10	9%	6	6%	10	12%
≥5,000	3	3%	1	1%	6	7%
Total ≥0.1	86	75%	71	68%	71	88%
Total ≥50	43	37%	16	15%	35	43%

*1 The total number includes buildings from which no samples were taken because they were considered not to contain relevant materials.

*2 Number sampled. In parentheses, number of buildings for which at least one analysis result has been received from a laboratory.

For each building category, the following expanded table (Table 51) shows how many of the buildings contain PCB in different concentration intervals broken down according to materials located outdoors and indoors respectively. The same data are shown as frequencies (%) in the following figure. The concentration intervals also indicate the highest measured value for each building for the individual materials and location. As an example of how the table should be interpreted, concentrations of ≥5,000 mg/kg were thus found in exterior sealant joints in seven office/frequently used buildings.

Sealant containing ≥5,000 mg/kg was primarily found outdoors in office/frequently used buildings and depots/workshops with one such joint being found indoors. In accommodation buildings, no sealant containing ≥5,000 mg/kg was found, either indoors or outdoors. For all building categories, the frequencies of buildings with sealant containing a high concentration of PCB are lower than the corresponding frequencies for the building type “office buildings and public institutions” in the ENS survey.

The survey shows that the frequency of buildings with paint containing high concentrations of PCB is greater in Danish Defence buildings than in the rest of the building stock. The results show that 35% of depots/workshops and 42% of offices/frequently used buildings contain paint with concentrations ≥50 mg/kg, which are significantly higher frequencies than were observed in the ENS survey. On the other hand, the frequencies of buildings with paint containing concentrations ≥5,000 mg/kg were generally lower than in the ENS survey, but the frequencies were low in both surveys. The presence of flooring with high concentrations of PCB is approximately the same as was observed in the ENS survey, and in both surveys the frequency of buildings with high PCB concentrations in flooring was significantly lower than that of buildings with high PCB concentrations in paint and sealant.

Table 51 *Surveyed **buildings** broken down according to the highest measured PCB concentration in materials broken down according to material type and whether the material was located outdoors or indoors.*

	Depots/workshops		Accommodation		Office/frequently used buildings	
Number surveyed	115		104		81	
Number sampled	107		103		78	
All materials, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	83	96	67	96	51	73
<0.1	30	10	39	25	11	2
0.1–50	35	43	25	55	23	36
50–500	6	30	1	9	2	19
500–5,000	6	10	2	6	8	10
≥5,000	6	3	0	1	7	6
Total ≥50	18	43	3	16	17	35
Sealant, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	34	37	44	42	32	23
<0.1	14	20	40	26	14	7
0.1–50	13	12	3	16	7	13
50–500	0	3	1	0	0	2
500–5,000	1	0	0	0	4	0
≥5,000	6	2	0	0	7	1
Total ≥50	7	5	1	0	11	3
Paint, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	68	78	40	63	43	62
<0.1	27	2	18	8	8	1
0.1–50	28	36	19	40	26	27
50–500	7	29	1	8	5	23
500–5,000	6	10	2	6	4	8
≥5,000	0	1	0	1	0	3
Total ≥50	13	40	3	15	9	34
Flooring, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	1	64	3	50	0	51
<0.1	0	11	0	25	0	11
0.1–50	1	47	3	23	0	31
50–500	0	4	0	2	0	4
500–5,000	0	1	0	0	0	3
≥5,000	0	1	0	0	0	2
Total ≥50	0	6	0	2	0	9

*1 Indicates that no materials which could have contained primary PCB were considered to be present.

*Table 52 Frequency of surveyed **buildings** broken down according to the highest measured PCB concentration in materials broken down according to material type and whether the material was located outdoors or indoors.*

	Depots/workshops		Accommodation		Office/frequently used buildings	
Number surveyed	115		104		81	
Number sampled	107		103		78	
All materials, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	83	96	67	96	51	73
<0.1	26%	9%	38%	24%	14%	2%
0.1–50	30%	37%	24%	53%	28%	44%
50–500	5%	26%	1%	9%	2%	23%
500–5,000	5%	9%	2%	6%	10%	12%
≥5,000	5%	3%	0%	1%	9%	7%
Total ≥50	16%	37%	3%	15%	21%	43%
Sealant, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	34	37	44	42	32	23
<0.1	12%	17%	38%	25%	17%	9%
0.1–50	11%	10%	3%	15%	9%	16%
50–500	0%	3%	1%	0%	0%	2%
500–5,000	1%	0%	0%	0%	5%	0%
≥5,000	5%	2%	0%	0%	9%	1%
Total ≥50	6%	4%	1%	0%	14%	4%
Paint, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	68	78	40	63	43	62
<0.1	23%	2%	17%	8%	10%	1%
0.1–50	24%	31%	18%	38%	32%	33%
50–500	6%	25%	1%	8%	6%	28%
500–5,000	5%	9%	2%	6%	5%	10%
≥5,000	0%	1%	0%	1%	0%	4%
Total ≥50	11%	35%	3%	14%	11%	42%
Flooring, mg/kg	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Total number of samples	1	64	3	50	0	51
<0.1	0%	10%	0%	24%	0%	14%
0.1–50	1%	41%	3%	22%	0%	38%
50–500	0%	3%	0%	2%	0%	5%
500–5,000	0%	1%	0%	0%	0%	4%
≥5,000	0%	1%	0%	0%	0%	2%
Total ≥50	0%	5%	0%	2%	0%	11%

*1 Indicates that no materials which could have contained primary PCB were considered to be present.

5.2.2 PCB in indoor air in Danish Defence buildings

As a follow-up to the survey of PCB in materials in Danish Defence buildings, measurements of PCB in indoor air were taken in many of the buildings in which the highest PCB concentrations in materials were found.

The results are presented in Table 53. The frequencies are specified as a percentage of the buildings in which PCB was measured in indoor air. Concentrations ≥300 ng/m^3 were thus found in seven of the 46 surveyed buildings, corresponding to 15% of the buildings which were surveyed for PCB in indoor air. No concentrations ≥3,000 ng/m^3 were found in any of the buildings. As the 46 surveyed buildings are the buildings in which the highest concentrations were found in materials, the probability of finding concentrations ≥300 ng/m^3 in the 254 buildings in which no measurements of PCB in indoor air were taken is considered to be low. Overall, concentrations ≥300 ng/m^3 were therefore found in seven out of 300 surveyed buildings, corresponding to approx. 2% of the buildings. If it is assumed that concentrations ≥300 ng/m^3 could be present in some of the buildings in which indoor air was not measured, it can collectively be estimated that 2–4% of Danish Defence buildings could contain ≥300 ng/m^3 in one or more rooms.

Data concerning relationships between PCB in indoor air and materials from the study of Danish Defence buildings are covered in the description of these relationships in section 4.3.2.

Table 53 PCB in indoor air in Danish buildings selected for study of PCB in indoor air.

PCB_{total} in indoor air, ng/m^3	Highest measured value per building							
	All buildings		Accommodation		Office/frequently used buildings		Depots/workshops	
	Number	Frequency of total	Number	Frequency of total	Number	Frequency of total	Number	Frequency of total, indoor air
<30	32	70%	4	57%	17	77%	11	65%
≥30	14	30%	3	43%	5	23%	6	35%
≥100	9	20%	2	29%	3	14%	4	24%
≥300	**7**	**15%**	**2**	**29%**	**2**	**9%**	**3**	**18%**
≥2,000	1	2%	0	0%	1	5%	0	0%
≥3,000	0	0%	0	0%	0	0%	0	0%
100–300	2	4%	0	0%	1	5%	1	6%
300–3,000	7	15%	2	29%	2	9%	3	18%
Total number of buildings surveyed for PCB in indoor air	46	100%	7	100%	22	100%	17	100%
Total number of buildings surveyed for PCB in materials	300		104		81		115	

5.3 Housing association surveys

Many surveys have been carried out on housing association properties. These are summarised in the table below. National housing associations and all housing associations in the municipal authorities covered were contacted in connection with the survey. Online searches were also performed for housing association surveys. It is possible that local associations have conducted surveys which have not been identified, but there are unlikely to be many.

Relatively few surveys were identified which generally only covered sealants. In addition to these, studies have also been conducted by certain local offices, e.g. in connection with renovation projects.

Compared with the extensive data that are available from the municipal authorities, the data from the housing associations are considered to be insufficient to significantly improve the statistical basis for the ENS survey, particularly given that the associations' studies only covered sealants and that the two surveys are therefore not comparable.

Many detailed studies are available from KAB's studies conducted in Farum Midtpunkt, which were used in connection with the analysis of PCB in indoor air, as well as the assessment of the importance of secondary and tertiary sources.

Table 54 Results from screening studies conducted by housing associations (summarised winter 2012/2013).

Housing association	Method of selection	Number of buildings/local office areas surveyed		Number of buildings/locations where PCB has been demonstrated		Proportion of surveyed buildings/locations	
		Where materials were surveyed	Where indoor air was surveyed	In materials (≥50 mg/kg)	In indoor air (≥300 ng/m³)	In materials (≥50 mg/kg)	In indoor air (≥300 ng/m³)
Lejerbo	All local office areas from the PCB period		653 buildings in 123 local office areas		5 buildings (local office areas)		1%
KAB	All local office areas from the PCB period	36 local office areas	indoor air surveyed in local office areas in which PCB was found	2 local office areas		6%	
Københavnsk boligselskab		[no specific data were available]		2 local office areas			
Midtjysk boligselskab	All buildings from the PCB period	2 buildings (48 of the same type)		2 buildings		100%	
Nordjysk-boligselskaber	Not specified	6 buildings		6 buildings		100%	
Nordjysk boligselskab		372 dwellings	372 dwellings [no specific data were available]				

5.4 Danish Environmental Protection Agency's study of PCB in materials from renovations and demolitions

As part of a project to prepare updated guidelines concerning the separation of waste containing PCB for the Danish Environmental Protection Agency, Niras obtained information on the results of material analyses in connection with renovations and demolitions (Alslev et al., 2013).

In the study, a total of 144 reports concerning renovations and demolitions were analysed, broken down as shown in Table 55. Each report typically represents one building.

According to the study summary, 80% of the buildings described in the reports contained materials in which PCB had been detected (left-hand columns in the table). This is in line with the results of the ENS survey, where PCB concentrations ≥0.1 mg/kg were demonstrated in more than 75% of the buildings.

The samples originated from across the country, but no attempt was made in the study to determine whether there were any regional differences in the presence of PCB.

Data for analysed samples containing ≥50 mg/kg were kindly summarised by Niras for the ENS survey. No corresponding summary was prepared for buildings (reports).

Note that private dwellings cover all types of private home. The contribution from detached houses is indicated as marginal in the report; in other words, the study is not deemed to cover detached and semi-detached houses.

Table 55 Proportion of reports with PCB (all concentrations) plus analysed samples with ≥50 mg/kg PCB in the material.

Building type	Reports (Alslev et al., 2013)			Analysed samples (summarised by Niras for the ENS survey)		
	Number	Number with PCB, every concentra-tion	Propor-tion	Total number	Quantity ≥50 mg/kg PCB	Propor-tion ≥50 mg/kg PCB
Industrial	7	6	86%	63	10	16%
Public buildings	71	66	93%	471	158	34%
Private homes	38	32	84%	400	121	30%
Unknown	28	15	54%	77	11	14%
In total	144	119	83%	1,011	300	30%

*1 Indicates measurements above the detection limit, which varies between the reports.

The results are broken down by concentration intervals. The table below contains an extract in which the proportions of the samples containing ≥50 mg/kg and ≥1,000 mg/kg respectively are stated. Note that it is proportions of samples that are indicated, not proportions of buildings.

The results show that 26% of the sealants contained ≥50 mg/kg PCB. The sealant in internal joints around windows in particular contained PCB, with almost 50% of the samples containing ≥50 mg/kg PCB.

The studies have shown that 21% of the samples of paint contained ≥50 mg/kg PCB. It can be seen that virtually all the analysed facade paint contained PCB concentrations ≥1,000 mg/kg.

For floor compounds/coverings it can be seen that a single sample of linoleum contained PCB in concentrations between 50 and 1,000 mg/kg. There were four measurements in the interval 1–50 mg/kg (not shown here), while one out of 24 measurements of the “Others” type contained more than 1,000 mg/kg, indicating that the PCB performs a technical function in this material.

Over 50% of the samples examined which came from sealed glazing units contained PCB at levels ≥50 mg/kg and of these the majority contained ≥1,000 mg/kg. This tallies with the results of the ENS survey.

Table 56 *Proportion of material samples containing ≥50 mg/kg and ≥1,000 mg/kg respectively (Alslev et al., 2013)*

Material/number			n (number)	Proportion with ≥50 mg/kg (% of samples)	Proportion with ≥1,000 mg/kg (% of samples)
Sealants		in total	754	26	20
	Windows	Exterior	480	23.3	18.1
	Windows	Interior	45	48.9	40.0
	Doors	Exterior	77	19.5	15.6
	Doors	Interior	27	18.5	11.1
	Element joints		99	28.3	22.2
	Wetrooms		26	50.0	42.3
Paint		in total	165	21	15
	Floors		34	17.6	0.0
	Facades		59	37.3	35.6
	Walls		38	7.9	0.0
	Windows		1	0.0	0.0
	Doors		4	0.0	0.0
	Other		29	13.8	13.8
Floor compounds/coverings		in total	47	9	2
	Render		4	0.0	0.0
	Linoleum		6	16.7	0.0
	Vinyl		4	0.0	0.0
	Concrete		6	0.0	0.0
	Dust binder		0	0.0	0.0
	Adhesive putty		3	0.0	0.0
	Other		24	12.5	4.2
Sealed glazing units		in total	45	56	29
	Sealant type: putty		21	57.1	42.9
	Sealant type: sealant adhesive		24	54.2	29.2

5.5 Summary and partial conclusion

The municipalities' surveys

Extensive data are available for public institutions and public office buildings from surveys conducted by municipal authorities. In most municipalities, surveys have exclusively been aimed at sealants, and the results of the surveys can only be considered to be representative as regards sealants. Overall, the frequency of buildings containing PCB at concentrations ≥50 mg/kg in sealant in public institutions and offices specified at location level was 14% (12–16%) (a location is a school, care home, etc.). An analysis of the results from the municipalities for which data were available for all the individual buildings at all locations (e.g. all buildings at a particular school) showed that the frequency at location level was approx. 20% higher than when specified at building level. The frequency of buildings with PCB in paint and floor compounds has been estimated on the basis of the ENS survey results, as most surveys conducted by municipalities did not include these materials. Overall, 19% (11–30%) of buildings contained paint or flooring containing ≥50 mg/kg.

High occurrences of PCB in sealant are more frequent in schools than in other public buildings. Amongst 87 schools across the country which took part in the municipal authorities' screenings, sealants with a high PCB concentration (≥5,000 mg/kg, but typically ≥100,000 mg/kg) were found in 31% of the schools.

Danish Defence buildings – FBE survey

Alongside the present survey, a survey of Danish Defence's buildings was carried out for the Danish Defence Estates and Infrastructure Organisation (FBE). The FBE survey studied 115 depots/workshops, 81 offices/frequently used buildings and 104 buildings used for living quarters. The results obtained from Danish Defence's buildings correspond well with the results of the ENS survey, and only minor differences were found in the use of materials containing PCB between the two surveys.

On the whole, the differences between the building categories within the ENS and FBE surveys were greater than the overall differences between the two surveys. The results of the FBE survey could therefore be used to supplement those of the ENS survey in analyses of connections between PCB in materials and PCB in indoor air.

The results of 1,377 indoor air measurements at 507 locations (schools, nursery schools, town halls, etc.) in 16 municipalities are summarised in this survey. The overwhelming majority of the data set is represented by surveys where measurements were taken at all locations (where appropriate within a sub-category of buildings only) or a random sample without any prior selection based on measurements of PCB in materials. As measurements from 507 locations provide an excellent statistical basis, the results of these surveys were used to estimate PCB in indoor air in all Danish public sector offices and institutions.

Housing associations

Relatively few surveys were identified which generally only covered sealants. In addition to these, studies have also been conducted by certain local offices, e.g. in connection with renovation projects.

Compared with the extensive data that are available from the municipal authorities, the data from the housing associations are considered to be insufficient to significantly improve the statistical basis for the ENS survey, particularly given that the associations' studies only covered sealants and that the two surveys are therefore not comparable.

Danish Environmental Protection Agency study of PCB in materials

The results of material analyses carried out in conjunction with renovations and demolitions, compiled as part of a project to draw up updated guidelines for the Danish Environmental Protection Agency on sorting waste containing PCB, show that 80% of the buildings described in the reports contained materials in which PCB was detected (left-hand columns in the table). This is consistent with the results of the ENS survey, which showed the PCB content to be ≥0.1 mg/kg in more than 75% of the buildings.

6 The presence of PCB in materials in buildings in Denmark

6.1 The number of buildings containing PCB in materials

6.1.1 Proportion and number of buildings from the PCB period containing PCB in materials

The following section contains an estimate of the number of buildings in Denmark that might have PCB in materials at levels which are above two of the set limit values in relation to the handling of materials containing PCB in connection with waste disposal:

› Recommended limit value of 0.1 mg/kg, which means that the materials must be destroyed, and

› Limit value of ≥50 mg/kg, which means that the materials must be handled as hazardous waste.

The value of 5,000 mg/kg is used here to indicate materials where there is a particularly high potential for people and the environment to be exposed to the substance.

Detached and semi-detached houses

The estimates for detached and semi-detached houses are based on a random sample of 154 detached and semi-detached houses distributed across the country. The houses were selected to be representative in terms of their distribution between the five regions, temporal distribution within the PCB period and distribution between the three sub-groups of buildings within the building type. As shown in both the ENS survey and the complete data set from the municipalities, the use of PCB was particularly frequent during the period 1965–1974 compared to the other sub-periods. When extrapolating from the random sample to the total number of buildings in Denmark, it is thus important for the buildings surveyed to be representative temporally; otherwise it would have been necessary to generate a weighted calculation that took these differences into account.

According to the OIS database, 588,691 buildings were built in Denmark during the period 1950–1977 within these three building types:

› Farmhouse for agricultural property.
› Free-standing detached house (bungalow).
› Terraced, link or semi-detached houses (vertical separation between the units).

When the data extract was performed there were 1,444,077 detached and semi-detached houses registered in the OIS database, of which 588,691 (41%) dated from the PCB period.

It can be estimated on the basis of OIS data and the results of the study that the number of detached and semi-detached houses with PCB concentrations ≥50 mg/kg in one or more materials is 80,000–140,000 (90% confidence interval), of which 20,000–60,000 will contain materials with PCB concentrations ≥5,000 mg/kg.

The frequency of detached and semi-detached houses with materials that have PCB concentrations ≥50 mg/kg is, as shown elsewhere in the report, significantly lower than the frequency of blocks of flats, offices and public institutions.

Table 57 *Estimated number of detached and semi-detached houses in Denmark dating from the period 1950–1977 with materials containing PCB.*

PCB_{total} in all materials, mg/kg	Buildings surveyed			Buildings in Denmark from the PCB period		
	Number of buildings	Frequency	90% confidence interval	Total number; see the OIS database	Number of buildings with PCB	90% confidence interval
Number	154			588,691		
≥0.1	113	73%	67–79%		430,000	390,000–470,000
≥50	28	18%	13–24%		110,000	80,000–140,000
≥5,000	10	7%	4–11%		40,000	20,000–60,000

* Values are indicated without decimal places, but one decimal place is included in the calculation of the number of buildings, which is then rounded off.

Blocks of flats

The survey covered 105 blocks of flats from 52 local office districts in five towns. The distribution by years does not quite match the national total from the OIS database, but 42% of the buildings date from the period with a high frequency of PCB, i.e. 1965–1974, compared to the national total of 45% of the buildings. This difference is deemed to be so negligible that there is no need to take it into account in the extrapolation from the properties surveyed.

When the data extract was performed, a total of 89,832 blocks of flats were registered in the OIS database, of which 14,928 (17%) date from the PCB period. This calculation was performed at property level, with the number of properties representing a much larger number of homes. According to Statistics Denmark, the total number of occupied homes in blocks of flats in 2012 was 984,718 (Statistics Denmark, 2012).

The total estimate is that there will be 3,600–5,900 properties that contain materials with PCB concentrations ≥50 mg/kg, while there are materials with concentrations ≥5,000 mg/kg in 1,000–2,700 properties.

It is not thought that the existing measurements from housing associations, which only covered sealant, would significantly improve the statistical basis.

Table 58 Estimated number of blocks of flats in Denmark dating from the period 1950–1977 with materials containing PCB.

PCB_{total} in all materials, mg/kg	Buildings surveyed			Buildings in Denmark from the PCB period		
	Number of buildings	Frequency	90% confidence interval	Total number; see the OIS database	Number of buildings with PCB	90% confidence interval
Number	105			14,928		
≥0.1	95	91%	84–95%		13,500	12,600–14,100
≥50	33	31%	24–40%		4,700	3,600–5,900
≥5,000	12	11%	7–18%		1,700	1,000–2,700

* Values are indicated without decimal places but one decimal place is included in the calculation of the number of buildings, which is then rounded off.

Public institutions and office buildings

With regard to public institutions and office buildings (meaning publicly owned office buildings), there is a large data set for municipally owned public buildings; as previously mentioned, this data set is deemed to be representative only for sealant.

The data set from the municipalities covers measurements of PCB in sealant from 532 locations in Denmark, thereby creating a strong statistical basis for estimating the presence of PCB in public buildings in Denmark. A survey has not been conducted of institutions and office buildings owned by the State (apart from the survey of Danish Defence's buildings, which is referred to elsewhere in the report) or the regions, but the view is that there is no reason to assume that the presence of PCB in these buildings should deviate significantly from that in the municipally owned buildings.

To make the results of the surveys conducted in the municipalities comparable, a decision was taken to perform the calculation at location level, e.g. a specific school or nursery school. An analysis of data from two municipalities indicates that the frequency determined at building level (where all buildings at the individual school are surveyed) will be approx. 20% lower.

The table below shows a comparison of the frequency of PCB in sealant at location level from the municipalities' surveys with the results of the ENS survey of public institutions.

As can be seen, higher levels were found in the ENS survey than in the municipalities' surveys. However, the difference between the results of the two surveys is not significant (*p* value of 0.24). The reason for the higher frequency in the ENS survey may be due to a slight overrepresentation of buildings which have not been renovated, but it may also be due to chance. Regardless of the reason, the much larger data set from the municipalities' surveys is deemed to provide the best basis for estimating the presence of sealants containing PCB in this building type.

Table 59 Comparison of the frequency of buildings/locations with ≥50 mg/kg in the two data sets.

	Entire country		
	Number of buildings/locations	Frequency	90% CI
Municipalities, locations	669		
≥0.1	202	30	27–33
≥50	96	14	12–17
≥5,000	58	9	7–11
ENS, buildings	57		
≥0.1	21	37	26–49
≥50	12	21	13–33
≥5,000	6	11	5–20

*1 90% confidence intervals (CI) calculated on the basis of a binomial distribution.

Since it is not possible to generate extracts from the OIS database at location level, in the sense of locations used in the municipalities' surveys, it is necessary to perform the calculation at building level with the moderate methodological uncertainty that is consequently introduced. It can be estimated on the basis of the existing knowledge that the frequency is 20% less when determined at building level, and a 90% safety interval is estimated by shifting the confidence intervals from the calculation at building level. This cannot be done using statistically exact methods, but the view is that the error will fall within the rounding of the results.

At the time the data were extracted, 171,804 public buildings and office buildings were registered in the OIS database, of which 44,587 were from the PCB period. Of these, 23,015 were registered as privately owned, while 21,572 were publicly owned.

Based on this, it is estimated that there will be 2,100–2,900 public institutions and offices with one or more materials containing PCB levels ≥50 mg/kg, and of these 1,200–1,800 with materials containing PCB levels ≥5,000 mg/kg.

*Table 60 Estimated number of public buildings in Denmark dating from the period 1950–1977 with sealants containing PCB *1.*

PCB_{total} in sealants, mg/kg	Buildings surveyed			Public buildings in Denmark from the PCB period		
	Number of buildings	Frequency	90% safety interval *2	Total number; see the OIS database	Number of buildings with PCB	90% safety interval
Number of buildings	669			21,572		
≥0.1	*3	24%	22–27%		5,200	4,700–5,700
≥50		11%	10–13%		2,500	2,100–2,900
≥5,000		7%	6–9%		1,500	1,200–1,800

*1 Values are indicated without decimal places but one decimal place is included in the calculation of the number of buildings, which is then rounded off.

*2 The term "safety interval" is used here to indicate that the interval was estimated on the basis of the confidence intervals calculated at location level.

*3 Data are only available at location level.

For paint and flooring, the results of the ENS survey are deemed to be more representative than the surveys from the municipalities, even though the number of buildings surveyed is much lower and the confidence intervals are wider as a consequence of this.

As can be seen in Table 61, it is estimated that 2,400–6,500 public institutions and offices will contain paint or flooring with PCB concentrations ≥50 mg/kg. There will be a significant overlap between buildings with sealant containing ≥50 mg/kg PCB and buildings with paint or floor compounds, so the total number of buildings with materials ≥50 mg/kg PCB will be less than the total. Since the two estimates are based on different data sets, it is not possible to create a combined estimate for all materials without further consideration.

Table 61 Estimated number of public buildings in Denmark dating from the period 1950–1977 with paint and flooring containing PCB.

PCB_{total} in all paint and floor compounds, mg/kg	Buildings surveyed			Buildings in Denmark from the PCB period		
	Number of buildings	Frequency	90% confidence interval	Total number; see the OIS database	Number of buildings with PCB	90% confidence interval
Number	57			21,572		
≥0.1	42	74%	62–83%		16,000	13,000–18,000
≥50	11	19%	11–30%		4,200	2,400–6,500
≥5,000	3	5%	1–13%		1,140	300–2,800

* Values are indicated without decimal places but one decimal place is included in the calculation of the number of buildings, which is then rounded off.

Office buildings

To make better use of the data set from the municipalities' surveys, it was decided to separate the data sets from the ENS survey for office buildings and public institutions respectively. This makes each data set smaller and the confidence intervals relatively larger but avoids any uncertainty about the representativeness. The office buildings are overwhelmingly privately owned but in some of the office buildings there may be a significant proportion in public ownership.

At the time the data were extracted, 171,804 public buildings and office buildings were registered in the OIS database, of which 44,587 were from the PCB period. Of these, 23,015 were registered as privately owned.

It can be estimated on the basis of the results that 4,900–11,000 private office buildings in Denmark will contain materials with PCB ≥50 mg/kg and of these 1,600–6,500 will contain materials with ≥5,000 mg/kg.

Table 62 Estimated number of private office buildings in Denmark dating from the period 1950–1977 with materials containing PCB.

PCB_{total} in all materials, mg/kg	Buildings surveyed			Buildings in Denmark from the PCB period		
	Number of buildings	Frequency	90% confidence interval	Total number; see the OIS database	Number of buildings with PCB	90% confidence interval
Number	36			23,015		
≥0.1	27	75%	60–86%		17,300	13,900–19,900
≥50	13	36%	23–51%		8,300	5,300–11,800
≥5,000	6	17%	8–30%		3,800	1,700–7,000

* Values are indicated without decimal places but one decimal place is included in the calculation of the number of buildings, which is then rounded off.

6.2 The number of buildings containing PCB in indoor air broken down by building types

The following section contains an estimate, based on the ENS survey, of how many buildings in Denmark are likely to have problems with PCB in indoor air. The calculations are based on the number of buildings constructed in the PCB period. Buildings constructed before this period will also to a certain extent have materials containing PCB as a consequence of renovation/extension and thus have elevated concentrations in indoor air, but there are no reliable data which can be used to estimate the extent of this.

A model based on the relationships between the PCB concentration in materials and indoor air that are described in section 4.3.7 was used in the calculations. The model is based on the following assumptions:

- The relationship between PCB in materials and indoor air can be described using the confidence ellipses described in section 4.3.7. The same ellipsis is used for all materials.

- The material distribution of the 352 buildings surveyed corresponds to that of all buildings in Denmark dating from the PCB period in each building type.

There is a certain amount of uncertainty associated with both assumptions, although it is difficult to estimate this accurately.

The total number of buildings with concentrations ≥300 ng/m^3 expected in the model is 15 for all building types. During the indoor air measurements, concentrations ≥300 ng/m^3 were measured in a total of 14 buildings, which indicates that the model calculations largely tally and that buildings with <50 mg/kg (in which indoor air measurements were not taken), as assumed in the survey strategy, will in total contribute a small number of buildings with ≥300 ng/m^3.

Detached and semi-detached houses

There are 154 detached and semi-detached houses distributed across the country which were surveyed for PCB in materials (described in detail in the previous section). Of these 154 houses, 20 buildings were selected that met the selection criteria applied to the taking of indoor air measurements (section 2.3.5) and of these, PCB in indoor air was measured in 15, while five building owners did not wish to participate. The frequency of detached and semi-detached houses with materials that have PCB concentrations ≥50 mg/kg is, as shown elsewhere in the report, significantly lower than the frequency of blocks of flats, offices and public institutions.

When the data extract was performed there were 1,444,077 detached and semi-detached houses registered in the OIS database, of which 588,691 (41%) dated from the PCB period.

It can be estimated on the basis of OIS data and the results of the model calculations that the number of detached and semi-detached houses with PCB concentrations ≥300 ng/m^3 in indoor air in at least one room is 19,300–22,800 (90% prediction interval). Of these, 390–810 will have PCB concentrations ≥3,000 ng/m^3 in indoor air in at least one room. The estimate is based on the model for the relationship between PCB in indoor air and materials and the concentrations found in materials in the 154 buildings surveyed.

Table 63 Estimated number of detached and semi-detached houses in Denmark dating from the period 1950–1977 with PCB levels in indoor air above 300 ng/m^3.

PCB_{total} in indoor air, ng/m^3	Buildings surveyed		Buildings in Denmark from the PCB period		
	Number of buildings	Frequency of surveyed for indoor air*	Number of buildings in Denmark, cf. the OIS database	Expected number with PCB	90% prediction interval
Number of buildings	14		588,691		
Number of buildings, materials surveyed	154				
≥300	1	7%		21,000	19,300–22,800
≥300–2,000	1	7%		19,800	18,400–21,300
≥2,000–3,000	0	0%		610	460–730
≥3,000	0	0%		610	390–810

Blocks of flats

The survey covered PCB in materials in 105 blocks of flats from 52 local office districts in five towns (see more detailed explanation in the previous section). Of these 105 blocks of flats, 31 properties were selected that met the selection criteria applied to the taking of indoor air measurements (section 2.3.5) and of these, PCB in indoor air was measured in 20, while one housing association with 11 properties selected did not wish to participate.

When the data extract was performed, a total of 89,832 blocks of flats were registered in the OIS database, of which 14,928 (17%) date from the PCB period.

It can be estimated on the basis of OIS data and the results of the study that the number of blocks of flats with PCB concentrations ≥300 ng/m^3 in indoor air in at least one room is 610–800 (90% prediction interval), of which 7–31 have PCB concentrations ≥3,000 ng/m^3. No measurements ≥3,000 ng/m^3 were taken in any of the blocks of flats surveyed, but the estimate is based on the model for the relationship between PCB in indoor air and materials and the concentrations found in materials in the 105 properties surveyed.

Table 64 Estimated number of blocks of flats in Denmark dating from the period 1950–1977 with PCB levels in indoor air above 300 ng/m^3.

PCB_{total} in indoor air, ng/m^3	Buildings surveyed		Buildings in Denmark from the PCB period		
	Number of buildings	Frequency of surveyed for indoor air*	Number of buildings in Denmark, cf. the OIS database	Expected number with PCB	90% prediction interval
Number of buildings	20		14,928		
Number of buildings, materials surveyed	105				
≥300	1	5%		700	610–800
≥300–2,000	1	5%		660	580–750
≥2,000–3,000	0	0%		21	11–33
≥3,000	0	0%		18	7–31

Public buildings

The results of the ENS survey confirm the relatively high frequency of PCB in indoor air in this building category, which was observed in the municipalities' surveys of 507 locations. Due to differences in the selection of buildings, it was decided not to combine these results, as this would not have had a significant influence on the estimated confidence intervals.

At the time the data were extracted, 171,804 public buildings and office buildings were registered in the OIS database, of which 93,724 were publicly owned. Of these, 21,572 were from the PCB period. On the basis of this and the frequencies observed in municipal properties and the calculated confidence intervals, Table 65 shows the number of public institutions and office buildings that could contain PCB in indoor air at levels higher than a number of relevant concentrations. When converting from frequencies at location level to building level, it is assumed that the frequency at building level is 20% lower; see section 5.1. The safety intervals for the estimates are also assumed to be 20% lower than the confidence intervals. This conversion cannot be performed using exact statistical methods, but the uncertainty of the conversion is deemed to fall within the rounding of the values to whole numbers.

The frequency of buildings with ≥300 ng/m^3 is 5.6% calculated at building level (90% confidence limits: 4–8%). The model calculations, which are worked out on the basis of the ENS survey results, provide an expected frequency of 5.8% (90% prediction limits: 5.0–6.6%). For the interval ≥3,000 ng/m^3 an expected frequency of 0.3% is obtained (90% prediction limits: 0.2–0.6%). Consequently the results of the two studies appear to correspond closely. The narrower prediction intervals compared to the 90% confidence intervals for the somewhat larger data set from the municipalities' surveys is somewhat surprising and may indicate that the prediction intervals do not reflect all the model uncertainty, something which is discussed in more detail in section 4.3.7.

It is estimated on the basis of the municipalities' surveys that there will be 900–1,600 public buildings in Denmark with PCB concentrations in indoor air higher than the Danish Health and Medicines Authority's lowest recommended action value of 300 ng/m^3. The highest recommended action value of 3,000 ng/m^3 is estimated to be exceeded in 20–200 buildings.

Table 65 Estimated number of public buildings in Denmark dating from the period 1950–1977 with PCB levels in indoor air above 300 ng/m^3.

PCB_{total} in indoor air, ng/m^3	Locations surveyed *1			Buildings in Denmark from the PCB period *3		
	Number of locations	Frequency *2	90% confidence interval	Number of buildings in Denmark, cf. the OIS database	Number with PCB	90% safety interval
Number of buildings	507			21,572		
≥300	35	7%	5-9%		1,200	900-1,600
≥300-2,000	28	6%	5-6%		900	800-1,100
≥2,000-3,000	5	1%	0.5-1.4%		170	90-200
≥3,000	2	0.4%	0.1-1.2%		100	20-200

*1 Data are only available at location level, i.e. entire institutions and not individual buildings.

*2 Values are indicated without decimal places but one decimal place is included in the calculation of the number of buildings.

*3 When calculating the number of buildings, it was assumed that frequencies of buildings are approx. 20% lower than the specified frequency at location level (see detailed description in section 5.1). The concept of "safety interval" is used here to indicate that the interval has been estimated on the basis of the confidence intervals calculated at location level.

Office buildings

The survey covered PCB in materials in 36 private office buildings. Of these 36 office buildings, 13 properties were selected that met the selection criteria applied to the taking of indoor air measurements (section 2.3.5) and of these, PCB in indoor air was measured in 12, while one building owner did not wish to participate.

At the time the data were extracted, 171,804 public buildings and office buildings were registered in the OIS database, of which 78,080 were privately owned. Of these, 23,015 were from the PCB period.

It can be estimated on the basis of OIS data and the results of the study that the number of office buildings with PCB concentrations ≥300 ng/m^3 is 740–1,070 (90% prediction interval). Of these, 6–33 will have PCB indoor air concentrations ≥3,000 ng/m^3.

The expected number is relatively small in terms of the number of office buildings in which PCB in indoor air was measured. This is related to the fact that in the case of most of the measurements high values in indoor air were found by chance when there were relatively low concentrations in materials, and these will therefore not be reflected in the model calculations.

Table 66 Estimated number of office buildings in Denmark dating from the period 1950–1977 with PCB levels in indoor air above 300 ng/m^3.

PCB_{total} in indoor air, ng/m^3	Buildings surveyed		Buildings in Denmark from the PCB period		
	Number of buildings	Frequency of surveyed for indoor air*	Number of buildings in Denmark, cf. the OIS database	Expected number with PCB	90% prediction interval
Number of buildings	12		23,015		
Number of buildings, materials surveyed	36				
≥300	5	42%		900	740–1,070
≥300–2,000	0	0%		870	720–1,020
≥2,000–3,000	0	0%		24	10–40
≥3,000	0	0%		18	6–33

6.2.1 The number of schools with PCB in indoor air

In the municipalities' surveys it was found that there was a very high presence of PCB in indoor air in schools, and for this reason a special calculation was performed for schools, which are also included as a sub-group in the above calculation for public buildings

According to the Danish Ministry of Education and Children's register of institutions1, there were 1,318 public schools, 537 free schools and private primary schools, 265 continuation schools, 184 special schools for children and 240 day treatment facilities in 2012, making a total of 2,544 schools.

The results from the municipalities largely concern only public schools. Some of the schools surveyed may, however, be municipally owned special schools. For this reason, the initial calculation of the number of schools which might contain PCB in sealant and indoor air only included public schools, but it may be assumed that PCB is likely to be present in the other types of schools.

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1 http://www.uvm.dk/Uddannelser-og-dagtilbud/Paa-tvaers-af-uddannelserne/Institutionsregister

The register of institutions does not indicate a year of construction for the buildings so data on year of construction have therefore been extracted from the OIS database. An extract was taken in which the use code “Building for teaching and research” was combined with the use code “Other municipal property (school, town hall, etc.)”. This produced a list of 8,910 buildings in 2,448 locations (which are approximately equal to institutions). An attempt was made to combine address details from the OIS database with address details from the register of institutions in order to determine which of the institutions are public schools. However, this proved to be a major task due to differences in the listed addresses, and it has not been possible to resolve these database differences within the framework of preparing this report.

It was thus decided to make a more uncertain estimate. Of the 8,910 buildings in the extract from OIS, 4,537 (51%) were constructed in the PCB period. Of the 2,448 locations there are one or more buildings dating from the PCB period in 1,669 locations, corresponding to 68% of the locations.

If it is assumed that there are one or more buildings dating from the PCB period in 68% of the 1,318 public schools, then there will be approx. 900 public schools with buildings from the PCB period. In order to take the uncertainty into account, the interval 700–1,100 is used in the calculation below. In light of this, it can be estimated, as shown in the table, that there will be rooms with ≥300 ng/m^3 in 60–210 public schools, while rooms with ≥3,000 ng/m^3 will be found in up to 60 public schools.

As mentioned previously, the results from the municipalities’ screenings cannot be assumed to be representative of the other 1,226 primary schools, where the presence of PCB may very well correspond more closely with the presence in other public institutions. The calculation of the total number of schools with PCB therefore assumes greater uncertainty for the other primary schools. As a consequence, it is assumed that 6–39% of the other primary schools contain sealant with ≥5,000 mg/kg and that there will be rooms with ≥300 ng/m^3 in 5–19% of the other primary schools. Note that these intervals are based on expert estimates and not on exact statistical methods.

If it is assumed that there are one or more buildings dating from the PCB period at around 68% of the locations, the number of other primary schools can be estimated at 650–1,230 schools.

On this basis, the total number of primary schools with sealant in concentrations ≥3,000 ng/m^3 can be estimated at 0–60, while the number of primary schools where there will be rooms with ≥300 ng/m^3 k can be estimated at 60–210.

Table 67 Estimated number of public schools with PCB in indoor air in Denmark.

PCB_{total} in ng/m³	Number of schools with PCB	Number of schools surveyed	Frequency	90% interval	Estimated number of public schools in Denmark with PCB (rounded)
Indoor air ≥30 ng/m³	54	130	42%	34–49%	240–540
Indoor air ≥100 ng/m³	29	130	22%	16–29%	110–320
Indoor air ≥300 ng/m³	17	130	13%	9–19%	60-210
Indoor air ≥2,000 ng/m³	6	130	5%	2–9%	10–100
Indoor air ≥3,000 ng/m³	2	130	2%	0–5%	0–60

6.3 Summary and partial conclusion

The number of buildings with PCB in sealant, paint or flooring

Based on the results of the ENS survey and a number of surveys in municipalities across the country, the total numbers of buildings in Denmark which contain paint, sealant and flooring with PCB concentrations ≥0.1 mg/kg, ≥50 mg/kg and ≥5,000 mg/kg respectively have been estimated as shown in the following table.

Table 68 Proportion and number of buildings in Denmark dating from the PCB period which contain PCB in sealant, paint or flooring.

Building type	Proportion and number of buildings in Denmark from the PCB period with materials over the specified concentration (90% confidence interval)		
	≥0.1 mg/kg	≥50 mg/kg	≥5,000 mg/kg
Detached and semi-detached houses	390,000–470,000 67–79%	80,000–140,000 13–24%	20,000–60,000 4–11%
Blocks of flats	12,600–14,100 84–95%	3,600–5,900 24–40%	1,000–2,700 7–18%
Private office buildings	13,900–19,900 60–86%	5,300–11,800 23–51%	1,700–7,000 8–30%
Public institutions and office buildings*	In sealants 4,700–5,700 22–27% In paint and flooring 13,000–18,000 62–83%	In sealants 2,100–2,900 10–13% In paint and flooring 2,400–6,500 11–30%	In sealants 1,200–1,800 6–9% In paint and flooring 300–2,800 1–13%

* There is an overlap for many buildings, with some buildings containing both sealants and paint at concentrations ≥50 mg/kg PCB; hence the total number of buildings containing one of the materials is significantly less than the sum of the two intervals.

The available data for PCB in indoor air are summarised in the following table, which presents the number of buildings within each building type which are estimated to contain one or more rooms contaminated with PCB at various concentration levels. It has not been investigated how many rooms in the individual buildings were contaminated above the specified level.

As mentioned previously, the model is considered to be very robust as regards the aforementioned mean values. The prediction intervals are surprisingly narrow, and it is possible that some uncertainty must be attached to the model assumptions, in particular the fact that the relationship between PCB in materials and indoor air was considered collectively for all materials and it was assumed that the 354 buildings in which PCB was measured in materials are representative of all the buildings in the country within the building types concerned. However, it is not possible to take account of this additional uncertainty in any precise way, which may well mean that the uncertainty intervals will be twice the stated intervals.

The table also shows the proportion of all buildings (not only those from the PCB period) for each building type containing PCB in indoor air at various concentration levels. The calculation does not take into account the fact that some of the buildings constructed before the PCB period may contain PCB in materials which were added during the PCB period and may give rise to PCB in indoor air. There will therefore be a tendency for the proportions to be underestimated, yet there are no data to indicate the extent of this underestimation.

Table 69 Estimated number of buildings with PCB in indoor air (90% prediction interval, rounded values).

	Number of buildings from the PCB period (90% prediction interval)			Proportion of all buildings (90% prediction interval) *3		
	≥300 ng/m^3	300–3,000 ng/m^3	≥3,000 ng/m^3	≥300 ng/m^3	300–3,000 ng/m^3	≥3,000 ng/m^3
Detached and semi-detached houses	19,300–22,800	18,900–22,000	390–810	1.3–1.6%	1.3–1.5%	0.03–0.1%
Blocks of flats *1	610–800	590–750	7–31	0.7–0.9%	0.7–0.9%	0.01–0.03%
Public institutions and office buildings as well as private office buildings *2	1,600–2,600	1,600–2,400	30–230	0.9–1.5%	0.9–1.4%	0.02–0.14%

*1 Note that it is the number of blocks of flats that is specified, not the number of flats, which is at least 10 times greater.

*2 Intervals for this building type indicate 90% confidence intervals.

*3 Stated as a percentage for all buildings in Denmark, not just buildings from the PCB period. Note that there is a difference between the building types as regards the proportion of the total building stock erected during the PCB period.

7 Residual amounts of PCB in building materials

The residual amounts of PCB in buildings are calculated in the next section. The calculations for sealant, flooring and paint only include the three building categories surveyed, collectively referred to as the "building stock". The estimates thus do not encompass industrial buildings or industrial facilities, warehouses, agricultural buildings (apart from farmhouses) or other commercial buildings which are not grouped with office buildings. With regard to paint and flooring, there may very well be a relatively higher presence of PCB in industrial buildings and industrial facilities that is not included in the calculated amounts.

Estimates for capacitors and sealed glazing units encompass all building types, so there is some inherent inconsistency in adding the figures together. No attempt has been made to correct for the fact that the amounts apply to all building types.

7.1.1 Residual amounts of PCB in sealant, paint and flooring

Sealants

The survey report from 1983 estimates the total amount used for sealant at 80–120 tons (Hansen, 1983). There is no information on how consumption was distributed between sealant joints around windows and doors and those between concrete elements.

– sealant joints around windows and doors

Estimates of the amount of residual PCB in sealant around windows and doors have been produced before. Gunnarsen et al. (2009) calculated the residual amount to be 5.6 tons, stated as the sum of analysed congeners and based on a mean value of 2,100 mg/kg for the analysed congeners. PCB_7 accounted for around 50% of the congeners examined. If these 5.6 tons are denoted as PCB_{total}, with the calculation method used in the ENS survey, this corresponds to approx. 14 tons.

Based on a questionnaire it was determined that 61% of buildings dating from the PCB period did not have replacement windows at the time in question (around 2006). The present study contains verified information that windows have been replaced in approx. 50% of the buildings, while the actual proportion with replaced windows is presumably somewhat higher.

Potentially up to around half of the original amount of PCB used around windows and doors may still be present in the buildings, but the total amount will probably be somewhat lower.

In this study, the estimate of the residual amount is based on the proportion of buildings in which PCB was found in the sealant, the average presence and the potential amount of sealant.

The total area of buildings from the period, based on the extract from the OIS database, is determined to be 142 million m^2, which is one million less than that used in Gunnarsen et al. (2009). It is assumed that there is 0.46 m of sealant per m^2, and that the sealant, if it is an elastic sealant, weighs 0.2 kg/metre (Gunnarsen et al., 2009). In Gunnarsen et al. (2009), it is also assumed that 0.46 m of sealant per m^2 is used internally. Most of the buildings surveyed in the ENS survey did not have sealant around the windows internally. The 0.46 m of sealant per m^2 indicates what there could potentially be if all the windows had internal sealant joints; the estimate is based on how many of the buildings actually contain elastic sealant and how many of the windows in these buildings have sealant containing PCB.

These calculation assumptions for a building with a floor area of 100 m^2 with internal and external sealant joints containing 200,000 mg/kg PCB mean the building could contain a total of approx. 4 kg PCB. For the purposes of comparison, the same building, if there are around 12 m^2 of sealed glazing units corresponding to approx. 10 windows with a glazed area of 1.2 m^2 fixed with sealant adhesive containing PCB, could contain around 700 g PCB in the sealed glazing units.

In 82 of the buildings (33% of all buildings), samples were taken of external elastic sealant joints around windows and doors, while samples of internal sealant joints were taken from 48 buildings (14%). There was a high proportion of buildings with flexible sealant, but samples were not taken around replaced windows because the focus has been on primary sources. The average content of all the sealant samples was 18,456 mg/kg (199 samples) and 3,322 mg/kg (130 samples) respectively for external and internal sealant joints. This average covers a broad interval as discussed in section 3.1.4. In the table below the average is stated with uncertainty. The largest amount of PCB is represented by sealants containing more than 100,000 mg/kg. They accounted for 8% of the samples of external sealants and 2% of the samples of internal sealants. However, greater uncertainty is introduced if only sealants with a high level of PCB are included because there is more uncertainty about the representativeness of the samples; the total amount will also be a slight underestimate.

The greatest uncertainty is associated with how many of the sealants in the individual buildings were identical to the samples taken. Samples of the different types of sealant in the buildings were taken during the sampling process. For example, 199 samples were taken externally from the 82 buildings. Using the mean values takes into account to a certain extent the fact there is variation within each building. However, there are several buildings for which it is stated that the sample was taken from around certain windows which have not been replaced and that the sealant around the other windows in the building is newer. For others the length of the sealant bead was recorded, and it can thus be determined how many metres of sealant per m^2 of building floor area are represented by the samples. The data do not permit an exact determination of the proportion of the buildings' sealant that is represented by the samples taken, but it is estimated to be around 30–50% for the external sealant joints. The internal sealant joints are not necessarily located around windows; they may also be around interior doors. It is estimated that the average of the samples taken corresponds to 0.05–0.15 m of sealant per m^2 of floor plan, which per m^2 is somewhat less than for the exterior ones.

As is apparent from the table below, it is first and foremost the exterior windows and doors that represent the high amounts of PCB. On this basis, the total amount of PCB is estimated to be 7–35 tons.

Table 70 Estimated amount of PCB in sealant around windows and doors.

Built-up area, million m^2	142
Metres of sealant per m^2, outdoors, regardless of type	0.47
Metres of sealant per m^2, indoors, potentially regardless of type	0.47
Weight of sealant, kg/metre	0.2
Proportion of buildings sampled, outdoors	33%
Proportion of buildings sampled, indoors	14%
Mean concentration sampled, outdoors, mg/kg	11,000–26,000
Mean concentration sampled, indoors, mg/kg	2,000–3,300
Proportion of sealant in the building represented by those sampled, outdoors	0.2–0.4
Proportion of sealant in the building represented by those sampled, indoors	0.1–0.3
PCB amount in tons, outdoors	7.2–33.9
PCB amount in tons, indoors	0.3–1.4
In total	7.4–35.2

For sealant joints between concrete elements or between concrete and masonry it is more difficult to estimate the total amount since the potential for sealant is unknown. The largest quantities of PCB were found in sealant containing ≥5,000 mg/kg, which on average contained around 110,000 mg/kg. Such sealant was found outdoors in 15 buildings (6% of all buildings) and indoors in six buildings (2%). Sealant joints with the high concentrations of PCB between other building components were thus found in a higher proportion of the buildings than sealant joints with high concentrations around doors and windows. In many cases, however, there were only modest amounts in the building concerned. Measurements of sealant length are available for some of the buildings, but the data are insufficient to provide a reasonable estimate of the number of metres of sealant per m^2 of building area. For this reason, the Danish Construction Association and people in the sealant industry with many years of experience were contacted. According to someone who has been in the industry since PCB was in use, more than 80% of elastic sealants were used around windows and doors during the period from the mid-1960s to 1977. At that time it was common practice to use sealant tape or so-called fir tree plugs between concrete elements externally and to cast the elements together internally. That is why it is believed that the residual amounts of PCB in sealant between concrete elements and other building components will be considerably less than the residual amounts in sealant around windows and doors. A rough estimate of the amount involved is 2–15 tons PCB.

In 2009, the residual amount of PCB in sealant for all purposes in Norway was estimated at 22 tons (Techno Consult, 2009). The size of the building stock in Norway is largely the same as in Denmark.

Paint

The total amount of PCB used in the production of paint and varnish in Denmark is estimated to be 130–270 tons, of which 160 tons were used before 1970.

The largest areas to which paint was applied were metal surfaces, for which there are strict requirements for resistance to chemical effects. Examples here include anti-fouling paint on ships and acid-proof surface finishing on industrial equipment. There is no indication of how much has been used for paint in buildings. In Norway, it is assumed that half of the PCB in paint has been used for ships, while the other half has been used in construction, steel structures and in industry. It is not known how much of it has been used in construction.

Since painted surfaces in buildings are often painted over and rarely replaced, it must be assumed that a significant proportion of the PCB used for painted building components will still be present in the building stock, even if some has dissipated due to wear and tear.

During the sampling process, samples were taken of all the paint, covering both paint applied in the PCB period and paint applied later on.

According to information provided by the paint industry, floor paint or facade paint is typically applied in quantities of 75–170 g/m^3. Over time a number of layers are applied, and some of the paint comes off due to wear, peeling and the surface being sanded before a new layer is applied. In this instance, it is assumed that over time 40–60% of the paint applied comes off. For buildings constructed during the PCB period, there may very well be 5–10 layers of paint and this is where we assume 6–8 applications, of which several may involve paint containing PCB. Consequently we have assumed that painted surfaces in buildings dating from the period will weigh 270–544 g/m^2, corresponding to an average layer of paint being 0.3–0.5 mm thick. There will often be thicker layers, while in other cases quite a lot of the paint will have peeled off, resulting in a thinner layer.

Areas of the expected primary sources in the rooms were measured in connection with indoor air measurements. It can be calculated that in 40 rooms (not the entire building) with painted surfaces as the most important source there was a total of approx. 25–50 g PCB in the paint. In two detached and semi-detached houses, with the highest content, there were 150–300 g (5 m^2 room) and 60–130 g (22 m^2 room) PCB respectively in the paint in the room. In relation to the calculated 4 kg that could potentially be present in a 100 m^2 house with sealant containing PCB, the total amounts in the paint are still significantly less. A single office building had 220–450 g PCB in paint in a 50 m^2 room.

An estimate based on mean values found in paint was made in order to gain an indication of the amounts of PCB. Samples of interior paint on floors or walls were taken in 52% of the buildings. The average concentration in 526 samples was 144 mg/kg. Some of this amount will be a tertiary presence, but it is not possible to accurately distinguish between the different types of sources.

Indications of m^2 of painted surfaces do not permit a precise calculation, particularly for larger buildings, but it is estimated that in the buildings from which samples were taken there will be around 5–15 m^2 per 100 m^2 of building area.

As can be seen below, with these assumptions the total amount will be in the region of 0.1–1.1 tons PCB.

Table 71 Estimated amount of paint on interior floors and walls.

Amount applied on each occasion, g/m^2	75–170
Number of applications	6–8
Percentage sanded off and abraded off	0.4–0.6
Residual amount, g/m^2	270–544
Built-up area, million m^2	143
Proportion of buildings with painted interior floors and walls	0.4–0.6
m^2 painted surface per 100 m^2 building	0.1–0.2
Area of painted surfaces represented by the samples, million m^2	2.9–12.9
Weight of paint represented by the samples, tons	772–7,001
Average PCB in painted floors, mg/kg	130–155
Total amount of PCB, kg	0.1–1.1

Samples of exterior paint on walls and bases had a mean of 182 mg/kg in 147 samples from 69 buildings (20% of the buildings). PCB was typically found in paint on bases and balconies but only in a few cases on the entire facade. In light of this it is estimated that the total amount of PCB in the exterior paint on facades and bases is barely any higher than in the interior paint estimated above.

The highest concentrations were found on metal located outside. In 66 samples from 33 buildings (9%) on average 1,906 mg/kg was found. These typically concerned railings and iron gratings and the surfaces were not measured precisely. As a rough estimate, it has been assumed that in 9% of the buildings there will be 0.5–3 m^2 per 100 m^2 building (= a balcony railing for a flat). With the same assumptions as those indicated in the table above, the total amount of PCB can be estimated at 0.1–3.2 tons. The painted metal objects found outdoors may thus very well represent a higher amount than that for interior painted floors and walls.

Based on the above calculations, a rough estimate of the total amount of PCB in paint in the building stock is 0.3–5 tons. The estimate is unreliable but the residual amount of PCB in paint is judged to be significantly less than in sealants.

In 2009, the residual amount of PCB in paint for all purposes in Norway was estimated at 7 tons (Techno Consult, 2009). It was not determined how much of it was specifically used in buildings.

Flooring

Floor compounds, flooring or adhesives for flooring materials containing PCB are not mentioned in the survey report from 1983. In Norway significant amounts of PCB have been used in mortar additives, for various purposes including flooring of different types. The Danish survey from 1983 states that such use is unknown in Denmark.

As is apparent from section 3.1.5, in 52 samples of floor compound a mean of 1,061 mg/kg was found, while in flooring itself a mean of only 47 mg/kg was found in 62 samples. Measurements of 86 samples of floor adhesives showed a mean of 15 mg/kg, which suggests that the adhesive is definitely not the most important source of PCB in flooring. Most of the PCB found in flooring may very well be a tertiary presence.

A total of 62 samples were taken from flooring in 36 buildings (10% of all buildings). The rooms are typically kitchens, storage rooms, classrooms and basement rooms. It is estimated that in the buildings from which samples were taken 5–15 m^2 of flooring can be found per 100 m^2 building. The measurements represent an average concentration for all the material, which will typically weighs 2.5–3 kg/m^3. Consequently the total amount in flooring can be estimated in the region of 0.06–0.6 tons. As mentioned previously, the majority of this may very well represent a tertiary presence of PCB.

The largest amounts in floor compounds were found in five samples with high concentrations (2,400–23,500) from basements in five buildings (1.5% of all buildings), while the floor compounds in the other buildings contained less than 50 mg/kg. In all cases it was established in the subsequent inspection carried out in connection with the indoor air measurements that it was presumably floor paint that was measured. However, due to the few samples and the uncertainty surrounding how much of the PCB measured actually originated from the underlying concrete/floor compound, there is no basis for a more accurate estimate of the amounts involved.

A rough estimate of the total amount of PCB in flooring will thus be in the region of 0.1–2 tons.

7.1.2 Residual amounts of PCB in sealed glazing units

As is apparent from that discussed earlier in the report, around 31% of the sealed glazing units collected at the recycling centres dated either from the PCB period or from an unknown period. Of these, 34% contained PCB at levels above 50 mg/kg in the sealant adhesive.

There are no Danish figures for how many sealed glazing units are disposed of annually or how many sealed glazing units from the PCB period are still in place in buildings.

There is a system for collecting sealed glazing units in Norway called Ruteretur (literally “window return”), thereby providing a good statistical basis for assessing residual amounts. In the period 2006–2010, around 70,000 sealed glazing units were collected each year, but in 2011 and 2012 this figure fell to 50,000 (Ruteretur, 2012a). The amount of PCB is estimated to be just over 3 tons. This decline is partly due to a fall in the total numbers of sealed glazing units classed as waste, but also due to Ruteretur becoming more efficient at only receiving windows dating from the PCB period in the system. The Norwegian statistical data do not reveal how many sealed glazing units are not collected by Ruteretur because they were made outside of the PCB period.

Sealed glazing units which upon replacement are installed in a window frame where there used to be PCB present could be contaminated by the secondary presence of PCB in the window frame itself.

The analysis results available on the Ruteretur website show that there is PCB >50 mg/kg in 43% of the windows collected. This corresponds very well with the fact that in the ENS survey ≥50 mg/kg was found in 34% of the windows surveyed. The average concentration in the Norwegian sealed glazing units containing ≥50 mg/kg was 51,000 mg/kg, compared to 120,000 mg/kg in the ENS survey. Only one of the sealant adhesives examined in Norway contained more than 200,000 mg/kg. However, the lower values found in the Norwegian analyses may be related to the method of calculating PCB_{total}, which is not stated. Yet the available data suggest that the situation in Denmark is reasonably comparable to that in Norway.

Of the windows known to date from the period 1965–1974, concentrations ≥50 mg/kg were found in 80% of the windows, while concentrations ≥50 mg/kg were found in 10% of the windows dating from 1975–1980.

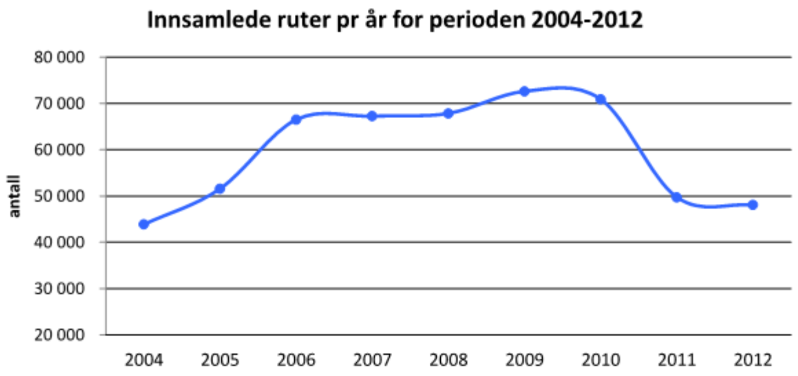

Figure 47 Windows collected via Ruteretur in Norway during the period 2004–2012 (Ruteretur, 2012a).

It is estimated that in Norway in 2012 there were around 220,000 sealed glazing units containing PCB still in place with a total content of 15 tons, corresponding to around 10% of the numbers originally installed. Based on these figures it can be estimated that on average each sealed glazing unit contains approx. 68 g PCB (and thus is just over 1 m^2) (Ruteretur, 2012b). An earlier Norwegian study from 2004 assumed that the average content was around 63 g in the sealed glazing units containing PCB (Ruteretur, 2004).

If the Norwegian empirical figure of 65 g PCB per window and an estimated consumption in Denmark of 86–100 tons are used, this means that a total of 1.3–1.5 million sealed glazing units containing PCB have been installed in Denmark. It is estimated that the total consumption of PCB in sealed glazing units in Norway was 140–150 tons, i.e. slightly higher than the original estimated consumption in Denmark, but just under the level of consumption estimated in Environmental Project no. 1084 from 2006.

One difference between the Danish and Norwegian situations could be that the windows do not last as long in Denmark due to the damp winters, but there is no information on average service life for sealed glazing units in the two countries.

No new statistics have been found on the number of sealed glazing units disposed of each year in Denmark. In a report from 1997 it is estimated that each year 25,000 tons of window glass are disposed of due to window replacement (23,000 tons of which come from the replaced windows, with 2,000 tons originating from demolitions) (Demex, 1997). Of this figure, 50% is calculated to originate from double-glazed windows (primarily sealed glazing units). According to the calculation assumptions in the report, these 25,000 tons correspond to approx. 1,600,000 m^2 (15.6 kg/m^3 for removed windows), of which approx. 50% corresponds to 800,000 m^2 of glass in dual pane windows. This is equivalent to approx. 400,000 m^2 in sealed glazing units.

If it is assumed that a similar amount exists today and that 12% of the sealed glazing units disposed of contain PCB ≥50 mg/kg, this is equivalent to a total of 48,000 m^2. With a PCB content of 37–47 g/m^2 (sum of sealant adhesive and sealant tape) the total amount of PCB disposed of could be estimated at 1.7–2.2 tons/year, although given the uncertainty of the data this amount is set at 1–3 tons/year. This figure is lower than the estimated amounts of PCB disposed of in sealed glazing units in Norway, but should be assumed to be around the same size, albeit with some uncertainty.

The Norwegian figures suggest that the amounts collected in 2012 correspond to approx. 22% of the residual amount. If the same figures are assumed for Denmark, the residual amounts in sealed glazing units can be calculated at 5–15 tons PCB. Given the uncertainties in the calculations, the amount will be estimated to fall within the interval 5–13 tons. The available data thus suggest that the residual amounts of PCB in Denmark are very similar to those in Norway.

7.1.3 Residual amounts of PCB in light fittings

As already mentioned, the survey report from 1983 estimates on the basis of Norwegian experience the accumulated consumption of small capacitors containing PCB in Denmark to be 8.5 million in the period 1950–1980, 90% (7.7 million) of which were used in fluorescent lamps. In the report it is assumed that consumption peaked at around 500,000 light fittings per year and that consumption fell steadily from 500,000 light fittings per year in 1971 to 0 in 1981. If the consumption was evenly distributed over the period, this would correspond to approx. 255,000 fluorescent lamps a year. Total PCB consumption in Denmark of small capacitors during the period 1950–1980 was estimated in the report to be 175–325 tons. In the estimate it is assumed that on average the capacitors contained approx. 30 g PCB.

The results of this study show that around 9% of the 516 fluorescent lamps collected at two electronic waste companies (480) or end-of-life light fittings found elsewhere (36) contained >100,000 mg/kg PCB in the insulating oils. These capacitors represent more than 99.9% of the total number of capacitors.

In Norway it was estimated that in 2008 there would still be around 8 tons PCB in light fittings (Techno Consult, 2005). Light fittings refers to fluorescent lamps, neon signs and mercury vapour lamps.

To get an idea of the historical use of fluorescent lamps and a distribution in the period 1950–1980, key figures from the Association of Manufacturers and Importers of Electrical Lighting Fittings, FABA (2013) were obtained for the study. According to the industry, the general approach is to have one light fitting for every 6 m^2 in office buildings and institutional buildings, while fewer than this have been used in other types of buildings. Office and institutional buildings are assumed to account for most of the usage of fluorescent lamps. According to the

OIS database, there is currently a total of 36 million m^2 in office and institutional buildings constructed in this period. If a figure of 6 m^2 per light fitting is assumed, this corresponds to 7.0 million light fittings. Since fluorescent lamps have also been used in private homes, in agriculture and in industry, the total number will actually be somewhat higher. Compared to the 8.5 million PCB capacitors mentioned above, the estimates could indicate that the vast majority of capacitors dating from the period did contain PCB, which corresponds well with what is stated in the literature. The stated number of m^2 rose during the period from 480,000 m^2/year in 1950–1954 to 2.1 million m^2/year, when construction reached a peak in the period 1970–1974. The period 1960–1980 thus accounts for 86% of the total number of m^2 in the period 1950–1980. Based on this calculation, around 350,000 light fittings a year would have been installed in office and institutional buildings in the period 1970–1974; when other applications are also taken into account, this figure corresponds well with the fact stated above, i.e. that peak consumption saw 500,000 PCB capacitors per year in use. As an average for the period 1970–1990, from which most of the equipment that is now being disposed of dates, it can be roughly assumed that a total of 300,000–400,000 light fittings per year were installed.

If it is assumed that 300,000–400,000 fluorescent lamps are disposed of annually, and that 9% of these contain PCB levels >100,000 mg/kg, this gives a figure of 27,000–36,000 light fittings. If these on average contain 30 g PCB, this gives a total amount of 0.8–1.1 tons PCB.

To calculate how many remain if around 30,000 light fittings with capacitors containing PCB levels >100,000 mg/kg are currently being disposed of, it is necessary to know the service life distribution for the equipment and the historical consumption.

The distribution of the historic consumption will be estimated by distributing the 7.6 million PCB capacitors assumed to be used for fluorescent lamps over the period 1950–1980 with the starting point being the area of institutional and office buildings in constructed m^2. The distribution of other types of building is almost identical to that of institutional and office buildings, which were discussed in the Phase 2 report for this project. The number of constructed m^2, based on extracts from the OIS database, is shown in the table below together with the estimated numbers of fluorescent lamp fittings.

Table 72 Assumed distribution of fluorescent lamps containing PCB.

	1950–1954	1955–1959	1960–1964	1965–1969	1970–1974	1975–1980
Constructed institutional and office buildings, m^2	2,413,210	3,576,401	5,964,049	8,200,142	10,389,863	11,677,568
Light fittings containing PCB, pcs	485,829	720,003	1,200,685	1,650,857	2,091,692	2,350,934

No estimates were found for the actual service life distributions of fluorescent lamps. A so-called Weibull distribution is often used for electronic components and electronic products to describe the service life distribution. The distribution is defined by two parameters: α, which expresses where the peak distribution is located, and β, which is dependent on the mean service life but not completely identical to it. In practice, however, it is often not only the technical service life that determines the service life of a product but also a number of other factors – e.g. its replacement for aesthetic reasons. This can be modelled using composite Weibull distributions. This is not an exact model, rather an attempt to describe the reality as closely as possible. The advantage of using Weibull distributions is that it is easy to alter the distribution in order to find the best distribution to explain actual observations and illustrate the spread of possibilities. The use of such composite distributions to estimate waste quantities, together with a detailed description and discussion of the method, can be found in a report published by the Danish Environmental Protection Agency in 2002 (Lassen and Heilemann, 2002).

To estimate the service life distribution the starting point used consisted of the numbers installed and the assumption that just over 30,000 light fittings containing PCB levels above 100,000 mg/kg were disposed of in 2013. Figure 48 shows two Weibull distributions that both result in just over 30,000 discarded light fittings in 2013 (α; β): (4; 26.8 and 2; 20.5) as well as a distribution composed equally of these two. One of the distributions has a long tail but a relatively short mean service life (distribution based on aesthetic considerations), while the other has more of a peak around a mean service life of approx. 25 years (determined more by the technical service life of the components). The composite distribution will probably be closer to reality.

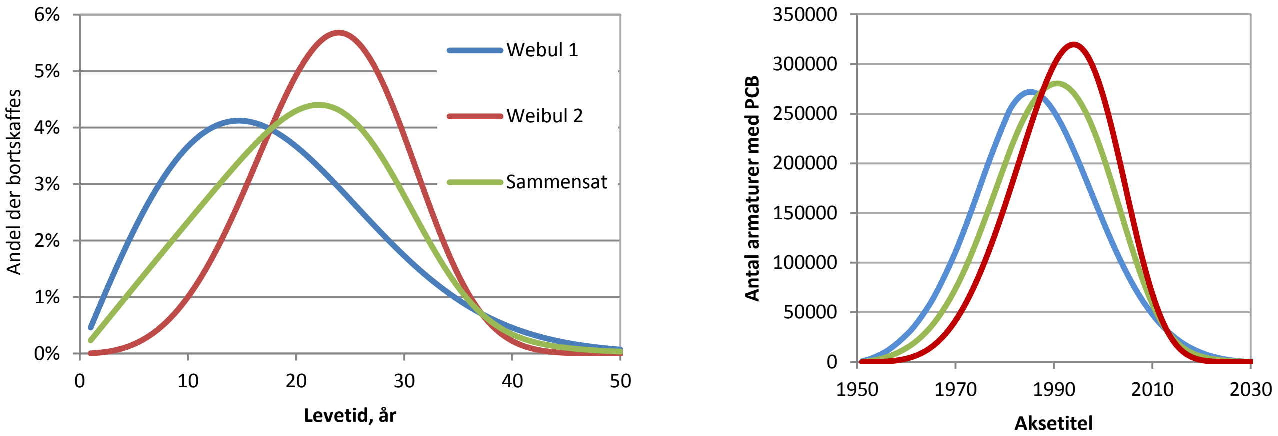

Figure 48 Service life distributions and the number of discarded light fittings with >100,000 mg/kg PCB when the composite service life distribution is used.

With all three of these service life distributions the quantity discarded for 2013 is calculated to be approx. 32,000 (which is the number the parameters are set to). The quantity still in use, which will be disposed of in the period 2014–2030, can then be estimated and will depend on the length of the tail in the distribution. With the distributions shown, the total number due for disposal in the period 2014–2030 will respectively be 2.4, 3.1 and 4.7 times the amount calculated to be disposed in 2013. Various compositions of distributions were experimented with, but it proved difficult to get below factor 2 or over factor 5. If it is assumed that the quantity still in use can be estimated at two to five times the quantity disposed of in 2013, it can be estimated that there will be 2–6 tons PCB left in fluorescent lamp capacitors and 2–7 tons PCB, if all light fittings are included (the rough estimate is that other light fittings represent a maximum of 1 ton PCB). This corresponds to 1–3% of the original amount of PCB used.

The residual amounts calculated correspond very closely with the Norwegian estimates, which are that in 2008 there would still be around 8 tons PCB present in light fittings. According to the model calculations, in the period 2008–2023 in Denmark a higher amount of PCB will be disposed of than the residual amount in 2013 and for this reason in 2008 there would have been an amount corresponding to or slightly larger than the estimated amount in Norway.

7.1.4 Secondary and tertiary presence of PCB

As can be seen from the results presented in section 3.6.4, there is considerable variation in how much of the PCB from a sealant will penetrate into the adjoining materials. For brick around a sealant joint, it has for example been calculated that the amount in the brick varies from 0.2 to 16.7% of the amount in the joint.

The most extensive study of the amounts of PCB in primary, secondary and tertiary sources was conducted as part of the studies concerning the Farum Midtpunkt development (Lundsgaard et al., 2010). According to this assessment, 82% of the PCB was present in the sealant, while the rest was present as secondary and tertiary contamination. Expressed as a percentage of the sealant, 16% was present in adjoining materials while 7% was present in paint and other presumably tertiary contaminated materials (some of this may in principle be a primary presence).

In his calculations for a model room, Gunnarsen (2013) calculated that after 40 years 92% of PCB will be present in primary sources, while 6% of the residual amount will have diffused into adjoining materials and 2% of the residual PCB may be present as tertiary contamination.

Based on results from a pilot project involving the redevelopment of a school in Odense, Grarup et al. (2011) calculated that 93% of PCB will be present in the primary source, 6% in secondary sources and 1% in tertiary sources.

It should be assumed here that secondary and tertiary presence will equate to 8–15% of the amounts found in sealant materials, which are the most important source of the secondary and tertiary occurrences.

7.1.5 Summary and partial conclusion

The estimated residual amounts of PCB in building materials and fluorescent lamp capacitors are summarised in Table 73. The total quantity is estimated at 17–87 tons.

The largest quantity is estimated to comprise sealants, with sealed glazing units representing the second largest individual source.

The calculated quantities in paint are subject to considerable uncertainty, but the total quantity is probably somewhat lower than the quantity in sealants, even though paint containing PCB can be found in a high proportion of all buildings.

The calculated amounts of PCB in flooring are also very uncertain, but flooring is in any case considered to be a minor source.

The estimates for residual amounts of PCB in sealants, sealed glazing units and fluorescent lamp capacitors correlate closely with corresponding estimates made in Norway. It is estimated that there is still 5–15 tons of PCB in sealed glazing units, and that a significant proportion of the quantities that are currently being disposed of are probably not being disposed of in accordance with the rules which apply to hazardous waste. The same would appear to be the case for fluorescent lamps with capacitors, with the residual quantity being estimated to be 2–7 tons of PCB.

Table 73 Residual PCB amounts in buildings in Denmark.

Material/equipment	Residual amounts of PCB in tons	% of total
Sealant around doors and windows	7–35	40%
Sealant between other building elements	2–15	16%
Paint	0.3–5	5%
Flooring	0.1–2	2%
Sealed glazing units	5–15	19%
Fluorescent lamp capacitors	2–7	9%
Secondary and tertiary presence	0.7–7.5	8%
In total	17–87	

8 Summary

8.1 PCB in materials

The most important results of the survey can be summarised in bullet point format as follows:

- Materials containing PCB at concentrations ≥0.1 mg/kg, which means that they must be destroyed upon disposal, were found in more than 75% of the buildings. This result is consistent with the outcome of the ongoing survey of Danish Defence's buildings and data collected concerning refurbishments and demolitions published by the Danish Environmental Protection Agency in 2012.
- Paint containing PCB occurs in a higher than expected proportion of the buildings. Even at the low concentrations involved, the PCB in the paint appears to originate from the paint manufacturing process, as over 50% of the analysed outdoor paints contained ≥0.1 mg/kg PCB. The survey shows that congener profiles of indoor paint containing PCB in the interval 1–50 mg/kg were markedly different depending on the presence of another PCB source in buildings.
- Both the ENS survey and the municipal authority surveys show that sealants containing PCB were used far more frequently during the period 1965–1974 than during the other sub-periods. In the case of paints and floor compounds, the period-related differences are less marked, which may well be due to the fact that these materials were incorporated into the buildings a number of years after their erection.
- The widespread presence of materials containing PCB can be observed in detached and semi-detached houses, but the frequency of detached and semi-detached houses with materials with a high PCB content is significantly lower than the frequency seen for blocks of flats and public institutions and offices. Only in one of the 154 detached and semi-detached houses was any indoor sealant with a very high PCB content found, as we saw with blocks of flats with PCB in indoor air.
- There is very little information available concerning PCB in private office buildings and it was very difficult to find companies willing to participate in the survey. The presence of PCB in the private office buildings was on a par with that known from public institutions and offices.
- Schools are a group of buildings with a particularly high frequency of sealants with a high PCB content, and the frequency of buildings with PCB concentrations above the Danish Health and Medicines Authority's action levels for PCB in indoor air is also significantly higher for schools than for other public institutions. The results indicate that schools dating from the period that have not already been examined for PCB should be given a very high priority.

- No noticeable differences were observed in the results of the ENS survey and those of the FBE survey. There was a significantly higher frequency of buildings with paint in the 50–5,000 mg/kg interval in the FBE survey, but the frequency of buildings with paint showing concentrations ≥5,000 mg/kg was higher in the ENS survey. The greatest differences were seen between the building categories within the individual categories; the FBE survey thus showed a markedly lower presence of PCB in storage buildings compared to offices and frequently used buildings.
- The widespread presence of PCB has been demonstrated in fluorescent lamp capacitors, with 9% of the light fittings examined containing a capacitor with pure PCB. The capacitors contain different types of PCB, with the two most common types having a markedly different congener profile than other primary sources; this means that the fingerprint from some of the capacitors can be seen in indoor air in several buildings. It was not investigated whether the capacitors emit PCB directly to indoor air or whether the effect is contamination of materials in the room in connection with PCB oil leaking.

8.2 PCB in indoor air

- In the selected detached and semi-detached houses and the selected blocks of flats, ≥300 ng/m^3 was only found in one building of each of the two building types, while concentrations ≥2,000 ng/m^3 were not found in any buildings in either building type.
- The results confirm the relatively high presence of PCB in indoor air in public buildings that was found in the municipal authority surveys, where ≥300 ng/m^3 was found at 7% of the locations and ≥3,000 ng/m^3 at 0.4% of the locations.
- The results for indoor air are consistent with the results for materials in that the presence of PCB in the private office buildings is comparable with that found in the public buildings.
- A clear correlation between PCB in primary, secondary and tertiary sources and in indoor air can be seen.
- Based on this relationship, there are clear indications that the primary sources in at least four of the measurements ≥300 ng/m^3 are capacitors because the congener pattern in indoor air and materials is a far better match with the congener pattern for capacitors than that for other known sources.
- The PCB content in indoor air in Danish Defence’s buildings was above the lower action value primarily associated with high concentrations of PCB in paint.
- The correlation between PCB in materials and PCB in indoor air is relatively weak, especially for paint and flooring, and several examples of elevated concentrations in indoor air were found, even though the PCB concentration in materials was relatively low. This weakness is in part due to it being difficult to determine whether primary or tertiary sources are involved. In order to investigate the occurrence of PCB in indoor air in a particular building, a survey strategy based on the analysis of materials would not be particularly

effective, as many of the buildings will subsequently still have to be surveyed for PCB in indoor air if we are to be certain of identifying all buildings with a high presence of PCB in indoor air. Such a strategy would have been satisfactory if just sealant was being studied, which was the case a few years ago, but it does not work for paint and flooring or any contributions from capacitors.

- This also means that the sampling strategy chosen in this study results in a relatively high uncertainty in relation to the presence of elevated values of PCB in each individual building.

8.3 Need for further knowledge

This survey covered studies of PCB in detached and semi-detached houses, blocks of flats and public offices and institutions. Nothing is known about the extent of PCB in industrial buildings, commercial buildings, warehouses and agricultural buildings.

There is considered to be a particular need for further studies of particularly sensitive industrial buildings in which food is stored, produced or processed.

Due to the content of PCB in durable paints, there is also considered to be a need to assess the indoor air impact in ships, off-shore facilities and other industrial facilities where there may be many painted surfaces containing PCB.

Based on the study of PCB in building materials there is considered to be a need to conduct further studies of the secondary and tertiary presence of PCB in plastic materials in the building stock. There is evidence to suggest that plastic may contain more tertiary contamination than other materials.

There is considerable variation in the penetration of PCB in materials adjoining primary sources. It would be useful to prepare some guidelines on the basis of the complete data from all studies on how a small number of depth profiles can be used to determine how much of the adjoining material needs to be removed and disposed of selectively.

Nothing is known about the evaporation of PCB from capacitors into indoor air or of the extent to which evaporation from capacitors can have an impact above the lowest action level in indoor air. This is also relevant for buildings constructed in the period 1977–1986.

It is unclear whether the capacitors' effect on indoor air occurs via materials contaminated with PCB that has leaked from a capacitor in the form of PCB oil or whether the capacitors contaminate the indoor air directly due to the evaporation of PCB during use. The fact that at least 12% of the cases with ≥300 ng/m^3 are apparently caused by leaks from capacitors without the building owner being aware of this shows the difficulty of managing this source of PCB in indoor air.

Studies conducted for municipalities and private building owners suggest that sealed glazing units with sealant adhesive and sealant tape containing PCB are the only primary source. Nothing is known about how indoor air is affected in the building or whether the evaporation from the sealed glazing units into indoor air is actually quite limited.

The content of PCB from sealant adhesive and any sealant tape to the frame and sill of sealed glazing units can vary considerably. There is considered to be a need to obtain more knowledge on the extent to which concentrations above or below 50 mg/kg can be demonstrated in the frame and sill of sealed glazing units.

In some studies PCB concentrations two to five times higher were found in buildings in which there was activity while PCB measurements in indoor air were being taken compared to buildings where there was no activity during the measurements. Additional documentation is also considered to be needed concerning whether such differences caused by varying levels of activity in the buildings can be measured generally across the building types.

More information is needed on the actual air exchange occurring in the buildings surveyed for PCB in indoor air while the building is in use.

There is evidence to suggest that the PCB does spread in multi-storey buildings as a result of air exchange. In other words, tertiary sources may be an important source in some of the buildings where an actual source cannot be proven. The impact may be below the lower action level, but the extent to which the tertiary sources could result in the lower action level being exceeded is not known.

The level of PCB in indoor air varies significantly over time due to many external factors. There is only limited knowledge of the actual variation over time in different building types, resulting in uncertainty in terms of how it can be determined precisely whether the recommended action levels have been exceeded.

It would be very useful to develop cost-effective methods of passive collection over a longer period of time. Doing so would allow the variation in the PCB concentration in indoor air over time to be taken into account.

9 Abbreviations and acronyms

EBST Danish Enterprise and Construction Authority (now defunct)

ENS Danish Energy Agency

FABA Association of Manufacturers and Importers of Electrical Lighting Fittings

FBE Danish Defence Estates and Infrastructure Organisation

OIS The public sector information server

PCB Polychlorinated biphenyls

PCB_7 Sum of the seven congeners: PCB #28, #52, #101, #118, #138, #153 and #180

PCB_{total} Estimate of total PCB content obtained by multiplying PCB_7 by 5.

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Annex 1 Sampling and analysis methods

A detailed set of sampling instructions was drawn up for the sampling work. The procedure is described briefly below.

Building review

As a first step, a building review was carried out to locate potential PCB sources. Information about the building and sources is entered in an iPad-based database system designed for the task. The system is structured so that the sample taker is guided through the building review, ensuring that the building conditions are recorded in a consistent manner.

Photographs of the building are taken as part of the review. The measuring points should be marked on a site plan/layout plan.

The building review is carried out both outdoors and indoors and on all floors of the building. If the use of the building means that there is no access to certain rooms, this must be accepted and noted.

Once the building review is complete, the sampling must be planned so that samples are taken of all potential PCB sources in each building.

If there are two identical buildings (as regards year of construction, size, interior fixtures and fittings, renovation conditions, use, etc.) at a location, samples are only taken from one of the buildings.

Material sampling

The sampling must be carried out in a way that causes as little damage to the buildings as possible, although the desired number and type of samples must still be obtained. Wherever possible the sampling must be carried out in places where its visual impact is minimised. In order to achieve clear analysis results, only primary samples are to be used in the selection of material samples. Mixed samples are not to be used.

Disposable gloves changed after each sampling are to be used when taking material samples to avoid cross-contamination of the samples. Sampling was carried out as follows:

Sealant: Sealant samples were taken using a disposable craft knife; the sealant joint was loosened with a screwdriver or multi-cutter was used. Tools that are not disposable were cleaned after each sampling to prevent the risk of cross-contamination.

Paint: Paint samples were taken using a paint scraper or multi-cutter. The tool used was cleaned between each sampling. Sampling was carried out in a place where the visual impact of the missing paint would be minimised, e.g. behind a door or underneath a cupboard.

Floor compound: Floor compound samples were taken using a craft knife, multi-cutter, chisel or screwdriver used as a chisel depending on the nature of the material. The tool used was cleaned between each sampling. Sampling was carried out in a place where the visual impact of the missing floor compound would be minimised.

When the material samples are taken, the sampling procedure must be documented by competing a field journal form in the iPad system, taking photographs of the sampling site and marking the measuring point on the layout plan/site plan.

All sampling sites must be measured in the field in connection with sampling and indicated clearly on a drawing with distance measurements to at least two walls and the height above the floor level.

The starting point is to take two samples from each potential PCB source. If, for example, one type of external window sealant and another type of internal element sealant are found in a building then two samples of each type of sealant will be taken. This makes a total of four samples. The same principle applies to paint and floor compounds. The two samples of the same source were taken from two different places in the building, e.g. from north- and south-facing facades.

The following average numbers of samples per building are assumed:

› Sealants: 8 samples per building

› Floor compounds/coverings: 2–3 samples per building

› Paint: 2–3 samples per building

Samples were placed in packaging from Højvang Miljølaboratorium and kept cool in lightproof insulated bags. The samples were numbered clearly with a label corresponding to the sample number generated in the iPad system. The insulated bags were collected by the analysis laboratory and used to transport samples from the sampling site once they had been picked up.

The collected samples were sent to the laboratory on a daily basis and the storage period in the field was thus less than 24 hours.

Taking indoor air samples

A Højvang pump with a type 24 V membrane pump, documented to be stable in long-term operation, was used to take indoor air samples. Each air sample was collected in an OVS-XAD-2 collecting tube. The laboratory recommended collection flow between 2 and 3 l/min, equivalent to the manufacturer's recommended collection flow for the collecting tube.

The laboratory recommended a collection flow of 2.5 l/min for this type of XAD-2.

During the sampling a minimum of 500 litres of air were collected, which corresponds to a collection time of at least 250 minutes.

The OVS collecting tubes used contain both XAD-2 material and PUF material (polyurethane foam) as well as a quartz filter to collect larger particles and aerosols.

The analysis section analysed by the laboratory contains the contribution from the quartz filter, first layer XAD-2 and first layer PUF.

The control section consists of second layer XAD-2 and second layer PUF. This means that the analysis method is suitable for both low- and high-chlorinated PCB congeners.

The air sample was taken 1.2–1.5 m above the floor level and at least 0.6 m from walls and furniture.

In rooms with mechanical ventilation the air sample was taken at the best possible distance from extraction and air supply.

In rooms with outdoor air vents in which the air is brought in from outside into the room (when the room is on the building's windward side or the room has exhaust ventilation), the air sample is collected from the back or approx. two thirds inside the room. If the air from the room flows to the outdoor air, the sample is collected approx. one third inside the room from the exterior wall.

Temperature and air humidity

Temperature and humidity data were collected using a Tinytag Ultra 2 TGU-4500 instrument; this records the temperature and relative humidity with an accuracy of less than ±0.4°C and ±3% RH respectively. The instruments were pre-programmed to log data every five minutes and then drained of data after each measuring day.

The instruments were placed close to the pump and at the same height as the pump when taking indoor air measurements.

Supplementary sampling of building materials when taking indoor air measurements

If the building was one of the 12 buildings selected from the total of 67 in which indoor air measurements were taken, supplementary sampling of building materials was carried out.

Sampling of building materials was not carried out until the indoor air measurements in room A and room B had been completed to avoid creating a sudden increase in the level of PCB in the indoor air.

An air sample was collected from where building materials had previously been sampled from the primary source and a probable primary source had been detected.

Another four samples of materials were taken. These were two samples of adjoining materials between 0 and 30 cm from the source and two samples of expected tertiary-contaminated surfaces between 30 and 50 cm from the source.

Differential pressure

Differential pressure was logged in one or two places in each test room, and the differential pressure was logged throughout the entire time period for the collection of indoor air every five minutes.

A type GMH3151 instrument with a GMS2.5MR sensor was used to measure the differential pressure above/below the floor, if the sampling took place in a room situated directly on top of the ground.

Based on the architectural drawings for the building, it was determined whether or not there were cavities between the exterior and interior walls of the building. The cavity wall in a wall in the sampling room was also used to produce a differential pressure measurement. The differential pressure was measured indoors and in the cavity.

Air exchange measurement

The air exchange measurement was carried out as a decay measurement with a known homogeneous tracer gas that was not already present in the room. The tracer gas was 100% H_2 5%.

The gas was dosed instantaneously in small amounts in front of a fan with a base that mixed the gas in the room. The gas concentration was monitored and logged close to the measuring point at which the indoor air sample had been collected. Once the gas concentration was homogeneously distributed throughout the room and the concentration level in indoor air had reached a suitably high level, the supply of gas was stopped and the gas mixed by the fan until it was fully mixed inside the room. This took about 5–10 minutes, depending on the size of the room. The fan was then stopped. A gas detector, which was connected to a timer, was turned on. The sample taker left the room and the gas detector began to log data after a time delay of approx. 10 minutes after the room had been vacated. The air exchange measurement itself took between 2.5 and 4 hours, depending on the actual air exchange in the room. The volume of the room was estimated to ensure that the decay was sufficiently large. The basis for this calculation was an average air exchange of around 0.35 times per hour. The logging of the gas concentration was stopped when the indoor air measurement equipment was removed.

The room's air exchange could be calculated based on the recorded decay in the gas concentration. The air exchange consists of the air supplied from outside and from adjoining rooms and any rooms above and below the room concerned. This air exchange is calculated as a gradient of the expected logarithmic decay of the gas per time unit.

The logger used was a Dräger X-am 5000 and the fans used were rechargeable type TL2201A fans.

Measuring mechanical ventilation

The supply and exhaust volume flow rates over fittings were measured in test rooms **with mechanical ventilation** using a funnel and hot-wire anemometer. The measurements were taken with doors and windows closed, about two minutes after the door to the room was closed in order to stabilise the pressure conditions in relation to outdoor climate and neighbouring rooms.

Photo 1 Type of exhaust for mechanical ventilation

Outdoor air vents can also be used as exhaust valves for mechanical extraction; see Photo 1. When there is mechanical extraction, the vent is so large that a very strong air flow can generally be heard or seen.

Extraction above extractor hoods in kitchens was measured using an impeller anemometer at a number of points, with each measuring point covering an area with sides of about 7–9 cm of the extractor grille surface. If a funnel could cover the area of the extractor grille, then a funnel and hot-wire anemometer were used to measure the area, as for other supply and exhaust devices.

The following qualifications applied to settings for mechanical ventilation in homes during the indoor air measurement process:

- an extractor hood must *not* be set to forced operation as it is during food preparation

- an extractor fan in a toilet or bathroom must *not* be in use as it is when someone takes a bath or uses the room for any another purpose or be controlled by a humidity sensor, light switch or on/off switch.

Measuring natural ventilation over outdoor air vents

If the room contained an outdoor air vent, the volume flow rate was measured through the opening with a funnel and hot-wire anemometer because this meant it would also be noted whether the air was supplied to or from the test room. The setting of the outdoor air vent was not changed before or during the test; see the photo below.

Photo 2 Natural ventilation

If the vent consisted of a sliding vent, e.g. a slit just behind the radiator, and the measurement could not be taken indoors, where possible the measurement was taken outdoors using a funnel or impeller anemometer. If the measurement could not be taken, the vent was closed.

The measurement was taken with doors and windows closed, about three to five minutes after the door to the room was closed in order to stabilise the pressure conditions in relation to outdoor climate and neighbouring rooms.

For all measurements smoke was used to note whether the air was being supplied to the room through the vent from outdoors or taken outdoors from the room.

Measuring mechanical ventilation in institutions and offices

In the case of institutions, offices, etc. which are not used for residential purposes but are mechanically ventilated, the company Bravida took measurements of the mechanical ventilation.

Measurements of the mechanical ventilation were taken in eight buildings where large mechanical ventilation systems were found.

The supply and exhaust volume flow rates over fittings were measured in test rooms with mechanical ventilation using instruments such as an Accubalance or Wallac type funnel and hot-wire anemometer.

In cases where there was both mechanical supply and exhaust, the ventilation system was inspected to see if it involved recirculation or a rotary heat exchanger.

Efficiency of the ventilation system

The mechanical ventilation measured was corrected for its efficiency at removing contaminants from the bottom of the occupied zone. If for example the supply temperature is higher than the room air temperature, less ventilation air is usually used, while the local air exchange in the occupied zone is correspondingly smaller.

The efficiency of the ventilation system is determined by measuring the supply, exhaust and indoor air temperatures, from which the correction factor for the ventilation principle concerned can be obtained in accordance with EU standard CEN 1752.

Measuring natural ventilation over outdoor air vents

If the room contained an outdoor air vent, the volume flow rate was measured through the vent using a Wallac funnel and hot-wire anemometer because this meant it would also indicate whether the air was supplied to or from the test room.

Measuring primary sources that contain PCB

After the sampling was carried out, all primary sources that may give rise to PCB in indoor air were measured so the surface area and volume of all primary source materials could be calculated.

Analysis, material samples

Analyses of PCB in material samples were carried out by Højvang Miljølaboratorium.

The materials were analysed in accordance with the reference method DS/EN 15308:2008 (Characterization of waste) and extracted using a mixture of acetone/hexane. The analysis method follows the laboratory's accredited internal methods: HM 44 to determine PCB in sealant, HM44.1 to determine PCB in soil and other solid materials.

Analyses were conducted for the following seven congeners which together signify PCB_7: PCB#28, #52, #101, #118, #138, #153 and #180. The uncertainty of the chemical analysis of the material samples is 0.02 mg/kg DM (dry matter). The detection limit for the individual congeners analysed is 0.003–0.02 mg/kg DM.

In accordance with the Danish Environmental Protection Agency's guidelines for PCB in waste, PCB_{total} has been calculated as the sum of the seven congeners analysed multiplied by a correction factor of 5:

$$PCB_{total} = 5 * PCB_7$$

Analysis, indoor air samples

Analyses of PCB in indoor air samples were also carried out by Højvang Miljølaboratorium.

Annex 2 Ventilation and air exchange

1.1 Air exchange measurement

The air exchange measurement is carried out as a decay measurement with a known homogeneous tracer gas that is not already in the room. The tracer gas is H_2. A Dräger X-am 5000 logger device with a measuring range of 0–2,000 ppm and a solubility of 20 ppm is used to detect the gas.

The gas was dosed instantaneously in small amounts in front of a fan with a base that mixed the gas in the room. The gas concentration is sampled close to the measuring point where the sample was taken for PCB in indoor air. The gas dosing stops at 1,500 ppm, while the logging of the falling gas concentration continues throughout the PCB sampling procedure, which typically takes between four and six hours.

The data logged for the hydrogen are shown on a logarithmic scale for each air exchange measurement, with data being represented by a straight line. At the start of mixing, 30–40 minutes have typically already passed before the mixing is complete in terms of the gas infiltrating into dead air pockets in cupboards, cracks, etc. and reaching equilibrium. The air exchange is calculated from this point to the lowest registered gas concentration. The lowest selected concentration is set not to fall below 250 ppm because the background concentration for hydrogen is 50 ppm and accuracy of the logger device is reduced to the lower detection range of below 75–100 ppm.

The air exchange is calculated at these two points using the expression:

$$N = \frac{1}{t_2 - t_1} * \text{Log}_e \left(\frac{C_2 - 50}{C_1 - 50} \right)$$

N = air exchange per hour
t_1 = time in hours with decimal places at start point
t_2 = time in hours with decimal places at finish point
C_1 = concentration in ppm at start
C_2 = concentration in ppm at finish
50 = background concentration in ppm for hydrogen

1.2 Measurements in rooms with mechanical ventilation in homes

The supply and exhaust volume flow rate over fittings is measured in test rooms **with mechanical ventilation** using a funnel and hot-wire anemometer. The measurement was taken with doors and windows closed, about three to five minutes after the door to the room was closed in order to stabilise the pressure conditions in relation to outdoor climate and neighbouring rooms.

Extraction above extractor hoods in kitchens was measured using an impeller anemometer at a number of points, with each measuring point covering an area with sides of about 7–9 cm of the extractor grille surface. If a funnel has covered the area of the extractor grille, then a funnel and hot-wire anemometer are used to measure the area, as for other supply and exhaust devices.

1.3 Measuring mechanical ventilation in institutions and offices

If institutions, offices, etc. have mechanical ventilation that differs from that found in homes, the mechanical ventilation is measured at its inflow and outflow points.

The measurement is carried out on a different day to the PCB sampling.

a) Efficiency of the ventilation system

The mechanical ventilation measured is corrected for its efficiency at removing contaminants from the bottom of the occupied zone. If for example the supply temperature is higher than the room air temperature, less ventilation air is usually used, while the local air exchange in the occupied zone is correspondingly smaller.

The efficiency of the ventilation system is determined by measuring the supply, exhaust and indoor air temperatures, from which the correction factor for the ventilation principle concerned can be obtained in accordance with EU standard CEN 1752. The supply and exhaust temperatures are measured at the entrances to the room at the start of the measurements, when the measuring equipment is set up, and at the entrances to the room at the end of the measurements, when the measuring equipment is dismantled. The measurement of the supply temperature takes place using a hot-wire thermometer or an IR radiation thermometer.

1.4 Measuring natural ventilation over outdoor air vents

If the room contains an outdoor air vent, the volume flow rate is measured through the opening with a funnel and hot-wire anemometer because this means it also indicates whether the air is supplied to or from the test room. The setting of the outdoor air vent is not changed before or during the test.

If for example an outdoor air vent consisted of an opening just above or behind the radiator and the measurement could not be taken indoors, the measurement was taken outdoors using a funnel or impeller anemometer.

If the window contains an air vent in the window frame, a measurement cannot be taken above this and the vent is closed before the measurement takes place.

The measurement was taken with doors and windows closed, about three to five minutes after the door to the room was closed in order to stabilise the pressure conditions in relation to outdoor climate and neighbouring rooms.

For all measurements smoke was used to note whether the air was being supplied to the room through the vent from outdoors or taken outdoors from the room.

1.5 Air exchange when measuring the decay of tracer gas

Determining the air exchange as a decay measurement with tracer gas provides information on the total air supply to the room, i.e. from outdoors and from adjoining rooms and any rooms above and below, see Figure B2-1.

The outdoor air is considered to be PCB-free, while the air supply from surrounding rooms may contain PCB, which is supplied to the room under the various pressure conditions affecting the building. The air supply from outdoors and surrounding rooms is determined by wind conditions, the difference between outdoor and indoor temperatures, flaws in wall and floor structures, the opening of windows and doors in other rooms and the existence of any mechanical ventilation and outdoor air vents in the room and surrounding rooms.

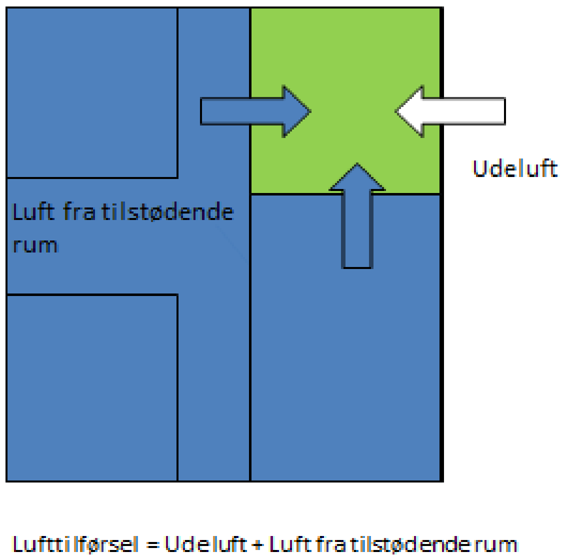

Figure B2-1. Measured air supply when measuring tracer gas.

The results of measurements taken in the three building categories are shown in Table B2-1.

Table B2-1. Mean, minimum and maximum values etc. for the measured air exchanges.

Building type	Number (quantity)	Mean (h^{-1})	Median (h^{-1})	Min. (h^{-1})	Max. (h^{-1})
Detached and semi-detached houses	15	0.32	0.10	0.029	1.79
Blocks of flats	20	0.23	0.13	0.032	1.13
Offices and public institutions	32	0.60	0.32	0.016	3.68

For all building categories, it can be seen that many rooms experienced remarkably little air exchange during the measurements, as the median values for detached and semi-detached houses, blocks of flats and for offices and public institutions were 0.10 h^{-1}, 0.23 h^{-1} and 0.32 h^{-1} respectively.

The fact that the mean is higher than the median in relative terms in detached and semi-detached houses was caused by some air exchanges being relatively high, e.g. a single test room in the detached and semi-detached houses had an air exchange of 1.79 h^{-1}. This room was a garage, which is not classed as a normal room in a home. The air exchange of 0.47 h^{-1} in another room in the same building category is associated with substantial uncertainty. If these two air exchanges are omitted, the mean value for the detached and semi-detached houses is 0.19 h^{-1}.

The cumulative relative distribution of the test rooms is shown in Figure B2-2.

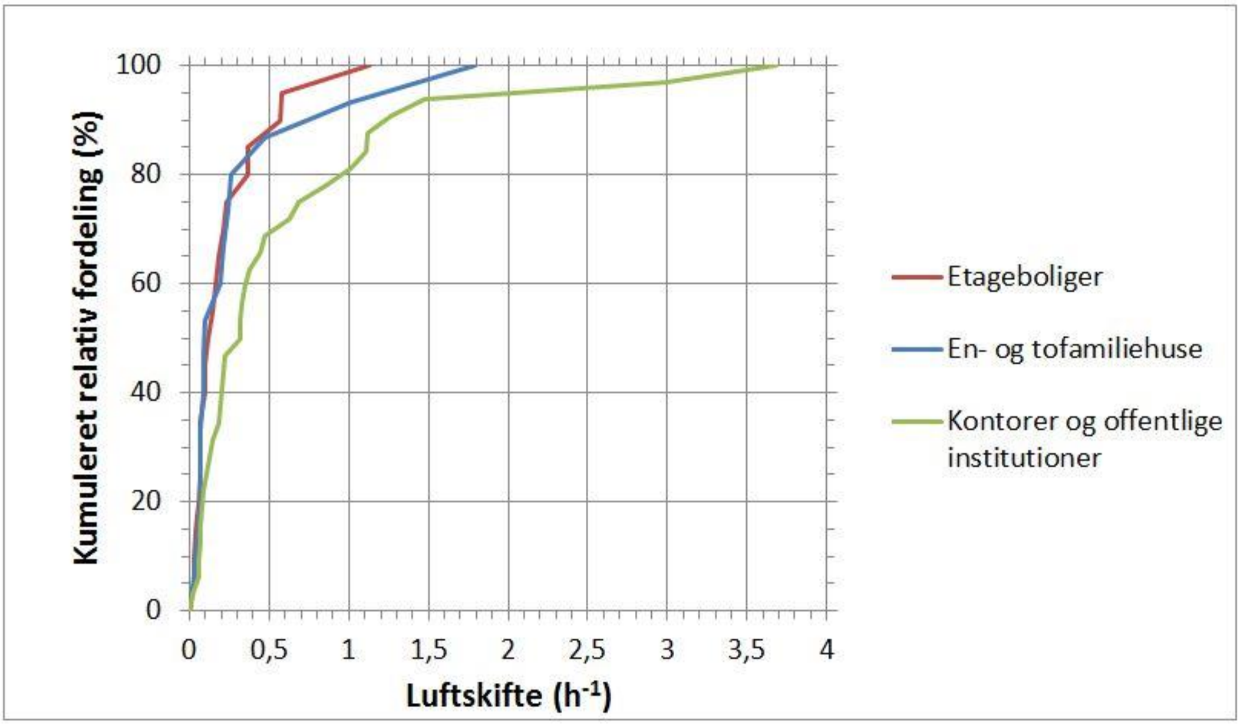

Figure B2- 2. Accumulated relative distribution of air exchanges in the three building categories.

This shows that approx. 40% of all test rooms in the dwellings were measured with an air exchange of less than 0.10 h^{-1}, and approx. 60% of the rooms measured had an air exchange of less than 0.20 h^{-1}. In relation to the requirement laid down in the Danish building regulations for a minimum basic outdoor air exchange of 0.5 h^{-1}, the PCB measurements were carried out under relatively low air exchanges. Only around 10% of the test rooms fulfilled this requirement at the time the rooms were measured. A proportion of the air inflow measured will also originate from rooms through walls or through the structural floor and cannot be considered to constitute outdoor air, so the outdoor air exchange is less than the air exchange indicated in Figure B2-2, cf. Figure B2-1.

The low air exchange measured in the dwellings was partly due to the decision to have the test room's door and windows closed during the measurements in order to control the air exchanges in the rooms where the PCB material and air samples were taken. Had the doors been open, the air exchange in the entire dwelling would have been measured and this would prevent relationships between the PCB content in the air and in the materials being established for an individual room. However, it is possible that some of the low air exchanges observed will constitute the air exchanges in the rooms concerned while the room is in normal use, e.g. if the room's door and windows are normally kept closed.

Another factor that results in some of the air exchanges being low is the fact that the measurements were taken in late spring and typically during the day when there was not much difference between indoor and outdoor temperatures.

The air exchange measurements were also taken while the rooms were not in use, i.e. windows and doors were not opened, forced extraction from extractor hoods and bathrooms etc. did not take place. The residents' use of the rooms will increase the air exchange in the property. A previous study of the outdoor air exchange for dwellings under normal use /1/, see Figure B2-3, found the total air exchange in the property over a period of one to two weeks. The air exchange in this study is generally higher, although the blocks of flats and detached houses concerned were built after 1982 and 1985 respectively. This means they were built after the period in which PCB was used in building materials and stricter requirements for ventilation were imposed, e.g. the stipulation that a total outdoor air exchange of at least 0.5 h^{-1} must be possible in each residential unit.

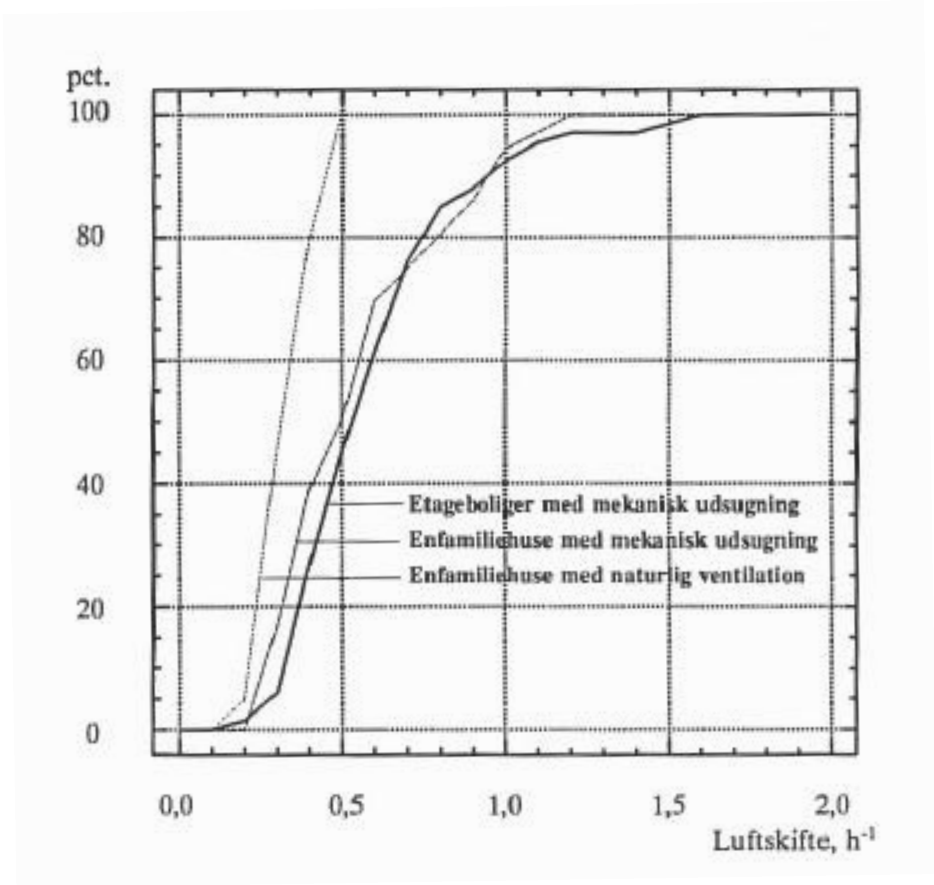

Figure B2-3. Accumulated relative distribution of the outdoor air exchange in blocks of flats and detached houses.

1.6 Mechanically ventilated test rooms

Many blocks of flats were ventilated with common extraction systems in kitchens and bathrooms/toilets, where the outdoor air was brought into the property through outdoor air vents.

Nine of the 32 rooms from Figure B2-2 had mechanical ventilation installed in the "Offices and public institutions" building category. Of these, measurements of the supply and exhaust volume flow rate were taken in eight rooms. The measurements were carried out with closed windows and doors once the low or excess pressure from the ventilation had stabilised. Figure B2-4 shows the measured differences between supply and exhaust volume flow rate – stated as air exchange – since a negative air exchange indicates that the room is ventilated with the low pressure shown and a positive air exchange with the excess pressure shown. For every site it is also stated how the exhaust air is treated in the ventilation system in order to assess whether the air and contaminants might be returned to the supply air.

Table B2-2 Measured supply and exhaust from eight mechanical systems in the studies.

Location	Supply Gr	Exhaust Gr	Room Gr	Supply air quantity	Exhaust air quantity	Recovery type	Recovery use	Recirculation
Institution	23	23.4	23.1	1* 56	1* 89	Cross	35%	No
				2* 65	2* 103			
School	23	27.5	26.5	1* 101	1* 622.5	Rotor	0%	No
				2* 199.3				
School	23.4	24.9	24.5	1* 106	1* 70.2	None	-----	Yes
				2* 123.2	2* 56.1			
School	25.1	27	26.5	1* 205.4	1* 130.2	None	-----	No
				2* 219.5	2* 133.4			
School	25.5	25.3	26	1* 185	1* 93.9	None	100	Yes
School	No supply air	27.4	26.6		1* 108.5	None	-----	-----
					2* 116.2			
					3* 96			
					4* 92.7			
Private office building	Building open without facade, measurement cancelled in following email from 09:32 on 07/08/2013.							
Private office building	19.7	22.2	22.1	1 * 108.4	1 * 59.8	None	0	Yes
					2 * 0.0			
					3 * 68.2			
Institution	22.2	22.5	22.4	1 * 42.8	1 * 79	Yes, but unknown type	?	Yes
Institution	22.3	22.6	21.5	1 * 57.7	1 * 97.8	Yes, but unknown type	?	Yes

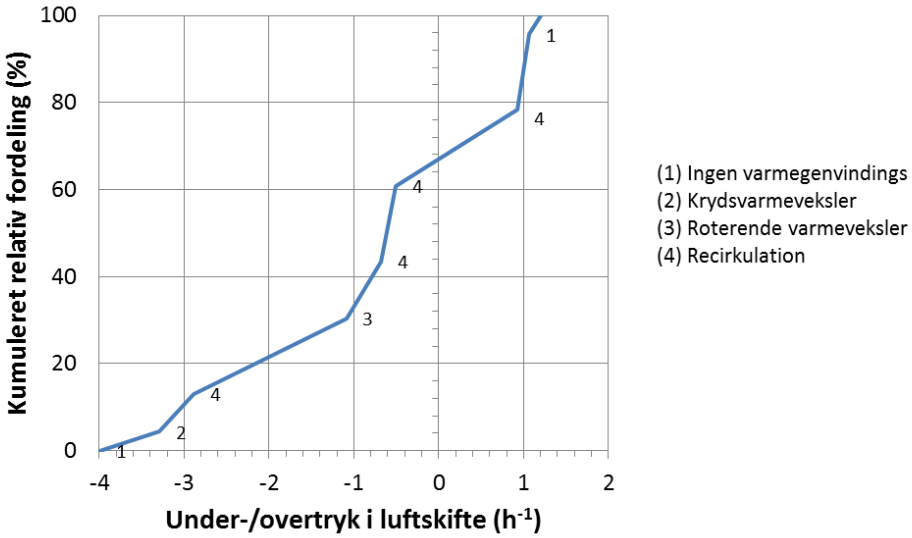

Figure B2-4 Difference between supply and exhaust volume flow rate converted to air exchange for each of the test rooms.

The figure shows that for some ventilation systems there is a major difference between the supply and exhaust volume flow rate indicated for the air exchanges in the rooms. When there is low pressure, air and any PCB contamination are drawn into the room air from adjacent rooms or materials and when there is excess pressure they are to some extent expelled into adjacent rooms.

There was recirculation in the case of four out of eight ventilation systems, where PCB in the exhaust air from the test room and any other rooms connected to the system is returned to the test room.

In a PhD project /2/ it was found that contamination is transferred from the exhaust air to the supply air via the rotary heat exchanger. In other words, rooms ventilated by ventilation systems with a rotary heat exchanger can presumably transfer smaller amounts of PCB to the supply air. Depending on the age and quality, a cross-flow heat exchanger transfers little or no exhaust air to the supply air.

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/1/ Bergsøe, N.C. (1991). SBi report 213: Undersøgelse af ventilationsforhold i nyere boliger. [Survey of ventilation conditions in new homes.] Niels C. Bergsøe. Danish Building Research Institute.

/2/ Pejtersen, J. (1994). Forureninger i ventilationsanlæg. [Contamination in ventilation systems.] PhD project. DTU, Technical University of Denmark.

Annex 3 Selected cases

Annex 4 Example of analysis and study report

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Annex 5 Photographic documentation of sealed glazing units, including sealant tape and sealant adhesive

Attached as separate PDF file. The attached example contains only one section of the fittings to demonstrate the scope of the complete file.

Each photograph includes a location number. This number shows the link between sealed glazing units and the subsequent detail photographs of the sampling material.

Annex 6 Photographic documentation of capacitors and light fittings

Attached as separate PDF file. The attached example contains only a selection of the fittings to demonstrate the scope of the complete file.

Each photograph includes a location number. This number shows the link between capacitors and fluorescent lamp fittings.