Unique investigation of chemicals in construction and indoor air of Swedish dwellings

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Summary

In 2006, The Swedish Board of Housing, Building and Planning was commissioned by the government to perform a larger study on the existing building stock. Approximately 1800 buildings, statistically chosen to represent the entire building stock, were investigated by experts. Two parts of this investigation was to take inventory on the occurrence of dangerous substances e.g. asbestos and PCB, and to measure pollutant levels e.g. formaldehyde and NO_2 in the indoor air. The first results were presented in 2009, and more extensive results in 2010.

The inventory shows that PCB is still present in the building stock, in spite of regulations to remove contaminated material. Asbestos and radon emitting materials also linger in the building stock. Phasing out such materials is a slow process, due to long service life of buildings.

The analyses show that indoor air in general have levels of substances that are below the WHO guidelines for indoor air. This may have a correlation with good ventilation and relatively clean supply air. For radon, however, the WHO has proposed a limit value which cuts the present one in half. It is considered socio-economically unreasonable to meet this new value.

Keywords: chemicals, indoor air, formaldehyde, PCB, VOC, radon

5. Introduction

The Swedish government has been discussing goals for improving the built environment, especially regarding indoor environment, damp and mould, for years. However, the information and statistics about the technical status of the building stock has been out dated and inadequate. The latest data were from the ELIB study conducted in the early 1990's. The National Board of Housing, Building and Planning, Boverket, was therefore in 2006 commissioned by the government to carry out a major survey that updated the description of the Swedish building stock.

The commission was composed of several themes, including technical design, indoor environment, damages and deferred maintenance, energy efficiency and roof safety. The acronym used for this study was BETSI. Approximately 1800 buildings, statistically chosen to represent the entire building stock, were investigated by experts. Two parts of this investigation was to take inventory on the occurrence of dangerous substances e.g. asbestos and PCB, and to measure pollutant levels e.g. formaldehyde, radon and NO_2 in the indoor air. The first results were presented in 2009

[1], and more extensive results in 2010-2011 [2-5]. This paper presents the inventory of hazardous materials and the measurements of certain substances in indoor air.

5.1 Previous studies in short

5.1.1 Rational use of electricity in the building stock, ELIB (1993)

The research program ELIB studied the technical characteristics, energy use and indoor climate of the Swedish building stock. The National Institute for Building Research (SIB) made a survey of 1148 statistically selected buildings in 60 municipalities. There are several reports from the program, but especially interesting for the BETSI study is report no TN:29. TN:29 deals with technical characteristics of the building stock, regarding household electricity, building electricity, heating, ventilation, construction type and moisture damage [6]. Comparisons between BETSI and ELIB and can be done for single-family houses and apartment buildings.

5.1.2 STIL2 schools and kindergartens (2006)

The Swedish Energy Agency is conducting a longer project, STIL2 (statistics on the premises), to improve the state of knowledge on energy use. Boverket participated in the sub-project on schools and kindergartens. The aim was to improve knowledge about energy use and indoor environment in schools and kindergartens. Results from the study STIL2 provides data on schools and kindergartens to the BETSI study. [7]

5.2 The BETSI study in short

Boverket was commissioned to conduct a larger study and would by means of surveys and questionnaires develop an updated description of the building stock. Particular focus was to produce data of damage to buildings and lack of maintenance, and data for development of the environmental quality objective A Good Built Environment.

5.2.1 Statistical selection

1800 buildings were chosen to statistically represent the entire building stock, divided into the three main categories of single-family houses, apartment buildings and commercial and public buildings. Criteria for selection were factors e.g. year of construction, climate zone, and type of building. [2]

5.2.2 Surveys

Approximately 1800 surveys were carried out in statistically selected buildings. The 50 surveyors underwent a two-day joint training in order to have the same starting points for surveys. A multitude of questions were asked about each building. Examples are questions on how and when the building was constructed, tenure status, foundation means, cladding and roofing materials, and heating method. A number of verification inspections have been conducted to assess the quality of survey records, instructions and how different surveyors had worked. [3]

5.2.3 Measurements

A series of measurements were carried out in connection with inspections. These measurements included air circulation, radon, temperature, moisture and chemical substances in indoor air. [3-4]

5.2.4 Questionnaires

Two types of questionnaires were sent to residents in private homes and apartment buildings. The residents were asked questions about the dwelling, its equipment and use. A parallel questionnaire which asked about the residents' health was conducted, in different versions for children, adolescents and adults. The questionnaires were sent to residents in surveyed buildings, but also to a larger number of people living in private homes to get data from more dwellings. About half of the questionnaires were answered.[5]

5.3 The basics

Sweden has about 9.3 million citizens. There are about 1.9 million single-family houses and 166.000 apartment buildings.

5.3.1 Single-family houses

The average single-family house was built in 1953 and is a 1.5-storey house with a basement. The facade is made of wood and the roof is a pitched roof with concrete tiles. The heated area is 160 m^2 and the U-value of the external walls is 0.334 W / (m^2 • K). 2.3 people live in the house.

91 % of the single-family houses are owned by those who live there. Detached houses are most common, with 82 ± 4 %. The largest proportion of detached houses is found amongst those that were built before 1960.

5.3.2 Apartment buildings

The average apartment building was built in 1959 and consists of a basement and three floors above ground. The facade is brick or stucco and the roof is a pitched roof with concrete tiles. The heated area is 1.426 m^2 and U-value of the external walls is 0.411 W / (m^2 • K). The building has 14.55 apartments and an average of 1.7 people live in each apartment. About 40 % of the apartment building stock is lamellar buildings.

Most apartment buildings, approximately 67 %, are rental apartments. The most common ownership in apartment buildings from 1996 – 2005 is housing tenure.

6. Survey – inventory of harmful substances

Boverket carried out about 1800 surveys, using 50 surveyors. The inventory of harmful substances was done based on observations and knowledge about age of the building, construction etc. The following substances were included in the survey:

- asbestos
- ozone depleting substances, CFC
- polychlorinated biphenyls, PCB
- materials in pipes for drinking water
- copper
- biocide treated wood
- oil cistern and separator
- mercury from dental surgeries
- tar
- radon emitting building materials

This paper includes results from the inventory of asbestos, PCB, CFC and radon emitting materials.

6.1 Radon emitting building materials

Radon in indoor air usually comes from the ground through leaks in the building structure. It may also be emitted from radon drinking water. Stone-based building materials can emit radon, usually in very small quantities.

Alum shale based aerated concrete, known as blue light concrete, is a material that can cause elevated concentrations of radon in indoor air. It was used as a building material in the years 1929 – 1975, and more commonly in apartment buildings than in single-family houses. Since this material is used as part of the supporting structure of the building, it is difficult to replace, and other remediating techniques are required to solve elevated radon levels in indoor air. [4]

6.2 Asbestos

Asbestos has been widely used for about a hundred years, especially during 1950 – 1976, the year of the national ban. Asbestos may be present in air ducts, tile adhesives and sealants, floor tiles, around pipes, as fire protection at the heat source and as a facade or roofing material (asbestos cement). BETSI shows that there is asbestos in about 40 % of single-family houses and 50 % of all apartment buildings.

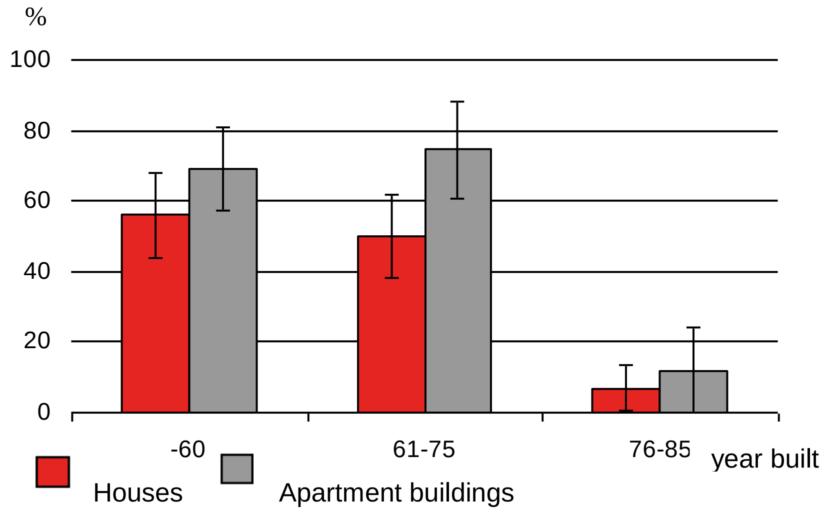

Fig. 1 Asbestos in single-family houses and apartment buildings, per construction period.

6.3 Polychlorinated biphenyls, PCBs

PCBs have been used in transformers and capacitors since the 1920s. The use of PCBs increased from 1945 until the climax was reached in the 1960's and 1970's, until the national ban in 1973. PCBs have been part of sealants, plasticizers, floor paints, insulating glass, insulator oil and hydraulic oil. PCBs have several good technical properties but show high toxicity in animals and humans.

A national law on inventory and remediation of PCBs in buildings is in effect. By 2008, a total of 52 000 buildings that were built or renovated during the years 1956 – 1973 should have been inventoried with respect to PCBs. Only a third of those buildings were inventoried in time. BETSI indicates that at least 17 500 buildings are likely to contain PCBs.

6.4 Chlorofluorocarbons, CFCs, HCFSs

In the construction sector, ozone-depleting substances have been used for example as refrigerants in refrigeration and as blowing agents in foam insulation. CFCs were banned from use in 1999, and refill of HCFCs in leaky refrigeration was banned in 2001.

Ozone-depleting substances were found in 16 % of commercial and public buildings, in 8 % of apartment buildings and in 5 % of single-family houses.

6.5 Conclusions

Science develops and we learn all the time to be careful with materials and substances that we previously thought were harmless. When such materials and substances are incorporated in buildings, it takes a very long time before they are phased out of the system due to the long service life of buildings.

Potentially harmful substances that are discussed today are lead in brass fittings for drinking water use, and bisphenol A which is used in relining of old water pipes.

7. Results from analyses

Two factors that may affect the levels of contaminants in indoor air are relative humidity and temperature. The analyses were carried out during the heating season when indoor air is relatively dry. The mean indoor temperatures in single-family houses is 21.2 ºC, and in apartment buildings 22.3 ºC. The relative humidity is about 30 % in apartment buildings, and slightly higher in single-family houses. [3]

The sampling equipment was placed in the dwellings by the surveyors. The inhabitants were given instructions on how to pack and send the equipment to the analytical laboratories within a specific time interval.

7.1 Radon

The radon levels were measured during the heating season 2007 – 2008 in all surveyed single-family houses, and in two apartments per surveyed apartment building. Not all sampling canisters were treated in line with the instructions, and therefore a second sampling round was performed in some buildings the following year.

Measurements show that the radon levels of in total 250 000 single-family houses and 75 000 apartments in apartment buildings are expected to exceed the limit 200 Bq/m^3. The previous estimation of dwellings exceeding the limit value indicated 280 000 single-family houses and 115 000 apartments. [8]

It has therefore been an improvement since the assessment of the in-depth evaluation of environmental quality objectives in 2003 when 280 000 houses and 115 000 dwellings were considered to have elevated radon levels.

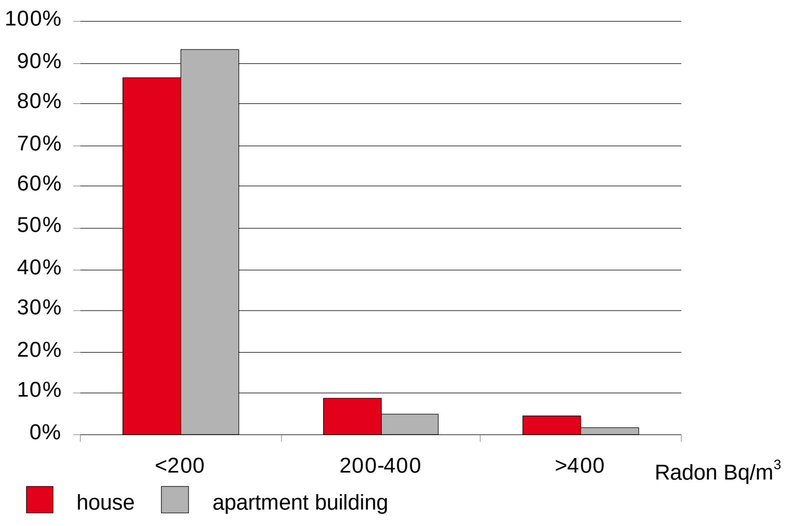

Fig. 2 Distribution of buildings with radon levels within specific intervals.

7.1.1 WHO proposes radon limit value of 100 Bq/m^3

In 2010, the World Health Organization, WHO, proposed a limit value of radon set at 100 Bq/m^3. [9]

BETSI shows that lowering of the limit value from 200 Bq/m^3 to 100 Bq/m^3 would affect 400 000 single-family houses and 230 000 apartments in apartment buildings, or about 1.3 million people. Regarding new construction, about 5000 people are affected on an annual basis by radon levels exceeding 100 Bq/m^3. [10]

The remediation cost for the existing building stock is estimated at 1.550 – 2.100 million Euro, with an additional increase in operating cost at 55.000 million Euro. Based on socio-economic calculation, lowering of the Swedish limit value from 200 Bq/m^3 to 100 Bq/m^3 is considered unreasonable. [10]

7.2 Volatile organic compounds, VOC

There are several sources of volatile organic compounds, VOCs, in indoor air, e.g. building materials, furnishings and human activities, such as the use of hygiene products and household chemicals. The total amount of volatile organic compounds, TVOC, is commonly used as benchmark. The value is obtained by summation of all compounds within the distillation range around 70-290 º C.

BETSI reports the TVOC values, and the ten most abundant elements in each individual home. Benzene, 1-butanol and 2-ethylhexanol were quantified in all samples, regardless if they were included among the ten most abundant elements or not.

Table 1 Mean TVOC results from BETSI, compared with measurements in ELIB.

	Year built	BETSI (µg/m³)	ELIB (µg/m³)
Single-family houses	before 1960	260 ± 100	-
	1961 – 75	360 ± 110	490 ± 230*
	1976 – 85	380 ± 170	380 ± 50
	1986 – 95	190 ± 60	-
	1996 – 2005	230 ± 40	-
	Total	300 ± 50	470 ± 180*
Apartment buildings	before 1960	200 ± 60	320 ± 40
	1961 – 75	150 ± 30	270 ± 50
	1976 – 85	150 ± 30	-
	1986 – 95	130 ± 20	-
	1996 – 2005	150 ± 90	310 ± 40
	Total	170 ± 30	-
Single-family houses + apartment buildings	Sum	230 ± 30	

* In one of single-family houses was measured a TVOC value of 5100 mg / m³. If the average is estimated without this outlier, the result is 380 mg / m³.

TVOC values for indoor air in single-family houses varied between 49 and 1424 µg/m³, and in apartment buildings between 57 and 854 µg/m³.

7.2.1 Comparison with ELIB

Like ELIB, BETSI shows a higher TVOC concentration in single-family houses than in apartment buildings. The levels have fallen by 20 - 45 % since the ELIB study. This reduction may be due to several factors, e.g. that producers have changed the chemical content of products, the use of voluntary emissions testing of building materials, such as floor coverings and paints. Other factors may be the introduction of the compulsory ventilation check, and increased awareness among the public in the use of chemicals indoors, including cleaning products.

7.2.2 Comparison with WHO guidelines etc.

Several national and international organisations, including the World Health Organization WHO, recommend that the TVOC levels in indoor air should not exceed 300 µg/m³. BETSI shows that this level is exceeded in 32 % of the single-family houses and in 10 % of the apartments in apartment buildings. Most of these are however within the margin of error of the measurement method. With regards to the measurement error margins, the BETSI study concludes that the Swedish housing stock largely meets the recommendations.

7.2.3 Limit value for TVOC

There is no limit for TVOC and it is unlikely that such a thing will be formulated in the future, as the concept of TVOC cannot be directly linked to human illness. It is possible that limits for individual VOCs may be introduced in the future. The current knowledge of these low exposure levels is however considered inadequate and in part contradictory, and do not provide enough scientific support for introduction of limit values.

7.3 Benzene

Today's construction products, furnishings and household chemicals do not contain benzene. Thus the building itself is not the source of benzene in indoor air. The sources are tobacco smoke, motor gasoline and some white spirits. Especially motor gasoline and emission from combustion engines that enter the building through the supply air are assumed to be the main sources of benzene in indoor air.

The environmental objective Clean Air states that the benzene level in outdoor air should not exceed 1 µg/m³ as an annual mean. This level may also be applied for indoor air. An inventory of outdoor air benzene levels in 2001 showed an annual mean of 1.6 µg/m³.
There is considerable uncertainty in chemical analyses of benzene concentrations near 1 µg/m³, and in this case, the total uncertainty was estimated at ± 40 %. The WHO recommended value is based on an annual mean, while the measurements in BETSI were performed for about two weeks. Translation of the recommended annual average gives a two-week average, which is estimated at 1.4 µg / m³.

7.3.1 Benzene levels in BETSI:

– More than half of the single-family houses show values exceeding 1,4 µg/m³, but most of them are only marginally exceeding this value. The conclusion is that low TVOC values generally correspond with low benzene levels, and high TVOC levels correspond with high benzene levels.
– Less than half of the apartment buildings show values exceeding 1.4 µg/m³, but most of them are only marginally exceeding this value. In apartment buildings, there is no co-variation between TVOC and benzene.

It is surprising that the benzene levels in indoor air are higher in single-family houses than in apartment buildings. This could be due to storage of fuel cans in rooms adjacent to the houses, e.g. stores, utility rooms, and garages.

7.4 Nitrogen dioxide, NO_2

Nitrogen dioxide comes from all combustion processes, such as tobacco smoke, traffic and industrial activities. The main source of nitrogen dioxide in indoor air in homes is the outdoor air. Heating with gas or cooking on a gas stove also raises nitrogen dioxide levels in indoor air, but the heating and cooking with gas is very unusual in Sweden. BETSI has found a gas stove in only 4 % of all homes, and most of these were in buildings built before 1960.

The levels of nitrogen dioxide in indoor air in single-family houses ranged from 2-36 µg/m³, with an average of below 10 µg/m³. Apartment buildings showed levels between 1-38 µg/m³, averaging just above 10 µg/m³. The levels in apartment buildings are generally higher than in single-family houses, in particular for the apartment buildings that were built before 1960. This may be due to the location of the buildings, as apartment buildings are located more centrally in urban areas with surrounding traffic, while single-family houses are located in the urban periphery.

Table 2 Mean values of nitrogen dioxide in indoor air, µg/m³.

	Built year	BETSI (µg/m³)
Single-family houses	before 1960	6 ± 2
	1961-75	6 ± 2
	1976-85	9 ± 4
	1986-95	8 ± 2
	1996-2005	7 ± 2
	Total	7 ± 1
Apartment buildings	before 1960	11 ± 3
	1961-75	11 ± 4
	1976-85	13 ± 3
	1986-95	19 ± 7
	1996-2005	10 ± 3
	Total	13 ± 2
Single-family houses + Apartment buildings	Sum	10 ± 1

7.4.1 Correspondence with WHO guidelines

The World Health Organization recommends a 1-hour limit value of 200 µg/m³. BETSI shows markedly lower values in indoor air.

7.5 Formaldehyde

Formaldehyde is present in dwellings mainly due to emissions from materials containing urea-formaldehyde resins and as an additive in consumer products..

Table 3 Mean values of formaldehyde in indoor air, comparison between BETSI and ELIB.

	Built year	BETSI (µg/m³)	ELIB (µg/m³)
Single-family houses	before 1960	20 ± 6	-
	1961-75	32 ± 7	14 ± 3
	1976-85	33 ± 12	16 ± 3
	1986-95	19 ± 6	-
	1996-2005	21 ± 2	-
	Total	25 ± 5	14 ± 2
Apartment buildings	before 1960	12 ± 3	-
	1961-75	21 ± 12	7 ± 3
	1976-85	12 ±3	9 ± 2
	1986-95	14 ± 2	-
	1996-2005	22 ± 8	-
	Total	16 ± 5	7 ± 2
Single-family houses + Apartment buildings	Sum	20 ± 3	-

7.5.1 Comparison with previous study ELIB

The results from both BETSI and ELIB show that single-family houses have higher indoor air formaldehyde levels than apartment buildings. The results from BETSI are higher than ELIB, in spite of the development of construction products with lower formaldehyde emissions. This may result from having a relatively short measuring period of 1 – 3 days in BETSI as compared with about 30 days in ELIB. The long sampling period in ELIB may have resulted in saturation of the sampling medium and thus underestimation of actual values. It is quite surprising that the single-family houses built in 1961 – 75 and 1976 – 85 show the highest values. Emission of formaldehyde from materials containing urea-formaldehyde resins generally decrease within a five year period, and therefore these older houses should show lower levels of formaldehyde in indoor air.

7.5.2 Comparison with WHO levels

In BETSI, the formaldehyde levels in indoor air in single-family houses varied between 7 – 141 µg/m³, and in apartment buildings between 2 – 91 µg/m³. The indoor air levels of formaldehyde in Swedish homes are significantly below the value recommended by WHO, which is 100 µg/m³ as a 30-minute mean value. Only one of the single-family houses showed a level that was well above the recommended WHO value.

8. Conclusions

Science develops and we learn all the time to be careful with materials and substances that we previously thought were harmless. When such materials and substances are incorporated in buildings, it takes a very long time before they are phased out of the system due to the long service life of buildings.

Potentially harmful substances that are discussed today are lead in brass fittings for drinking water use, and bisphenol A which is used in relining of old water pipes.

Levels of contaminants in indoor air are generally lower than the WHO guidelines. Ventilation is one important factor that affects the levels, and is considered important in indoor air discussions. Older single-family houses are naturally ventilated, while newer ones have mechanical systems. Apartment buildings are in general mechanically ventilated and the function of those systems are regulated by law.

The radon limit value is set at 200 Bq/m^3, while the WHO recommends 100 Bq/m^3. It is not considered socio-economically reasonable to lower the Swedish limit value to meet that of the WHO.

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