SUMMARY

L. Mølhave, G.R. Lundqvist, I. Andersen: The Atmospheric Environment in Six Energy Efficient Single Family Houses. Air pollution due to volatile compounds in six unoccupied houses with intended low energy consumption was measured. The measurements included air temperature, air humidity, ventilation rate and concentration of organic gases and vapours. On average 14 different compounds were identified in concentrations exceeding 0.005 mg/m³ in the samples, and Toluene and alpha-Pinene were the most frequent compounds. A total concentration of organic gases and vapours averaged for the five periods of measurements 0.46 mg/m³ (0.032-5.5 mg/m³). The concentration decreased systematically during the year, and was halved after, on an average, 112 days (63 to 187 days). The concentration of organic gases and vapours of the solvent type was similar to that found earlier in other Danish houses. Differences in indoor air pollution could not be explained by the materials used for the houses.

RESUME

L. Mølhave, G.R. Lundqvist, I. Andersen: L'environnement atmosphérique dans six maisons individuelles à faible consommation d'énergie. La pollution de l'air causée par combinaisons volatile organiques a été mesurée dans six maisons inhabitée, construites pour une consommation basse d'énergie. Les mesurages ont compris la température, l'humidité de l'air, teaux de la ventilation, la concentration des gaz et des vapours. A la moyenne des 14 substance volatile differents ont été identifiées les échantillons en des concentrations dépassants de 0,005 mg/m³. Toluene et alpha-pinene ont été les substance volatile le plus fréquentes. Une concentration totale des gaz et des vapours organiques avaient pour moyenne 0,46 mg/m³ (0,032-5,5 mg/m³). La concentration a baissée d'une manière systématique durant l'année et a été réduite a moitié par la suite en moyenne de 112 jours (63 jusqu'a 187 jours). La concentration des gaz organiques et de vapours de type de solution était le même qu'on a trouvé dans autres maisons auparavant. Les différences de la pollution de l'air de l'intérieur ne pouvait pas être expliquées par les materiaux employés.

KURZFASSUNG

L. Mølhave, G.R. Lundqvist, I. Andersen: Das atmosphärische Raumklima in sechs energiewirksame Einfamilienhäuser. Luftverschmutzung, von flüchtigen organischen Komponenten verursacht, wurde in sechs unbewohnten Häusern mit beabsichtigt niedrigem Energieverbrauch gemessen. Die Messungen umfassten Lufttemperatur, Luftfeuchtigkeit, Ventilationskapacität, und die Konzentration organischer Gase. Durchschnittlich wurden in den Proben 14 verschiedene Komponente in Konzentrationen von mehr als 0.005 mg/m³ identifiziert. Toluene und alpha-Pinene waren die am häufigsten vorkommenden Komponenten. Eine totale Konzentration von organischen Gase und Dampfvorkommen war durchschnittlich für sämtliche fünf Messungsperioden 0,46 mg/m³ (0,032-5,5 mg/m³). Die Konzentration fiel im Laufe des Jahres systematisch und war nach 112 Tagen (63-187) durchschnittlich die Hälfte. Die Konzentration von dem löslichen Typ war vergleichbar mit der früher im dänischen häusern gemessenen Konzentration. Unterschiede in der Verschmutzung des Raumklimas liessen sich nicht durch die in den Häusern benutzten Materialien erklären.

THE ATMOSPHERIC ENVIRONMENT IN SIX ENERGY EFFICIENT SINGLE FAMILY HOUSES

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Introduction

In 1978 six experimental low-energy single family houses were built in Denmark. These houses included the most up-to-date information on building techniques and materials. The present study was therefore initiated to investigate the indoor climate to be expected in future building types. All houses were uninhabited through the first year after the completion. In this period it was therefore possible to measure the off-gassing from the building materials and permanent textures in the houses. The aim of these measurements was to investigate differencies due to different use of building materials and building methods.

Material and Methods

The six low energy houses were all prototypes, built near Copenhagen, Denmark, by six different building companies. The technical performance of the houses have been described elsewhere (1). The technical aim was low energy consumption, high air tightness and controlled air changes.

In each house the same room was used for all measurements. This room was chosen to be the smallest sleeping room. Table 1 shows some of the features of the six rooms.

Table 1. Main features of the six test rooms.

House	A	B	C	D	E	F
Floor area m^2	9.1	8.5	19.2	10.8	7.6	8.1
Volume m^3	20.6	20.5	24.0	29.8	21.8	18.0
Heating media	Electr.	Water	Water	Air	Electr.	Water
Exhaust through:	Bathroom kitchen scullery	Each room	Bathroom kitchen scullery	Two bathrooms kitchen	Bathroom kitchen scullery	Bathroom kitchen scullery

All rooms had windows which could be opened and fresh air was supplied to each room by the mechanical ventilation system.

The rooms were cleaned before the measurements and doors, windows, and ventilation systems were closed at least 12 hours before the measurements. No adjustments were done regarding air humidity and air temperature, although these parameters were registered. During the whole testing period a simulated energy consumption was maintained. This energy consumption was equivalent to that of 4 persons. Measurements of the outdoor environment were performed simultaneously to the indoor measurements. These outdoor measurements took place at least 5 m away from the building.

The sampling programme included 5 visits to the houses. During the first and the last visit all six rooms were examined while only two houses (B and F) were examined during the three other visits. These two houses were those where the highest and smallest concentration of indoor air pollution were found during the first visit. The five visits took place in May, August, October, and in January and March/April. Through the two series of measurements in all six houses it was possible to investigate differences due to different use of building materials and different building methods in the six houses. The aim of the consecutive measurements was the changes during one year.

The measurements in one room included measurements of air temperature, air humidity with thermohydrograph and ventilations measurements through elimination of radioactive tracer gas (Kr-85). The ventilation was measured with doors and windows closed, and the results therefore indicate the sum of air-change due to fresh air through the ventilation system and the exchange of air between neighbouring rooms. Volatile organic compounds were measured by combined mass-spectroscophy and gaschromatography after sampling on charcoal adsorbers. The detection limit for this version of the charcoal method is about 5 µg/m^3 (29 PPB) (2). The accuracy is about (RSD) 30%.

Results

Measurements were successful in all rooms except one. During the forth visit house B could not be examined due to on-going reparations after water damage. Outdoor air temperature and air humidity were normal for the Danish climate, whereas windspeed was lower. Wind pressure do therefore have little influence on the ventilation in the test rooms.

No thermohydrographic results were obtained for the indoor climate during the first visit to the six houses due to a defect instrument. The average air temperature during the remaining four visits was 24.7 ± 3.0°C, significantly higher than normal standard for dwellings. Air humidity was in the normal range of 4.1 to 8.9 g/kg with an average of 5.9 ± 2.0 g/kg.

The ventilation in each room varied from 0.8 to 3.0 air change per hour. The average ventilation (and Standard Deviation) for the six houses A to F was respectively 1.3 (0.1), 0.86 (0.1), 1.1 (0.1), 1.7 (0.3), 2.9 (0.4), and 0.79 (0.1) airchanges per hour.

In average 14 compounds were identified in the air samples from the six rooms. The range was from 0 to 30 compounds exceeding 5 µg/m^3. A total of 23 different chemical compounds were identified by name as shown in table 2 which shows the average total concentration and the frequency with which the compound was identified. Toluene and alfa-Pinene were found in five of the six houses. The highest concentration of any individual compound was found for Toluene and Trichlorethane, while Undecane had the highest average concentration for compounds identified in more than one room. The distribution of the identified compounds on the four different chemical groups: alkanes, aromatic compounds, terpenes, and the group of "other" is shown in table 3. The compounds from all six rooms were equally distributed on the four chemical groups. No statistical analyses were performed due to the small numbers. House A, however, seems to be missing compounds of the group of "other"; these compounds, on the other hand, are relatively more frequent than the average in house B. No aromatic compounds were found in house C, and here alifatic compounds are more than normal represented. The geometric average of the total concentrations was 0.46 mg/m^3 for the 17 airsamples. The range was 0.032 mg/m^3 to 5.5 mg/m^3.

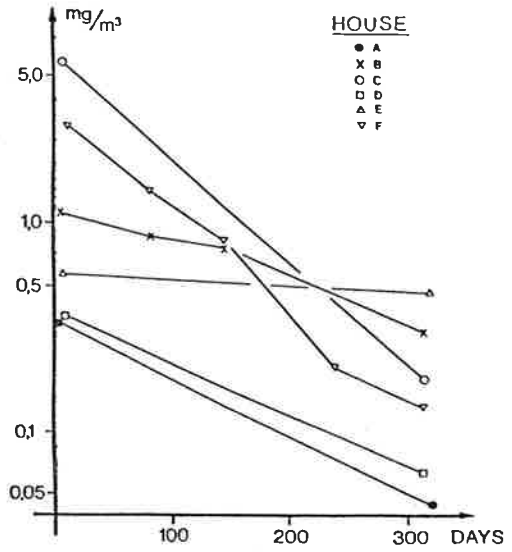
Table 2. The 23 compounds identified, their average and maximum concentrations (mg/m^3) and their frequences.

Compound	Average concentr. mg/m^3	Frequences	Compound	Average concentr mg/m^3	Frequences
Toluene	0.25	5	Trichlorethane	1.01	1
α-pinene	0.25	5	3-methyl-2-butanone	0.08	1
Δ 3-carene	0.15	4	1-Hexanone	0.05	1
Decane	0.17	4	2-Butanone	0.04	1
Ethylbenzene	0.01	4	Pentanole	0.04	1
n-Undecane	0.31	3	1-Heptanone	0.04	1
n-Dodecane	0.23	2	n-Nonane	0.02	1
Alkane *)	0.12	2	β-pinene	0.02	1
Butylacetate	0.11	2	1-Pentanone	0.02	1
Ethylacetate	0.04	2	4-xylene	< 0.005	1
3-xylene	0.02	2	C_3-benzene *)	< 0.005	1
2-xylene	0.01	2			

*) Incomplete identification

The total concentration in each room decreased during the test period as shown in figure 1. The decrease rates for five rooms were almost equal. In house E no decrease was observed. The average halftimes for the decrease in concentration for the five houses were 112 days (SD: 49) and the range 63 to 187 days.

Fig. 1.



The change through 320 days of the total concentration of organic gases and vapours (mg/m^3) in six rooms.

Table 3. The distribution on four chemical subgroups of the identified compounds.

House	Total number of identified compounds	Percentages			
		Alkanes	Aromates	Terpenes	Other
A	4	25	50	25	0
B	16	13	38	19	31
C	6	67	0	17	17
D	5	20	20	40	20
E	7	14	29	29	29
F	10	30	40	10	20
All	23	25	31	21	23

Discussion

All six houses included untraditional building details as described in reference (1), as their construction should provide new information about future building techniques and building materials. These untraditional details were, however, not so unusual that the six experimental houses could not be sold normally after the one year experimental period. Part of the work reported here was to investigate if these new building details had any influence of the total concentration of organic gases and vapours.

The same type of compounds were found in these six houses when compared to other similar Danish measurements. The air in these six low energy houses as a group, however, matched the air in another experimental house (the zero energy house) the best (3). House A is similar to seven new particle board houses (4) while house B and E are similar to the average of 39 old occupied dwellings (4). House F looks like a zero energy house (3) while house C and D have no previous match. The differences among the six houses could not be explained through the known use of building materials.

The best atmospheric indoor climate with regard to air pollution was found in house A and D where only few compounds were found and where the concentrations were low. In house C and E more compounds were found. In house C alifatic and aromatic compounds dominated while trichloroethane was found in house E. The concentration of gases and vapours were high but decreased rapidly in house C where the suspected sources were painted hessian and glued floor carpet. In house E the concentration was almost constant which may be explained by compounds previously absorbed on the surface of stones in a subterranian heat recevoir. In house B the largest number of compounds were identified. Most of these compounds belong to the group of "Other". Concentrations were not pronounced, but the concentration decreased only slowly. The least acceptable atmospheric indoor climate was found in the younger house F where both many compounds were identified and a high total concentration measured. This building was, however, 8 months younger than the other five and through the test period this building reached the same level as the other buildings had had in the first measurements.

The measuring methods used here had earlier been used in a laboratory experiment on degassing of volatile organic compounds from five building materials (5). In the laboratory-investigation it was shown that the degassing rate for each material was halfed every 40 to 100 days. In this investigation halftimes for the total concentrations between 63 and 187 days

were found. These higher halftimes may be due to the fact that the houses (excluding house F) were 270 days old when the first series of measurements were performed. The emission may therefore have changed to a more slow emitting phase.

Acknowledgement

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