CHEMICAL AIR QUALITY IN ENERGY-EFFICIENT HOUSES

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Abstract

Chemical pollutants and ventilation rate have been measured in newly built energy efficient private dwellings. The samples were taken in the absence of normal human activity in the houses. The data show that the main source of organic pollutants seems to be indoor building materials and furniture. For dust an important source could be the outdor environment. Formaldehyde was primarily found in houses where chipboard was used while levels of radon daughters was very low in all houses tested.

Introduction

In Trondheim 14 energy-efficient houses were built for a research program on new methods for energy conservation. The main emphasis has been on architecture, building technology and testing of equipment for energy conservation. Thus, the houses has been characterized in detail with regard to ventilation rate and energy consumption. We decided to study the indoor contamination of chemicals liberated from building materials and furniture. Thus we have been looking at the relationship between the chemical quality of indoor air, ventilationrate and building materials, and we have excluded the effects of human activity (e.g.smoking, cooking, pet animals).

Description of the houses

Energy-efficient houses. Out of the 14 houses, 7 were selected for a study of air quality. All our houses are on two levels with the ground-floor partly below ground level. Four of the 7 houses were built of Leca (light-weight expanded clay aggregates), the other 3 had a wooden frame. Interior walls were made by plaster and covered with latex paint. The floors in the living area were made of wood treated with terpentin oils. On the ground floor carpets covered a sement floor.

Ventilation systems. Three of the houses were built as solar energy houses with electricity as second energy source. Another three houses have heat-pumps as primary energy source with oil or electricity as secondary source. The last house use electricity as the single energy source.

During air quality sampling the heating systems were shut off and the heating was supplied by electric ovens. This procedure was carried out because heat-loss measurements were carried out at the same time.

Reference houses. The same sampling program was carried out in three houses with chipboard used in interior walls and floors. The chipboard surface was covered by wall paper, paint or wooden panels. Standard ventilation in reference houses was through piping from kitchen, bath room and toilet to above the roof. Other rooms were ventilated by ducts through the wall.

Sampling equipment

Vapors. Sampling of vapors was carried out using tubes filled with active carbon. SKC 226-16 tubes were used and suction was created by a Reciprotor pump. Correct air flow was maintained by the method of capillary tube. During each sampling two tubes were used; one tube each for qualitative and quantitative analysis.

Formaldehyde. Sampling was carried out using Orbo-22 absorption tubes from Supelco Inc. These are specially made for formaldehyde sampling.

Particulates was collected on a Whatman A-E glasfiber filter (150 mm diameter) mounted in an open-faced filterholder. An Edwards vacuum pump was used and the sampled air volume was determined using a dry gas meter. For qualitative analysis a Staplex high volume sampler was used with a 90 mm diameter filter (Whatman A-E).

Radon daughters. Samples were taken during 5 minutes on a 47 mm glasfiber filter and air-flow 15 l/min. The analysis was carried out at a specified time interval after sampling.

Sampling strategy. All sampling was started during the morning and carried out for approximately 24 hours. Sampling for radon daughters were carried out in the morning at the end of the sampling period for chemical pollutants.

Sampling place. All samples were taken in the main living room. This floor contain living room, kitchen, bathroom and one bed-room. Additional samples for radon daughters were taken in the basement.

Analysis of organic compounds were carried by gas chromatography. Identification of compounds were done comparing retention times of samples and standards and by coupled gas chromatography/mass spectroscopy.

Results

Energy efficient houses.

Organic vapors. A number of organic compounds were found in the vapor fraction and the major compounds are listed in table 1.

The total concentration was 2.2-4.4 mg/m^3 and the most prominent components were -pinene toluene and xylene. The concentration of individual compounds were 1.0 mg/m^3 or less. The qualitative composition was very similar in all houses tested. There was an iverse correlation between organic vapors and the air exchange rate as shown in fig. 1A ($r^2 = 0.94$).

Table 1. Organic compounds identified in the vapor fraction of room air taken from energy-efficient houses

Solvents	Terpenes	Aliphatics
Ethanol	α-pinene	Nonane
Methylethylketone	β-pinene	Dekane
Methylisobutylketone	3-carene	Undekane
Trichloroethylene	Limonene	Dodekane
Toluene		Tridekane
Xylene		Tetradekane
Ethylbenzene		
Styrene		
Methylstyrene		

Formaldehyde. Concentration of formaldehyde were below 0.1 mg/m^3, and the data did not permit a proper correlation to air exchange rate to be carried out.

Total particulates. Total concentration of particulates varied from 0.013 to 0.038 mg/m^3 and was proportional to the air exchange rate as shown in fig. 1B (r^2 = 0.72). Organic compounds were extracted from particulates collected on the filters and a number of compounds were identified on GC/MS (table 2). The concentration of a individual compound was 1 µg/m^3 or less.

Table 2. Organic compounds identified in the particulate fraction collected in energy efficient houses

Organic acids	Plastizicers	Others
Octanoic	Tri-isobutylphosphate	Cyclohexylcyclohexane
Nonanoic	Tri-n-butylphosphate	Nicotine
Dekanoic		Methyl-n-tetradecanoate
n-Dodecanoic	Phthalate-diisobutylester	
n-Tetradecanoic	Phthalate-dibutylester	Methylesters
n-Pentadecanoic	Phthalate-diisooctylester	di-2-ethylhexyadipat

Radon. The radioactivity of radon daughters was measured to be 0.1-0.3 pCi/l. No difference was noted between the houses or the three sampling areas in each house.

Reference houses

Organic vapors. Mainly the same chemical substances were found in the reference houses compared to energy-efficient houses. In the three houses investigated the concentration varied from 0.3 to 1.25 mg/m^3.

Formaldehyde. In these houses the concentrations were found to be 0.3-0.7 mg/m^3 which is considerably higher compared to the energy-efficient houses.

Total particulates was found to vary between 0.02 to 0.04 mg/m^3 which is similar to energy efficient houses.

Radon daughters were not measured in the reference houses.

Discussion

Most of the identified vapors can be traced back to certain building materials. Tests for evaporization of chemicals from building materials have been carried out in Denmark /1/. The inverse proportionality between concentration of organic vapors and air exchange rate, strongly suggest that the sources for organic vapors are indoors.

Total particulate concentration increases with increasing ventilation which may indicate that a major source of dust is the outdoors. Sampling was carried out during winter when the ground was covered by snow, thus likely sources of outdoor dust would be heating system and automobile traffic. The organic compounds associated with the dust probably originate from indoor sources.

Formaldehyde was mainly found in the houses where chip boards were used as structural elements in the house (floor, walls, ceiling). Other sources of formaldehyde (textiles etc) seems to have less importance. The concentrations of formaldehyde found in our study are similar to these reported elsewhere /2/.

The level of radon daughter activity was similar inside and outside the houses. We could not detect any significant difference inside houses built by wood or Leca (light-weight expanded clay aggregates).

Acknowledgement

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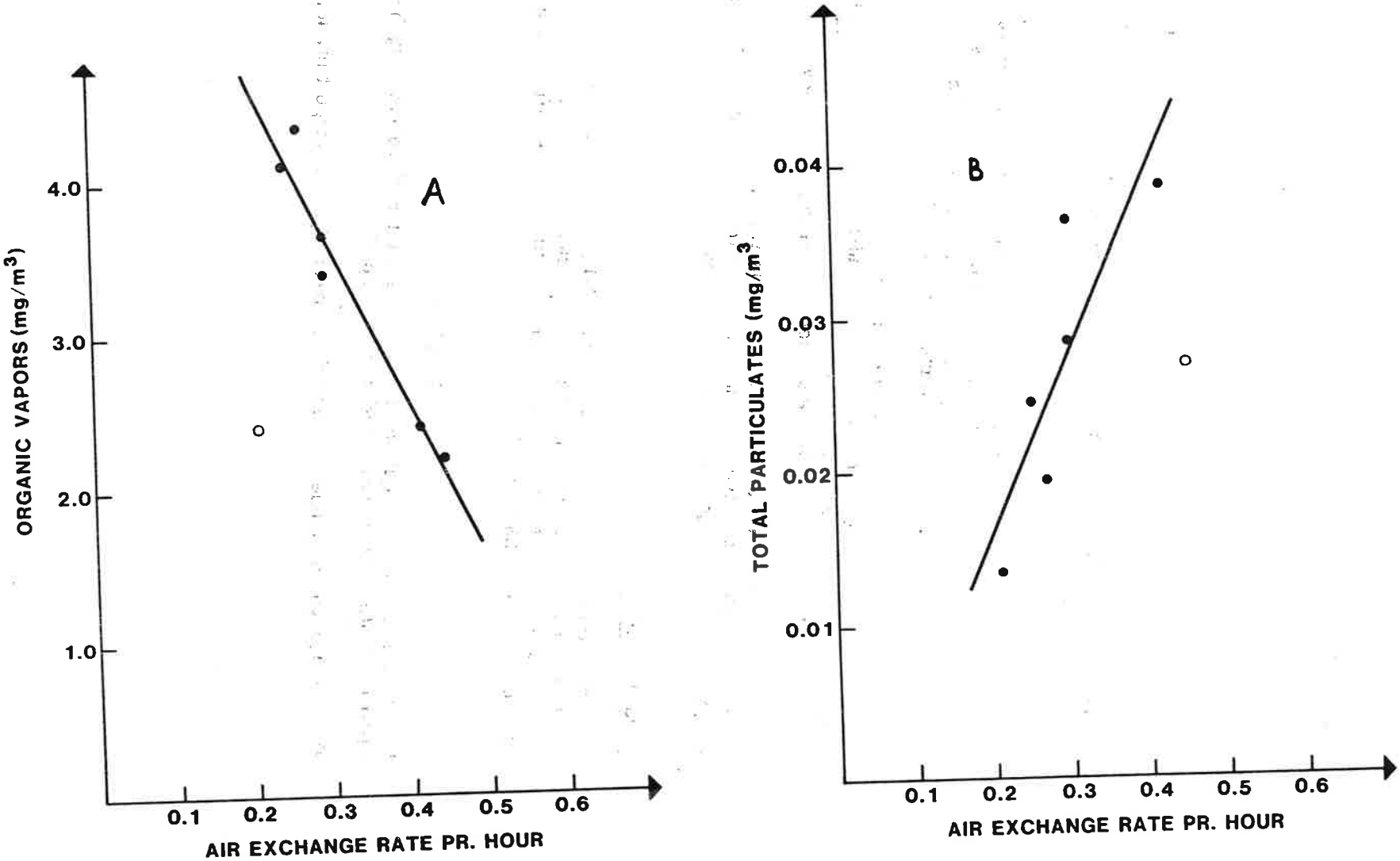

Fig. 1. Concentration of organic vapor (A) and total particulates (B) in energy efficient houses plotted against the air exchange rate. Open circle represent values which were excluded from the regression analysis.