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Methods for Indoor Climate Measurements in Large-Scale Surveys

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ABSTRACT

The principles and design of passive devices to measure long-term averages of a number of indoor climatic variables are briefly described. The methods, some of which were developed recently, are to be used in a survey study of the indoor climate in Swedish dwellings. The variables are (1) indoor temperature, (2) ventilation rate, (3) relative humidity, (4) radon, (5) formaldehyde, and (6) volatile organic compounds (VOCs).

INTRODUCTION

A set of physical indoor climatic variables are to be measured in a large survey of indoor climate in the Swedish housing stock. The goal and design of this survey is described in a companion paper by Norlén et al. (1991).

This paper gives a short description of the methods to be used for measuring the following indoor climatic variables:

- Indoor temperature
- Ventilation rate
- Relative humidity
- Radon concentration
- Formaldehyde concentration
- VOC concentrations (TVOC and five main pollutants).

The methods are all of the passive integrating type, yielding monthly averages of the variables. One reason for this is that the result is intended to be used only for statistical interpretation. Other reasons are to allow for the effects of occupant habits and to minimize the effect of extreme weather conditions during measurement. The chosen techniques are relatively inexpensive, robust, and give a negligible disturbance to the occupants. From laboratory and field trials, the methods are shown to yield satisfactory accuracies.

Indoor temperature, ventilation rate, relative humidity, and radon concentration will be investigated in 1,600 apartments (1,200 houses). Formaldehyde and VOC levels will be measured in a subsample of 200 units.

METHODS

Indoor Temperature

Since one goal of the planned project is to estimate the potential for energy conservation in the Swedish housing stock, it is essential to measure the indoor temperature (Holgersson and Norlén 1984). There are, however, other reasons, connected to the indoor climate, for measuring the temperature. First, it is an important parameter for comfort; second, the emission of contaminants may be strongly dependent on temperature. Furthermore, temperature is a variable that is important for computation of other measured variables, such as humidity, ventilation rate, and radon concentration.

The temperature-measuring instrument to be used is a simple battery-driven electronic device using an RC-oscillator circuit with an NTC resistor as the sensing element. The pulses from the temperature-dependent frequency are summed up in an electronic counter. After the measurement period, the counter content is transferred to a computer. The time-averaged temperature is computed from the number of stored pulses using a device-dependent calibration constant. Some specification data for the device are:

- temperature range: 0–50 °C
- inaccuracy in temperature (10–40 °C): < 0.2 °C
- long-term instability: < 0.1 °C
- maximum sampling time: 1 year
- resolution: 0.1 [K · h]

One or two units are planned to be used in each home.

Ventilation Rate

The ventilation rate is to be measured using a passive tracer gas method. A similar method, known as the BNL-AIMS method, was described in Dietz et al. (1986) and is now used extensively. The present method relies on the same basic principles, that is, continuous constant emission of perfluorocarbon tracer gas (PFT) from permeation tubes and diffusion sampling of air with adsorption tubes. There are, however, major differences in the tracer compounds, the adsorbent, and the analytical technique.

The SIB method was recently developed at the National Swedish Institute for Building Research (Stymne and Eliasson 1991). The tracers (perfluorobenzene and perfluorotoluene) are released from the tracer gas sources at a rate of 10 to 20 micrograms per hour. The concentration in the air depends on the ventilation flow rate and may typically amount to 100 ng/m^3. The sampling rate of the diffusion samplers (standard charcoal sampling tubes) is approximately $1.5 \cdot 10^{-5}$ m^3/h. Thus, a sampler may contain on the order of 1 ng tracer after four weeks' sampling. After the sampling period, the samplers are sent to a laboratory and analyzed for the amounts of adsorbed tracers. The analysis is performed through liquid extraction of adsorbed compounds, gas chromatographic separation (on commercially

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available equipment), and quantitative analysis with an electron capture detector. The average ventilation flow rate can be estimated from the adsorbed amounts of tracers, the known sampling rates, and the tracer source strengths.

Figure 1a illustrates the design of the permeation tubes and samplers. Figure 1b shows the analyzed amounts as a function of sampling time.

The passive tracer gas technique has a number of limitations, and the accuracy of the result is influenced by such factors as incomplete mixing of tracer and ventilation air, a time-varying flow rate, and the temperature of the tracer gas source. However, with proper sampling strategy, it has been shown that the accuracy is satisfactory and comparative to that of more elaborate methods of measuring ventilation flow rates.

Humidity

Two categories of passive samplers for water vapor can be identified, one based on the adsorption/desorption characteristics of hygroscopic materials and the other on the diffusion rate of water vapor through a tube with an adsorption material with a known equilibrium vapor pressure. The former type has recently been employed in a field survey in Denmark (Nielsen 1989; Bergsøe 1990). Small blocks of preconditioned beechwood were weighed before and after exposure. This type of device yields a kind of moving average of the relative humidity

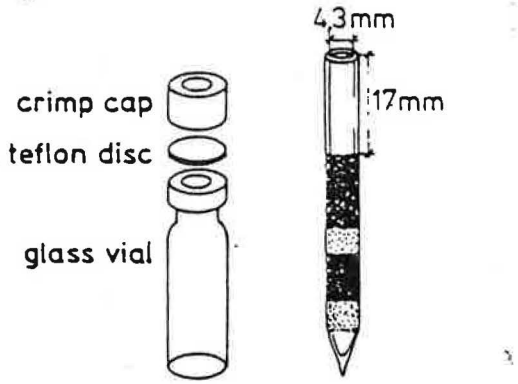

Figure 1a Design of the tracer gas source and diffusion sampler.

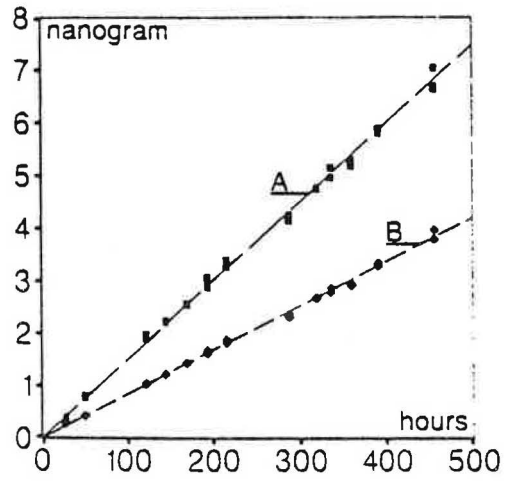

Figure 1b Example of a laboratory sampling test at constant ventilation rate. The graph displays the analyzed amounts of two different tracers (A and B) after different exposure times. Data are displayed for duplicate analysis of two samplers per occasion.

with declining significance of previous conditions as the exposure continues.

In order to obtain the average humidity over four weeks, the integrating type of sampler represented by the second category was chosen for the present study. Samplers based on this concept, using silica gel or concentrated sulfuric acid, were originally described by Palmes and Gunnison (1973) and more recently by Girman et al. (1986), who considered a molecular sieve (zeolite) as the adsorption medium. Due to a limited water adsorption capacity and a concentration-dependent equilibrium vapor pressure, none of these devices is suitable for sampling periods longer than approximately one week. A further complication with silica gel and molecular sieve is the interference from carbon dioxide.

In order to eliminate the inconveniences mentioned, we have chosen lithium chloride monohydrate ($LiCl \cdot H_2O$) as the absorption medium. In equilibrium with its saturated solution, this hydrate has a water vapor pressure at 20 °C corresponding to 11% RH. This equilibrium water vapor pressure remains constant as long as the absorbed amount of water is kept below approximately 50% of the initial weight of the solid monohydrate.

According to Fick's first law of diffusion, the sampling rate in a diffusion tube is directly proportional to the difference in vapor pressure at the opening of the tube and at the trapping medium interface at the bottom of the tube.

Figure 2 shows the result of a laboratory test at different RH at 20 °C. The plastic tubes used have an inner diameter of 9.7 mm and are filled with approximately 1 g of moist porous crystals of lithium chloride monohydrate in the bottom, covered with a glass fiber filter disk. The diffusion length from the tube opening to the salt hydrate was 60 mm. The result shows a closely linear relationship between sampling rate and RH up to approximately 65% RH, indicating that this type of sampler is suitable for integrating sampling over this range.

Radon Concentration

Radon measurements are performed with passive integrating nuclear track detectors. The detectors are produced and analyzed at the Swedish Radiation Protection Institute (SSI).

The detectors (see Figure 3) are based on a standard technique comprising CR-39 as detector material, a plastic holder, chemical etch, and automatic reading in an image analysis system.

SSI has adapted the technique primarily to the needs of an ongoing nationwide epidemiological study (Mellander and Enflo 1991). The needs are:

- low cost per detector
- long exposure time (1 to 12 months)
- good accuracy in exposures ranging from 100 to more than 4,000 kBqh/m^3
- ease of handling (small size).

The SSI detectors are characterized by:

- CR-39 as detector material, exposed area 3 cm^2
- electrically conducting polypropene in holder
- antistatic treatment of detector material
- chemical etch
- automatic reading in batches of 39 detectors
- extensive quality controls.

The detection limit for radon gas is approximately 20 kBqh/m^3, which corresponds to less than 10 Bq/m^3 for three-month exposures. The sensitivity factor is 2.6 tracks/cm^2 per

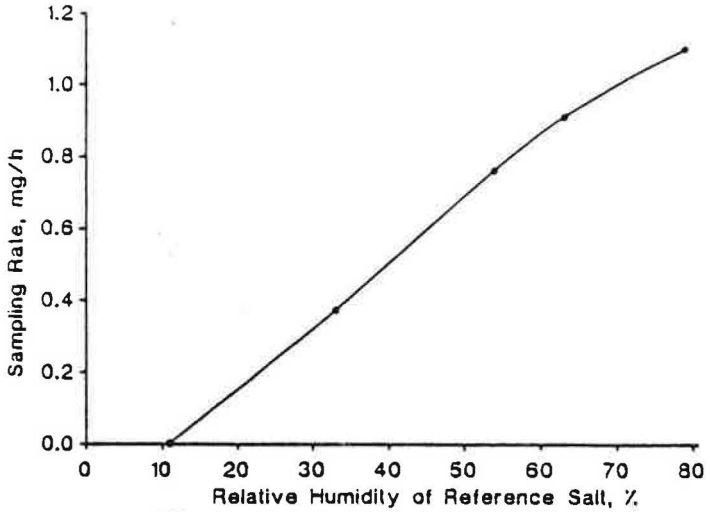

Figure 2 Experimentally determined water vapor sampling rate vs. relative humidity in a laboratory hygrostat test at 20°C. The reference humidities are maintained by the use of a saturated solution of a set of salt hydrates.

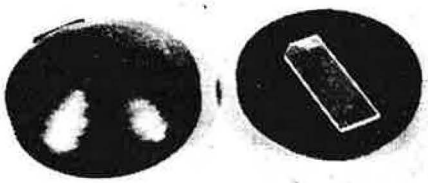

Figure 3 Design of the passive radon detector.

kBqh/m^3. The accuracy, measured as one standard deviation in a set of detectors exposed to 800 kBqh/m^3 (corresponding to a three-month exposure at 400 Bq/m^3), is approximately 5%.

The detectors are calibrated by exposing every fifteenth detector to an atmosphere with an accurately known radon concentration in one of the SSI radon rooms. Background is estimated by etching and reading every thirtieth detector.

In the indoor climate study described in this paper, the detectors will be exposed for a duration of more than one month during the heating season, i.e., September to May. In each dwelling, two to three detectors will be used, one in each of the most used rooms and on each floor in detached houses. After exposure, the detectors will be returned to SSI for read-out.

Formaldehyde Concentration

Formaldehyde is trapped on diffusion samplers. The principle is based on chemisorption of aldehydes on 2,4-dinitrophenyl hydrazine (Levin et al. 1986). The samplers will be exposed to the indoor air in a bedroom and a living room for two weeks. Analysis will be performed by liquid chromatography. The lowest air concentration to be quantified is estimated to be 0.005 mg/m^3, and the uncertainty is estimated to be ±0.005 mg/m^3 at a level of 0.15 mg/m^3.

Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are defined as organic compounds in the air with boiling points from +50°C to 240°C. The sampling tubes are designed to allow for diffusion sampling for two weeks. Shortly before exposure, the adsorbent is thermally activated. The sampling tubes will be positioned adjacent to the formaldehyde samplers.

Analysis is done through thermal desorption at 260°C in a stream of helium. Separation and quantitative analysis is performed by a gas chromatograph, with a connected mass spectrometer (MS) as detector. Peak identification is done by direct comparison of MS peak pattern with a standard NBS library. Quantitative estimates are expressed as toluene and decane equivalents. The lowest detectable concentration is 0.001 mg/m^3. The estimated uncertainty for a single compound is 0.005 mg/m^3 at a concentration of 0.100 mg/m^3. The five most abundant organics will be identified and quantified. The sum of concentrations of volatile organics (TVOC) is also to be determined.

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