Surveys of air pollutants in UK homes

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Evaluating the quality of indoor air in dwellings in any country can be considered a challenging task because they represent a large number of individual environments. Each dwelling is to some extent unique because of the sources of pollutants they contain, the occupants that influence both source and ventilation characteristics and the temporal and spatial variation in pollutant concentrations that is known to occur. For example, in England there are 21 million dwellings and these differ in size, building type and number of occupants and there are differences in climate and levels of outdoor pollutants because of the geographical spread. The UK housing stock is largely naturally ventilated and this differs from some countries where mechanical ventilation, often with heat recovery, is more common. Table 1 summarises some characteristics of the building stock based on the English House Condition Survey of 2001 [1].

Knowledge about the occurrence of indoor air pollution in UK buildings has been gained from two main types of study; investigations of particular buildings, often in response to complaints by occupants about air quality, and surveys of groups of buildings including a national survey to develop a database on levels of indoor air pollutants. These studies are now outlined in chronological order and an overview provided about the current state of knowledge.

Studies of indoor air quality in the UK before late 1990s

Prior 1990 there were few studies of indoor air quality in UK homes and those that were undertaken focussed on concerns about single pollutants. For example in the late 1970s the influence of gas cookers on the concentration of nitrogen dioxide (NO_2) was reported [2]. During the 1980s formaldehyde vapour was associated with incidents of complaints by some occupants of homes shortly after the installation of urea formaldehyde (UF) foam cavity wall insulation [3] and there was concern about formaldehyde in dust [4]. UF foam has been installed in over one million dwellings in the UK and requirements were introduced within the Building Regulations (Approved Document D) for quality of the foam and suitability of the property to prevent complaints about formaldehyde vapour. Radon in buildings was the subject of national and regional studies to determine the distribution of exposures for the UK population [5].

During the 1990s there was a growing awareness of the impact of indoor air quality on the health and comfort of building occupants. Investigations of several hundred buildings where occupants complained of poor air quality were reported [6, 7]. Often the source of the problem was a particular product, sometimes used inappropriately, and there were also instances of water damaged buildings, ground contamination and inadequate ventilation, although in a significant minority of cases the measurements did not identify any cause of the reported problem.

The first major study of a range of indoor air pollutants in the UK was the BRE Indoor Environment Study to determine concentrations of NO_2, volatile organic compounds (VOCs) and biological particulates in 174 homes over a 12 month period in Avon, South West England [8]. All participants were expectant women when they joined the study and they were enrolled in the ALSPAC study of childhood health. The study was conducted between 1990 and 1993 and provided extensive data on seasonal changes in pollutant concentration and informed development of sampling strategies for future studies of indoor pollutants in homes.

National survey of IAQ in England

In the late 1990s BRE undertook a nationally representative survey of a number of indoor pollutants in England. This involved the measurement of NO_2, carbon monoxide (CO), formaldehyde and VOC concentrations using diffusive samplers in over 800 homes [9]. The study was designed to increase knowledge of baseline pollutant levels and the factors associated with high concentrations.

The study used the Survey of English Housing (SEH) to select homes and to invite householders to participate in the study. The SEH is a survey undertaken by government to provide data on the housing stock and involves visits by interviewers to 20,000 randomly selected homes each year. In a sample of these homes, interviewers asked the occupants if they would participate in the IAQ survey. For those that agreed a questionnaire was conducted addressing issues that could impact on IAQ and locations were agreed for placing of the samplers which were subsequently provided to the householder by post. The characteristics of the 876 homes completing the study was compared with that of the 20,00 homes [10] and shown to be representative with some small biases for particular population groups such as the proportion of participants aged over 75 years (8.5% in BRE IAQ survey and 12.5% in SEH).

NO_2 was monitored using Palmes type diffusion tubes. Samplers were exposed for two weeks in each home, in the kitchen, the main bedroom and outdoors. CO was monitored for two weeks in the kitchen and a bedroom using colorimetric diffusion tubes. Formaldehyde levels were measured over a period of three days in the main bedroom of each home using a passive badge type sampler that consists of a filter paper impregnated with 2,4-dinitrophenylhydrazine (DNPH) that is retained in a plastic housing. VOCs were determined by diffusive sampling tubes packed with Tenax TA adsorbent with an exposure period of four weeks. TVOC concentrations were determined as well as the concentration of 22 individual VOCs.

Table 2 summarises results for some pollutants. In about 5% of homes the TVOC concentration exceeded 1,000 µg.m^{-3} and the geometric mean (GM) value for all homes was 210 µg.m^{-3}. Formaldehyde levels exceeded 100 µg.m^{-3} in 0.7% of the homes. There were seasonal differences in the TVOC concentration with highest mean concentrations occurring in autumn. Concentrations were higher where painting had occurred in the home during the sampling period or the previous four weeks, and homes with an integral garage were higher than those with a detached garage or no garage. After adjusting for homes that had painting undertaken, concentrations of TVOC were higher in newer homes and in bedsits and flats than other types of dwellings. Formaldehyde varied significantly with building age, newer homes having higher concentrations. The presence of particleboard flooring was associated with higher formaldehyde concentrations. Benzene concentrations were higher in urban areas and in homes with smokers and those with attached or integral garages.

NO_2 concentrations were significantly higher in kitchens than in bedrooms because many homes had cooking related sources in the kitchen. CO levels were higher in autumn and winter than spring and summer and the highest levels in kitchens were associated with the presence of a gas oven for cooking. Raw *et al.* (2004) identified some implications for mitigation of exposure arising from the results of the study [9]:

- avoid being in the same room as gas cooking activities, especially if a gas oven is in use, and/or ensure good extract ventilation close to gas cooking appliances,
- use low emission materials in the construction and furnishing of homes, and ensure good ventilation, especially during construction and the first year of occupancy,
- efforts to improve outdoor air will lead to improvements in the indoor air, especially in winter in urban areas, but will do little to affect the largest exposures indoors,
- the mere provision of ventilation devices has little effect, they need to be used,
- avoid exposure to tobacco smoke.

The national survey determined average concentrations of pollutants over periods of days to weeks and did not consider short term peak concentrations which are also a potential health concern. To address this issue, at least for CO and NO_2, a separate study of 73 gas cooking homes was undertaken using continuous monitoring methods [11]. This study found that 13% of the homes during summer and 18% of the homes during winter had CO levels that exceeded the WHO one-hour guideline value (WHO 2000). The sample mean of maximum hourly-averaged NO_2 levels in the kitchen was 310 µg.m^{-3} in the summer and 424 µg.m^{-3} in the winter.

Other major studies

The studies undertaken prior to 2000 provided a database of concentrations of selected pollutants in homes in England and they identified a range of factors determining the pollutant levels. One important determiner of indoor air quality not investigated was the rate of ventilation and this was because of the technical difficulties and costs of such measurements. A further study of 37 newly built homes in England during 2002 did involve simultaneous measurements of air quality and rates of ventilation [12]. All homes in the study had central heating with radiators and were double glazed with trickle ventilators in the window units to provide background ventilation.

Measurements of airtightness of the homes with windows and doors closed, expressed as air changes per hour at 50 Pa, were undertaken using a fan pressurisation technique prior to the monitoring of indoor pollutants. VOCs, NO_2, CO and formaldehyde were measured using diffusive samplers with an exposure period of three days to two weeks, depending on the pollutant. PM_{10} was measured using a pumped gravimetric method with a sampling period of 24 hours. Information was collected about the characteristics of the properties and the activities of occupants using questionnaires. Concurrent with the pollution measurements, a perflurocarbon tracer method was used to determine the mean rate of air exchange of the indoor air with outside air for the two week period.

The results from the measurements were statistically analysed, based on data from questionnaires, including house characteristics and occupant activity diaries.

In winter, 68% of homes had a whole house ventilation rate below the minimum design value of 0.5 ach, which according to BRE research is necessary to avoid condensation. In summer, 30% of homes had a whole house ventilation rate below 0.5 ach. Some relationships between the amount of ventilation and the concentration of some pollutants were found as well as correlation between particular sources and pollution, such as the presence of a gas cooker and the concentration of NO_2.

A particular driver of several studies of indoor air quality in the UK since 2000 has been the investigation of risks to human health due to contaminated land where contamination is found to be present either beneath or adjacent to existing buildings. Part 2A of the Environment Protection Act 1995 came into force in April 2000 and to support the regime Model Procedures have been developed to assist in the management of contaminated land (Environment Agency 2004). These incorporate the use of risk assessment and risk management techniques that assess potential pathways for exposure of people to ground contaminants, including the inhalation of vapours and gases that may enter buildings through the floor.

One major study in North-West England involved the measurement of concentrations of chlorinated

butadienes in 145 buildings in the vicinity of a historic industrial waste disposal site [13]. The measurement programme found that concentrations of hexachlorobutadiene (HCBD) exceeded 0.6 ppb in 22 homes. The UK Department of Health Committee on Toxicity (COT) advised that continuous exposure to HCBD in air of less than 0.6 ppb can be regarded as being without appreciable adverse health effects. In consequence residents moved out of the affected homes and a number were demolished, this being the most cost effective option for breaking the pollutant – receptor linkage caused by the ingress of vapours from the ground into the homes.

A further study undertaken in Scotland involved the assessment of the possible ingress of benzene from the ground into the living space of two blocks of maisonettes built on a former gas works site [14]. An investigation was undertaken over a 12 month period to measure the benzene concentration in the 24 households situated on the contaminated site and in 30 control properties situated in the vicinity, but not on contaminated land. The use of control properties enabled an investigation of confounding factors, in particular other possible sources of benzene indoors. It was shown that ingress was not causing a significant elevation in benzene concentrations indoors, but homes where at least one occupant was a smoker had benzene concentrations significantly higher than homes without a smoker.

Overview

Studies in the UK have provided a considerable amount of information about the concentrations of some pollutants in buildings, particularly homes. There have been fewer systematic surveys of other building types, notably offices, and until recently schools. Most of the data is for buildings in England and there are few measurements in Scotland, Wales and Northern Ireland. Factors associated with relatively high levels of particular pollutants have been identified such as use of gas cookers, presence of environmental tobacco smoke, an integral garage containing a car, painting and decorating activities, and newly built properties. Relationships have been found between the rate of ventilation and the indoor air quality, but relatively few studies have involved simultaneous measurements of air exchange rates and concentrations of pollutants. There is little information on some pollutants such as SVOCs, MVOCs, particulates and biological particulates, except dust mites.

While challenging to undertake, a national survey provides valuable information on the exposure of the population to air pollution, a means of assessing the impact of particular sources on air quality and a database by which to identify pollutants and concentrations occurring at unusual concentrations. Also, if repeated at intervals of several years, it will provide a valuable tool to assess whether policies to control population exposure to air pollutants are having the desired impact. This is particularly important at the present time where pressures to improve the energy efficiency of buildings are resulting in greater use of insulants, more air tight structures and use of more innovative designs and materials.

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Table 1.
Some characteristics of dwellings in England [1]

Type	% in each group	Age (1)	% in each group	Floor area	m^2
Terraced house	28.5	Pre 1919	21.0	factor	
Semi detached house	27.6	1919-1944	17.7	Mean	87
Detached	15.4	1945-1964	21.1	25 percentile	60
Bungalow	9.7	1965-1980	21.7	50 percentile	76
Flat	18.8	Post 1980	18.5	75 percentile	98

(1) Many properties have later additions e.g. more than 50% of detached houses of all ages have more recent additions.

Table 2.
Concentrations of some of the air pollutants measured in bedrooms of English homes [9]

Compound	Concentration µg m^{-3}		
	GM	10th percentile	95 th percentile
NO_2	11.9	4.4	38.1
CO	390.0	120.0	1 680.0
Formaldehyde	22.2	9.8	61.2
TVOC	210.0	72.0	1 010.0
Benzene	3.0	1.0	14.6
Toluene	15.1	4.4	74.9
Limonene	6.2	1.3	51.0