Air Quality and Ventilation in Dwellings

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Her work at BRE has been largely in the field of environmental physics and she has published papers on the prediction of building performance and energy use in dwellings. She spent three years on secondment to the Building Research Energy Conservation Support Unit, working closely with local authorities and housing developers on projects aimed at improving the energy efficiency of dwellings. Eighteen months ago, she returned to mainstream research within BRE, to work on the problems of ventilation and indoor air quality in housing.

INTRODUCTION

Concern about the quality of air in dwellings and other buildings is growing, particularly in those countries which have, over the last few years, been engaged in active energy conservation programmes. Some indoor contaminants, such as radon and formaldehyde, have only recently begun to attract attention; others such as water vapour and the products of combustion appliances have been acknowledged for many years. The importance of adequate ventilation in maintaining good indoor air quality is becoming more widely recognised, not least because of the tendency towards lower ventilation levels in dwellings, either as a result of changing construction styles and techniques or deliberate action to reduce heat losses.

VENTILATION AND INFILTRATION

In its most general sense, 'ventilation' refers to the total exchange of internal and external air, through purpose provided openings, such as airbricks and openable windows and through 'adventitious' openings, such as cracks around windows, door frames and skirting boards. Natural ventilation is caused by pressure differences across openings in the fabric of the dwelling, as a result of wind movement around and over the structure and differences between internal and external temperatures. The level of ventilation depends on two factors: the size of the pressure differences, and the size and characteristics of the openings.

All dwellings can, by virtue of their openable windows, support ventilation rates which are way beyond those normally required for the control of indoor contaminants. Openable windows make provision for a far wider range of ventilation rates than would be achieved, for example, by a mechanical ventilation system. In practice, most occupants *do* use windows to control internal conditions, particularly on milder winter days and during the summertime. Problems of poor indoor air quality are generally found in dwellings which remain 'closed up' for prolonged periods, often because occupants are trying to prevent the loss of valuable heat or perhaps because of security risks. In discussing indoor air quality, it is appropriate to consider the minimum rate at which fresh air is likely to enter the dwelling, when all controllable openings such as windows and ventilators are closed. This is usually referred to as the 'infiltration' rate of the dwelling and results from air entering the dwelling through gaps in the structure and through permanent fixed openings.

In some dwellings, infiltration rates may be in excess of the levels required for maintaining good indoor air quality and unnecessary heat loss may result. Equally, infiltration alone may be inadequate, leading to problems of poor indoor air quality, unless occupants introduce additional ventilation through purpose provided openings or mechanical systems.

INDOOR CONTAMINANTS

A certain level of fresh air input is required in all dwellings, for breathing, the safe and efficient operation of combustion appliances, the control of contaminants and the removal of odours. Occupants will often take action to control contaminants which they perceive as being troublesome, such as condensation on windows or tobacco smoke. Of greater concern are the contaminants which occupants do not generate directly and which cannot be detected by them, for example, the products of combustion appliances. Recent publicity has been given to four domestic contaminants; in the case of three of these (combustion products, water vapour and formaldehyde), as a result of problems caused by inadequate control of the contaminant and in the case of the fourth (radon decay products), because of an awareness that a potential problem may exist. The following sections summarise what is known about these contaminants and the guidance currently offered on their control:

Combustion products

One of the major factors in determining ventilation requirements is the need to supply fresh air to both open-flued and conventionally-flued appliances for cooking and heating. Air is required for two purposes; firstly to ensure that combustion of the fuel is as complete as possible and secondly to ensure the dilution and removal of the products of combustion. These are predominantly water vapour and carbon dioxide with small quantities of other gases, depending on the type of fuel and burner, such as oxides of nitrogen, carbon monoxide, formaldehyde and sulphur dioxide. If adequate combustion air is not provided, circulation within the dwelling of carbon monoxide could occur at sufficiently high concentrations to incur fatal consequences.

Problems of inadequate air supply should not occur if permanent ventilation openings are provided, as specified in the Building Regulations and Gas Board literature. However it is not uncommon for occupants to block airbricks or grilles, in an attempt to eliminate draughts, without appreciating the potential danger of their actions. Although the Gas Boards are empowered to disconnect the gas supply from any dwelling in which the supply of outside air to appliances is thought to be inadequate, such action is likely to be taken only if circumstances have prompted an inspection of the dwelling. It is important that all householders should understand the importance of regular servicing and maintenance of appliances and the need for clear, unobstructed flues, airbricks and grilles.

In cases where there is no statutory requirement for permanent ventilation openings, as is the case with most gas cookers, gas fires and paraffin heaters, adventitious gaps in the structure are relied upon to supply air to the appliance. For example, in the case of a typical gas fire, the assumed adventitious opening is 30 cm^2. Although an effective opening of this size would be found in the rooms of most dwellings, the fitting of well sealed windows or draughtproofing measures could in some cases result in a significant reduction in the open area. In such cases, it may be necessary to incorporate additional controllable ventilation openings in the window frames, to ensure that the required ventilation rate can be provided.

Surface condensation and mould

The presence of water vapour in indoor air is essential for a comfortable environment but if relative humidity levels exceed 70% for prolonged periods, surface condensation leading to mould growth and damage to surfaces can occur (Ref. 1). The scale of the dampness problem in the UK has been investigated by BRE's Scottish Laboratory, in a survey of the dampness complaints received by five local authorities in one week (Ref. 2). On the basis of this, it was estimated that in England alone, some 500,000 dwellings are affected by mould resulting in damage to carpets, floors and furniture, and a further 2.3 million dwellings are affected by less severe mould, affecting decorations. Whilst condensation is not the sole cause of dampness, the survey found that about two thirds of the diagnosed cases were caused by condensation. The scale of the problem in the rest of the UK is likely to be similar to that in England, which means that as many as 2.5 million dwellings in the UK are affected by serious surface condensation.

Condensation is most commonly caused by a combination of four factors:

(i) Poor ventilation, i.e. the rate of supply of outside air is inadequate, or mixing of air in certain parts of the dwelling is inadequate.

(ii) Poor thermal insulation standards, i.e. structural elements are cold in relation to internal air temperatures and water vapour condenses on surfaces.

(iii) Inadequate or highly intermittent heating.

(iv) Relatively high rates of generation of water vapour by occupants.

Improvements in thermal insulation standards can require considerable capital expenditure but have been shown to be effective in reducing condensation related problems. Action in respect of the other three factors can be equally effective and may require only minor changes in occupants' lifestyles.

From the foregoing it is clear that the minimum ventilation rate needed to maintain moisture levels at an acceptable level can vary markedly from one dwelling to another. The key factor is to ensure that internal relative humidities stay below 70%, since above this level the risk of surface condensation and mould growth increases significantly. In addition, internal temperatures should not be allowed to fall below 10°C, since temperatures lower than this can promote condensation-related problems.

In dwellings which are heated to reasonable standards, and in which moisture generation rates are not excessive, an average room ventilation rate of between 0.5 and 1.0 air changes per hour should minimise the risk of surface condensation. If the dwelling is relatively airtight and infiltration alone is unlikely to provide the required 0.5 to 1.0 air changes per hour, additional ventilation will need to be provided. Additional ventilation is also essential when kitchens and bathrooms are in use; required rates can be in excess of 10 air changes per hour, if moisture is to be removed at source. In practical terms, the optimum solution is for all rooms to have provision for introducing low levels of additional ventilation without introducing draughts or creating a security risk, and for kitchens and bathrooms to have, in addition, electrically operated extract fans, preferably incorporating humidistat control.

Useful guidance on ventilation rates and the other factors affecting condensation, for both designers and occupants, is given in British Standard BS 5250:1975 and BRE Digest 297.

Formaldehyde

Formaldehyde is a vapour which is found in most dwellings and which can cause irritation to the eyes, nose and throat in those affected. Sources of formaldehyde include adhesives in particle boards, furnishing materials, urea-formaldehyde (UF) foam insulation, tobacco smoke, ripening fruit and the combustion products of natural gas. Particle boards and UF foam have been the subject of much publicity in recent years and as a result, British Standards now exist to govern the manufacture and testing of board products and the installation of UF foam insulation. In the case of these two sources, any emission of formaldehyde vapour is usually a temporary problem and in general, can be overcome by increased ventilation to all rooms of the house.

Longer term problems can occur with UF foam if foam enters the dwelling, through discontinuities in the inner leaf which were not detected during the initial survey. In this event, steps must be taken to remove that part of the foam which has found its way into the dwelling (Ref. 4). In the case of particle boards, indications are that for those manufactured in the UK, the British Standard specification has been effective in preventing any formaldehyde related problems.

Radon decay products

Radiation, from natural sources and manufactured products, constitutes a contaminant in dwellings and one which can be detected only by sophisticated monitoring equipment. In the UK natural sources account for about 78% of the total mean exposure of occupants to radiation. Of the natural sources, radon decay products account for about one third of the total and represent the highest single source (Ref. 3) Radon, which is an inert radioactive gas, is one of the decay products of uranium and since uranium is present in the earth's crust, all soil and masonry products are potential sources of radon.

Studies by the National Radiological Protection Board are underway at present to determine how radon levels vary across the UK. Preliminary findings have made it clear that regional variations are large, with higher radon levels in areas of igneous geology than those in areas of sedimentary geology. In the UK, most homes support relatively small doses of radon and the associated risks are very small compared with other everyday risks. In such cases, estimated to be over 99% of the housing stock, the ventilation levels required to control other indoor contaminants will ensure the control of radon and its decay products.

In those areas where houses are affected by high levels of radon, remedial measures may need to be taken to reduce the exposure of occupants to radiation. A joint programme between the National Radiological Protection Board and the BRE is underway to study remedial treatments which are likely to be acceptable and effective in the UK. Control of the radon at source seems likely to be the most appropriate solution, either by ventilation of the underfloor space or sealing of the floor, using membranes and sealants. Evidence available to date suggests that high ventilation rates are not an appropriate solution; in those houses which are affected by high doses of radon, the ventilation rates which would be required to control radon are so high that they would not be tolerated by occupants.

VENTILATION REQUIREMENTS

Control at source is now recognised to be the optimum solution for controlling some indoor contaminants; nevertheless ventilation has a very important role to play in ensuring good indoor air quality and it is therefore necessary to define suitable ventilation rates for dwellings. Acceptable levels of many domestic contaminants are established (Ref. 5) and if these levels can be linked with estimates of the rates of production of the contaminant, it is possible to define a required ventilation rate. However in dwellings, a less detailed approach may be all that is possible, because of the large variations in contaminant production rates and the need for generally-applicable advice.

Statutory requirements for the ventilation of dwellings are set out in the Building Regulations. The requirements of Part M, in respect of certain types of combustion appliance, ensure that sufficient outside air is provided to ensure the safe operation of the appliance. Part K, in respect of the ventilation of habitable rooms, ensures that *provision* for adequate ventilation is made. In England and Wales (except Inner London where GLC regulations apply), minimum areas of ventilation opening are specified, as a percentage of floor area, viz, 5% in all rooms. If this area of ventilation opening, usually a window, is fully open, the resultant room ventilation rate will be of the order of 10 ach, which is considerably higher than would normally be required to control indoor contaminants. The provision of adequate ventilation area is however not in itself sufficient to ensure that adequate ventilation is provided at all times.

In general, the ventilation requirements dictated by moisture control will be sufficient to control other contaminants. Thus, a ventilation rate of between 0.5 and 1.0 air changes per hour in living rooms and bedrooms is usually sufficient to maintain good indoor air quality. However in many dwellings, particularly newer dwellings or those which have been extensively draughtproofed, this rate will not be provided by infiltration alone and additional ventilation will be required for much of the time. The guidelines set out in BS5250 are relevant in this context, since they are aimed at ensuring that ventilation openings are designed and installed in such a way that they will be used by occupants. The most important requirements are that ventilation openings must allow fine control; they must be positioned at high (but not inaccessible) level to prevent draughts and they must be secure so that they can be left open for long periods if necessary. Often such features can be incorporated into window units.

Kitchens and bathrooms require more careful provision, because of the high rates of moisture generation. When moisture is not being generated, the ventilation rates required for other rooms will suffice, subject to the requirements of combustion appliances. When moisture is being generated, the opening of a window during and for a short period after use (with internal doors closed) will usually serve to remove moisture. This practice may however be unacceptable during cold weather. The use of humidistat controlled extract fans provides more reliable control of moisture levels although the installation of such fans must not interfere with the operation of any combustion appliance.

VENTILATION AND AIRTIGHTNESS – MEASUREMENT AND PREDICTION

Having defined a range of ventilation rates for dwellings, the next stage is to determine whether or not a given dwelling supports that level of ventilation. The dwelling's infiltration rate alone may be sufficient to ensure good indoor air quality but if it is not, additional permanent or occupant controlled ventilation will be required. The infiltration rates which actually occur vary considerably from one dwelling to another. The histogram of Figure 1 shows whole house infiltration rates measured in 26 post war UK dwellings (Ref 6). A total of 430 measurements are included, covering a range of weather conditions at each house. The mean level measured was 0.7 air changes per hour, which, under normal conditions of

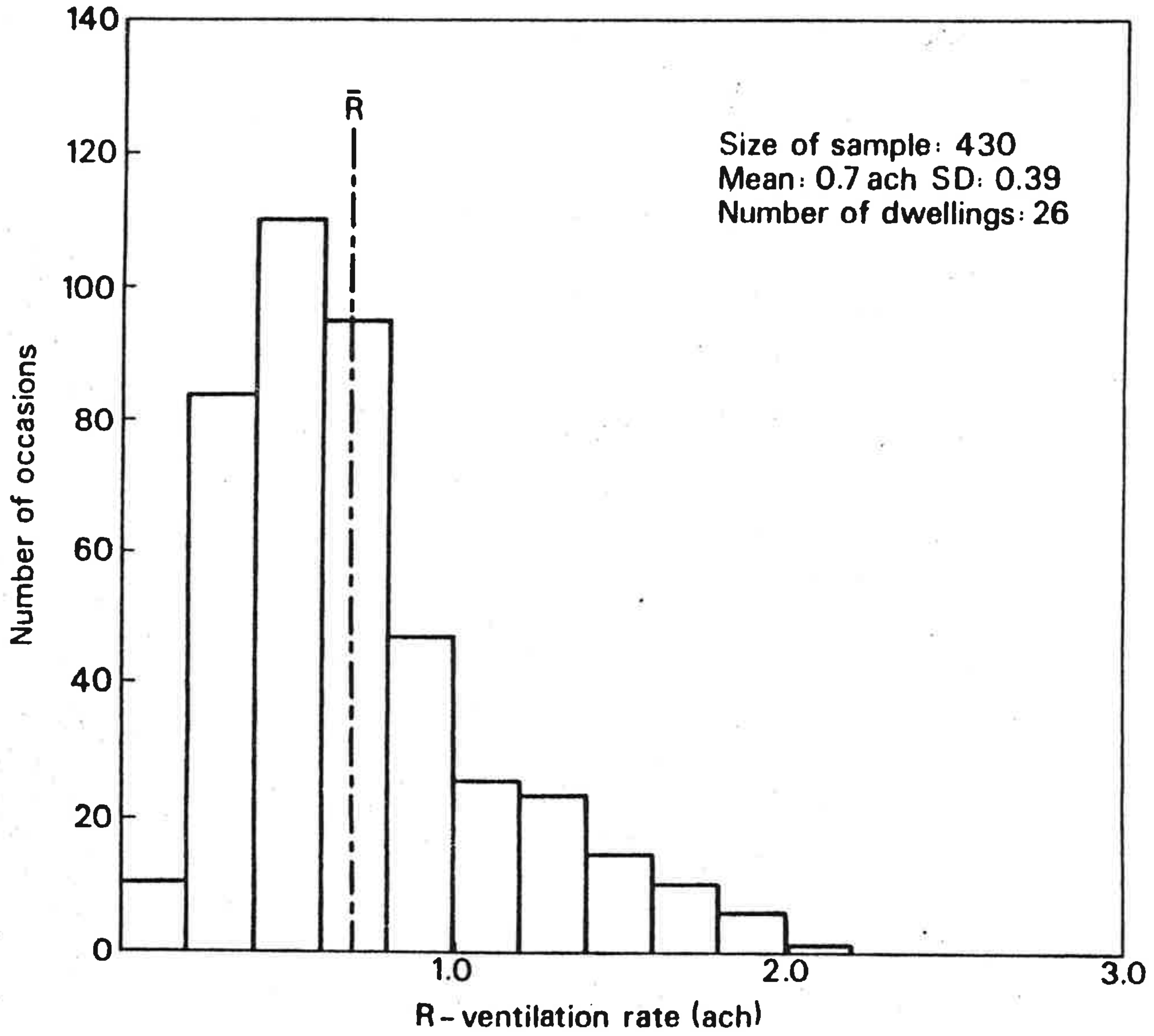

Figure 1 Distribution of Whole House Ventilation Rates (Ref. 6)

occupancy, is likely to be a satisfactory level for the removal of most contaminants. The variation in measured levels is the interesting factor, reflecting some houses where infiltration alone is likely to be inadequate and others where heat losses due to air infiltration may be excessively high.

Measurement of the actual infiltration rate of a dwelling is an expensive and time-consuming exercise. The technique most commonly used is to introduce a 'tracer' gas into the dwelling, ensure that it is well mixed, by the use of fans, and then observe the rate at which the concentration of gas decays with time. The gas used is usually one which does not occur naturally in the atmosphere, such as nitrous oxide or sulphur hexafluoride. Because of the variation of infiltration rate with wind speed and temperature, measurements are usually carried out over a two to three week period, to cover a representative range of weather conditions. The disadvantage of tracer gas techniques is that they require complex and expensive equipment and trained specialist staff. In the foreseeable future, their use is likely to be confined to specialist research organisations.

There is however an alternative, much simpler method becoming more widely available which enables an assessment to be made of the air leakage characteristics of a house. With the aid of a mathematical model (Ref 7), the results of the air leakage test can be interpreted in terms of the likely air infiltration rate of the dwelling under chosen weather conditions. The 'pressurisation' technique involves the use of a large fan, usually mounted into a doorway, to progressively pressurise or depressurise the house. The air flow rate through the fan (and hence through the fabric of the house) is measured at a series of pressure differences in the range of 10 to 60 Pa. These pressures are higher than those generated by wind and temperature effects, (typically less than 10 Pa), and so the technique is largely independent of weather conditions. A full test can be completed within about two hours, which is the major attraction of this technique.

The air leakage characteristics of any given dwelling depend on its built form, style and quality of construction, number and type of openings and many other factors which may be peculiar to that dwelling. Part of the current BRE research programme on ventilation in housing is aimed at increasing our understanding of the leakage characteristics of dwellings, so that guidance on required ventilation rates can be interpreted more directly in terms of required permanent and adjustable ventilation openings. To date, pressurisation tests have been conducted on about 200 houses in the UK and the results have demonstrated a wide range of leakage rates, corresponding to a wide range of likely infiltration rates.

The pressurisation technique can be used to a limited extent as a tool for diagnosing the causes of certain indoor environment problems. For example, if a house suffering from severe condensation problems is found to be very airtight (say an air flow rate of less than 5 air changes per hour at a pressure difference of 50 Pa), then one of the causes of the condensation is almost certainly inadequate ventilation, unless occupants keep windows permanently open. Use of pressurisation in this way is becoming established in the UK, with a few organisations having the equipment and expertise to conduct the test.

Although the pressurisation technique is much simpler and less expensive than tracer gas techniques, it nevertheless requires specialist equipment and trained staff. The aim of part of the current BRE research programme is to develop even simpler methods of assessing air infiltration or leakage rates, including on-site assessment by a surveyor or other professional.

Measurement techniques are useful only for dwellings which have built; when dwellings are at the drawing board stage, it is useful to be able to predict the likely air infiltration rate of the dwelling, on the basis of its construction type and ventilation related characteristics. The mathematical models which already exist at BRE to enable such predictions to be made are currently being developed for use by building professionals.

CONCLUSIONS

Maintaining good indoor air quality in dwellings is the responsibility not only of the occupants but also of architects, designers and those involved in the supply and maintenance of domestic equipment. In most dwellings, ventilation rates of between 0.5 and 1.0 air changes per hour will suffice to control indoor contaminants, provided that adequate heating is provided and that steps are taken to remove water vapour at source during periods of moisture generation.

In some dwellings, air infiltration alone may be sufficient to ensure good indoor air quality; in others particularly those which are relatively airtight by virtue of their construction or window type, infiltration alone may be inadequate. Determination of the actual air infiltration rate of a dwelling is not in general a practicable proposition and for this reason, it should be assumed that all dwellings will require additional ventilation for some or all of the time. It is recommended that all habitable rooms in a dwelling should, in addition to large openable areas, have provision for finely controllable ventilation. either by the use of 'trickle' ventilators in window frames or fine control catches on openable windows. Ventilation openings should be designed and positioned in such a way as to prevent draughts and not pose a security threat. Moisture generated in kitchens and bathrooms should be removed at source, if possible by the use of humidistat controlled extract fans.

Dwellings which have combustion appliances other than the room sealed type must have provision for a permanent supply of outside air to the appliance. If the appliance is of a type covered by the Building Regulations, the specified area of ventilator must be provided and must be kept clear. Appliances which do not require a permanent ventilator nevertheless require a supply of outside air and if rooms containing such appliances are tightly sealed, additional ventilation through controllable openings should be provided whilst the appliance is in use.

Occupants have a role to play and where their lifestyle is one of the factors contributing to an indoor air problem, advice from appropriate professionals may be necessary. The importance of ensuring fresh air supply to each room, particularly kitchens and bathrooms and of keeping airbricks clear and unobstructed, especially in rooms containing any type of combustion appliance, must never be understated.

The problems of poor indoor air quality are not yet fully understood and research has an important role to play. In addition to improving our understanding of the contaminants themselves, there is a need to improve our understanding of how houses are used with respect to ventilation. Developments in measurement techniques should soon enable a detailed assessment of an individual dwelling to be made, for relatively low cost and with minimal disturbance to occupants.

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