How is the indoor environment related to asthma?: literature review

George Richardson MSc MPhil
PhD Student, Faculty of Health and Social Work, University of Plymouth, Plymouth, UK

Susan Eick BSc (Hons)
Resource & Resolutions Officer, AC&T Ltd, Plymouth, UK

Raymond Jones PhD
Professor of Health Informatics, Faculty of Health and Social Work, University of Plymouth, Plymouth, UK

Accepted for publication 19 January 2005

Correspondence:
George Richardson,
Faculty of Health and Social Work,
University of Plymouth,
12 Woolwell Drive,
Plymouth PL6 7JP,
UK.
E-mail: ionian@tiscali.co.uk

RICHARDSON G., EICK S. & JONES R. (2005) *Journal of Advanced Nursing* **52**(3), 328–339

How is the indoor environment related to asthma?: literature review

Aims. This paper reports a review conducted to identify the factors in the indoor environment that have an evidence-based link with the exacerbation or development of asthma and to identify measures that healthcare professionals can promote to reduce exposure to these risk factors in the home.

Background. The indoor environment, particularly at home, has been recognized as a major source of exposure to allergens and toxic chemicals. Exposure to allergens and toxins is thought to exacerbate respiratory conditions, in particular, asthma.

Methods. Searches were made of health and indoor environment databases, including Cochrane Library, National Health Services Centre for Reviews and Assessment Reports, British Medical Journal, CINAHL and Ovid library, MEDSCAPE/MEDLINE, EMBASE, INGENTA, Science Citation Index, Web of Science. Searches were also made of other Internet-based resources, including those of international and government bodies. The following keywords were used: allergens, allergen avoidance, asthma, asthma prevention, cat, damp, *Der p* 1, dog, environmental control, house dust mites, indoor air quality, indoor environment, meta analysis, mould, pets, remedial actions, respiratory illnesses and systematic reviews.

Findings. There is evidence of a link between asthma and a small number of indoor environmental factors. There is currently only reasonable evidence for one causative factor for asthma in the indoor environment and that is house dust mite allergen. Although there are many studies of different remedial actions that can be taken in the home, often these give evidence of reduced risk of exposure but not clinical improvement in asthma. Although there is a lack of medical evidence for the reduction of known sensitizers such as mould, this is because of a dearth of research rather than evidence of no association.

Conclusions. There is some evidence of a link between the indoor environment and asthma. There are measures, which could be promoted by healthcare professionals to alleviate asthmatic symptoms.

Keywords: asthma, health education and promotion, health visiting, homes, indoor environment, literature review

Introduction

The asthma epidemic

There has been an inexorable rise in the number of asthma cases and respiratory illnesses, especially in industrialized countries over the last 30–40 years. Asthma is a respiratory disease involving inflammation of the airways and reversible symptoms of bronchospasm (Crocket 1993). Along with New Zealand, Australia and Ireland, the United Kingdom (UK) has one of the highest prevalence rates of asthma symptoms in the world (ISAAC Steering Committee 1998). Around 8 million people in the UK are currently diagnosed asthmatics (Asthma UK 2003). It is the most common chronic childhood disease (Liu 2001), with one in eight children suffering from it (Asthma News 2003). About 38% of asthmatic children miss one school week and 8% miss one school month every year (Asthma UK 2003). The cost to the UK National Health Service of treating asthma has been estimated at £850 million per year (Asthma UK 2003), to which can be added a further £161 million in social security costs and £1·2 billion in lost productivity (Asthma News 2003). In Australia, the cost of treating asthma has been estimated at £290 million (NAC Australia 1992), with similar figures in New Zealand (£306 million). In the United States of America (USA), £6·8 billion is spent on the indirect and direct costs of asthma (American Lung Association 2004).

It has been suggested that the rise in cases indicates a tendency to over-diagnose childhood asthma; however, research by Clark *et al.* (2002) in the USA does not vindicate this, and suggests that there is under-treatment of asthma.

Changes to the indoor environment

There is awareness that the indoor environment is a source of health risk factors. The modern home is 'sealed up' and highly thermally insulated to improve energy efficiency, often to the detriment of indoor air quality. As well as structural changes, activities within the home have changed. House-cleaning routines predominantly use vacuum cleaners and a variety of chemical-based cleaning agents, adding to the environmental burden indoors. A good quality indoor environment is important because most people spend more than 90% of their time indoors, and more than half of this time at home. Custovic and Woodcock (2000) and the National Academy of Sciences Institute of Medicine (NAS) (2000) have illustrated the stages of a child's life where prevention of sensitization to allergens and prevention of triggers for asthma symptoms could be important. All the triggers they highlight are abundant in the home environment. The Joint Research Centre for the European Commission has stated that 20% of Europeans suffer from asthma because of substances inhaled indoors [Joint Research Council (JRC) 2003]. In industrialized countries, 60–80% of asthmatic children and adults have at least one positive skin prick test to a common airborne allergen (Eggleston 2000).

Aim

The aim of this review was to identify the factors in the indoor environment that have an evidence based link with asthma and to identify measures that health professionals can promote to reduce exposure to these risk factors in the home.

Search methods

Searches were carried out using the following keywords singly or in combination: allergens, allergen avoidance, asthma, asthma prevention, cat, damp, *Der p* 1, dog, environmental control, house dust mites, indoor air quality, indoor environment, meta analysis, mould, pets, remedial actions, respiratory illnesses and systematic reviews. Papers written in English, German, Swedish, and French were considered. The following databases were searched: Cochrane Library, National Health Services (NHS) Centre for Reviews and Assessment Reports, British Medical Journal, CINAHL and Ovid library, MEDSCAPE/MEDLINE, EMBASE, INGENTA, Science Citation Index, Web of Science. Other Internet-based sources were also searched, including those of US and UK government departments and institutions; asthma charities, manufacturers of anti-allergen products, advisory companies on the indoor environment.

Consideration was given to conducting a meta-analysis in combination with a Jadad scoring system (Jadad *et al.* 1996); however, in September 2003 there were not enough studies available to carry out such an evaluation. Therefore, a book commissioned by the US Environmental Protection Agency (EPA) in corroboration with the National Academy of Science's Institute of Medicine (NAS 2000) was used as the benchmark for the review. Research conducted after the book was compiled or conducted prior to 2000 (not reviewed by NAS) or research of special interest already reviewed has been included. The cut-off date for this review was September 2003. The inclusion criteria were that the research (1) was current and provided experimental evidence that indoor environmental variables are causative or exacerbative triggers in respiratory illnesses, and (2) provided evidence of practical, primary and secondary measures which demonstrated a statistically significant reduction in the targeted variables and improved clinical outcomes or asthmatic symptoms.

Findings

General

Table 1 lists the variables with a negative association with health highlighted by different organizations in the UK and USA. Similar reviews have been pursued in other countries, e.g. Sweden, Finland, and Germany (JRC 2003). The present review and those cited in Table 1 have found other indoor environmental variables associated with health, with limited evidence of a link with asthma and respiratory problems. In this paper, variables are only discussed if there was a strong evidence base available.

There is strong evidence of a link between respiratory illness and carbon monoxide (CO); however, CO is a specific pollutant which can be easily prevented by the correct installation and venting of gas appliances, and therefore will not be discussed further. Tobacco smoking and associated environmental tobacco smoke are detrimental to health. There is sufficient evidence to conclude that there is an association between environmental tobacco smoke and the development of asthma in younger children (NAS 2000). The only reliable remedial action for smoking at home is either to give up smoking or ban all smoking within the home.

Humidity, dampness, and temperature are commonly cited as being important to the health of occupants. As humidity and dampness are strongly indirectly linked to asthma, they are discussed in detail here. Temperature has not been highlighted by NAS (2000) as a risk factor in asthma, although in the UK it is often implicated in asthma morbidity (Collins 2000). Problems traditionally associated with cold homes are being addressed in the UK by an extensive housing modernization and energy efficiency programme. In parts of Europe, particularly Scandinavian countries, housing has been energy efficient for generations, with no marked differences between the health of people living in energy efficient houses compared with energy inefficient houses. An association is often offered of worsening health conditions with reduced dispersion of indoor pollutants in energy efficient houses, because of reduced ventilation (Sieger *et al.* 1987, Ashmore 1998).

Ventilation is a decisive factor in determining the concentration of the variables in Table 1 and controlling

Table 1 Common indoor environment variables and the strength of evidence for their relation to respiratory health, according to previous reviews

Variable	Institute for Environment and Health (IEH) (2001) General Health	US Environmental Protection Agency (EPA) (1994) Respiratory Health	NAS (2000) Asthma
House dust mite allergen (*Der p* 1)			Strong evidence for causal relationship for exacerbation and development
Environmental tobacco smoke	Strong evidence of an association	Strong evidence of an association	Strong evidence of a causal relationship with exacerbation and association with development
Cat allergen (*Fel d* 1)		Limited evidence of an association with exacerbation	Strong evidence of causal relationship with exacerbation
Cockroach allergen			Strong evidence of causal relationship with exacerbation
Dog allergen (*Can f* 1)		Limited evidence of an association with exacerbation	Limited evidence of an association with exacerbation
Moulds	Insufficient evidence	Limited evidence of an association with exacerbation	Sufficient evidence of an association with exacerbation
Nitrogen dioxide	Strong evidence of a low risk		Sufficient evidence of low risk
Carbon monoxide	Strong evidence of an association		
Allergens (general)	Strong evidence of an association		
Formaldehyde			Limited evidence of an association with exacerbation
Pesticides, polycyclic aromatic hydrocarbons, endotoxins, volatile organic compounds	Insufficient evidence		Inadequate evidence of an association

humidity and dampness. Ventilation is one of the few remedial actions that can alleviate many indoor problems. Present UK, Canadian, French, and Swedish building regulations for residential buildings, suggest a minimum continuous air exchange rate of 0·5 ac/h (air changes during 1 hour).

House dust mite allergens

Ecology

Voorhorst *et al.* (1969) identified the allergen *Der p* 1 from the mite *Dermatophagoides pteronyssinus* as the major, virtually omnipresent, allergen in house dust in temperate climates. The diet of photophobic *D. pteronyssinus* mites consists of skin cells, partially broken down by the mould *Aspergillus* sp. (Douglas & Hart 1989), providing moisture and nutritional benefit (van Asselt 1999). Both *Aspergillus* sp. and *D. pteronyssinus* require humid surroundings (> 50% relative humidity) to prevent dehydration (Arlian 1992). *Der p* 1 is a chemically stable (up to 4 years) allergen made up from enzymes produced in the mite's gut and contained in faecal pellets. House dust mites excrete ~20 dry faecal pellets a day, with a diameter of 10–20 μm (Critchley *et al.* 2000). It has been estimated that foam-backed, fitted carpets contain up to 1,500,000 mites m^2, producing 30 million pellets per day. When these pellets are ground down (through abrasion and cleaning) to 0·5 μm, this results in 900 million fine pellets every day in 1 m^2 of carpeting. Vacuum cleaning (without a high efficiency filter), general cleaning and activities indoors will break up faecal pellets and re-suspend smaller, inhalable particles (often termed 'dung-dust'), which only settle after many hours.

Health impact

Despite the fact that humans have cohabited with mites throughout the ages, there is an increasing number of dust mite allergy sufferers. One explanation is the increase in favourable conditions for the mites brought about by housing modernization and the increased amount of time spent indoors (Howieson *et al.* 2003). However, such observations only apply in temperate climates and do not explain the growing number of asthma cases elsewhere (ISAAC Steering Committee 1998). No longitudinal studies were found that compared the average amounts of airborne *Der p* 1, i.e. has the average household concentration of *Der p* 1 increased over the past half century? No research has been found comparing the levels of *Der p* 1 in older mattresses/carpets in relation to breathing problems, despite the fact that they are skin cell and dust reservoirs, which might support large dust mite colonies.

NAS (2000) concluded that:

- There is sufficient evidence of a causal relationship between *Der p* 1 allergen exposure and the development of asthma in susceptible children.
- There is sufficient evidence of a causal relationship between *Der p* 1 allergen exposure and exacerbations of asthma in individuals specifically sensitized to dust mites. Continual exposure to *Der p* 1 allergen is also a contributing cause of chronic bronchial hyperreactivity.

These findings have been confirmed in many countries and are specific, i.e. mite sensitization is associated with asthma and not with any other lung disease (Sporik *et al.* 1992, NAS 2000).

Inhaled dung-dust sticks to the mucous in the bronchioles and, because *Der p* 1 is water-soluble, a sensitized individual quickly develops a short-lived inflammatory reaction. When the inflammatory reaction is repeated, the illness asthma ensues. The accepted threshold for *Der p* 1 is ≤ 2 μg/g {μg of allergen per g of house dust [World Health Organization (WHO) 1988]} to prevent sensitization in children already sensitized to other inhalant allergens (Sporik *et al.* 1990).

Environmental control

The most effective, inexpensive remedial action associated with clinical evidence of reduced risk of sensitization to mite allergens in atopic children is the encasement of bedding and mattresses in impermeable material (Nishioka *et al.* 1998, Custovic & Woodcock 2000, Arshad *et al.* 2002, Tsitoura *et al.* 2002, Halmerbauer *et al.* 2003). However, Woodcock *et al.* (2003) showed that using allergen-impermeable encasements as a single measure to avoid exposure to dust mite allergens was ineffective for adults. A number of trials have shown a reduction in dust mite allergens when allergen-impermeable encasements were used, but did not show clinical improvements (Oosting *et al.* 2002, Rijssenbeek-Nouwens *et al.* 2002, van Strien *et al.* 2003). When there is a reduction in allergen in a study but no improvement in health, this might be because of confounding factors such as other sources of allergen from schools and occupational settings (Oosting *et al.* 2002).

Feather-filled pillows are associated with fewer incidents of wheeze compared with synthetic-filled pillows. Custovic *et al.* (2000) established that feather-filled pillows contained less allergenic material because they had very tightly woven encasements (ticks). Campbell *et al.* (2003) concluded that the available research on pillows is inadequate to assess possible clinical benefits for asthmatics.

Few studies address reducing humidity as a remedial action for reducing mite numbers. Howieson *et al.* (2003) installed mechanical ventilation and heat recovery (MVHR) systems in bedrooms, which resulted in a 12% reduction of relative humidity and 96% reduction of *Der p* 1 in carpets and mattresses. Htut *et al.* (1996) state that, to reduce the proliferation of mites indoors, the following atmospheric conditions are needed: 3·5 ac/h; relative humidity < 50%; and temperature 15–19°C. Such conditions are practically impossible to support when a room is in regular use.

Acaricides (pesticides developed specifically for mites) temporarily reduce the number of dust mites in soft furnishings. Mihrshahi *et al.* (2003) showed that, in combination with allergen-impermeable mattress encasements, acaricides reduced *Der p* 1 in bedding but not below 2 μg/g. An Australian study of aggressive mite avoidance measures, including acaricidal carpet shampoo and mattress encasing, demonstrated that both techniques reduced *Der p* 1 concentrations (Sporik *et al.* 1998). The study highlighted that *Der p* 1 concentrations were lower in uncarpeted floor areas. Bahir *et al.* (1997) showed that a combination of avoidance measures plus an acaricide was no more effective for asthmatic symptoms than using the avoidance measures on their own. Cloosterman *et al.* (1999) found a statistically significant reduction in *Der p* 1 when combined methods were used, but did not achieve an improvement in clinical measures. Although opinions are divided on acaricides, the treatment of bedding through simple hot washing (> 55°C) is widely advocated as an effective measure to reduce mite numbers (NAS 2000, Woodcock *et al.* 2003).

Pet allergens

Characteristics

All domestic animals add to the bio-burden indoors through shedding dander, bringing in biological material from outdoors, and from indoor activities. There are ~9·2 million cats and ~6·6 million dogs in UK homes (Cats Protection League 2003). Only cat allergen will be discussed, since 80% of the allergenic material from dogs (*Can f* 1) is found on non-respirable particles > 5 μm (Custovic & Chapman 1997), whereas the majority of allergenic material from cats (*Fel d* 1) is found on particles < 5 μm (Custovic *et al.* 1998). The difference in size means that *Can f* 1 is more difficult to inhale. More asthmatics are sensitized to *Fel d* 1 than any other pet allergen. *Fel d* 1 is a water-soluble glycoprotein (Schou 1993), normally measured in ng/g (ng of allergen per g of house dust). The protein is produced in sebaceous, salivary, and anal glands (de Andrade *et al.* 1996). The protein is sticky and can be transported for long distances on cat dander (Custovic & Chapman 1997), causing transference of *Fel d* 1 to homes and buildings without cats (Etkin 1995, Smedje & Norbäck 2001). Large amounts of *Fel d* 1 can be found in a house – van der Heide *et al.* (1997) measured the amount of *Fel d* 1 shed in a living room over a 6 month period at 50,000 mU (milliunits of allergen).

Health impact

Fel d 1 is a serious cause of asthma in sensitized individuals (van der Heide *et al.* 1999), who are often classed as suffering from 'pet allergic asthma'. In industrialized countries, up to 40% of adults or children (2–4 years of age) with atopy and asthma may be sensitized to *Fel d* 1(Eriksson & Holmen 1996). Lau *et al.* (2000) tracked 939 children from birth to 7 years of age to find correlations between early pet exposure and the prevalence of asthma, but no relationships were found.

NAS (2000) concluded that:

- There is sufficient evidence of a causal relationship between cat allergen exposure and exacerbation of asthma in individuals specifically sensitized to cats.
- There is inadequate or insufficient evidence to determine whether an association exists between cat allergen exposure and the development of asthma.

Environmental control

It has been suggested that subjecting a newborn child to *Fel d* 1 might offer some protection against cat allergy. However, in a study of 3000 primary school children, no such protection was recorded (Anyo *et al.* 2002). If there is a protective effect from early exposure, it is not known how long this will last, because cats and dogs can live more than 10 years and a child might develop allergic asthma over time (de Blay *et al.* 2002a). Popplewell *et al.* (2000) have shown that a reduction in *Fel d* 1 levels can improve lung function in those with atopic asthma, especially those with cat-sensitivity, provided they have no cat at home.

High efficiency air filtration units and other air cleaners running at 2–3 ac/h can reduce *Fel d* 1 (Fisk *et al.* 2002). There is no limit of *Fel d* 1 that pet allergy sufferers can tolerate, therefore the beneficial effects of small reductions through air filtration might be negligible (Gore *et al.* 2003). Reduced ventilation in combination with carpeted floors has been shown to increase the airborne concentration of *Fel d* 1 (de Blay *et al.* 2002b).

Feather-filled pillows carry less *Fel d* 1 compared with synthetic pillows by a factor of ~6 (Custovic *et al.* 2000), for the same reasons as discussed under 'house dust mites'. Deep-cleaning strategies will only work if the source of the allergen (the pet) is removed, although *Fel d* 1 will remain in the building for at least 6 months (Carswell *et al.* 1999, Boleman 2000). Despite the fact that it is known that pets cause allergies, the issue of owning a pet is a contentious on that is often not possible to solve logically within a family.

Mould

Ecology

Mould is a saprophytic fungus (Ochmanski & Barabasz 2000) which requires appropriate temperatures, moisture, oxygen, and nutrients to germinate and grow (Sedlbauer 2001). There is a high risk of exposure to indoor sources of mould, which are not visible until they have established roots, by which time the mould colony is fully grown. Mould spores are 2–10 μm in diameter, although the majority are < 5 μm. Hundreds of mould species are found indoors, including *Alternaria* sp., *Cladosporium* sp., *Aspergillus* sp., *Penicillium* sp., and *Fusarium* sp. (Flannigan *et al.* 1991, Ochmanski & Barabasz 2000, Nolard 2001, Portnoy *et al.* 2001, Zureik *et al.* 2002, Hargreaves *et al.* 2003).

Health impact

Mould spores are commonly associated with respiratory morbidity (Strachan 2000). Dharmage *et al.* (2002) studied the effect of seasonal fluctuations of mould and visible mould on asthmatics sensitized to mould, and concluded that homes with mould do have an adverse effect on asthma independent of season.

NAS (2000) concluded that:

- There is sufficient evidence of an association between fungal exposure and symptom exacerbation in sensitized asthmatics. Exposure may also be related to non-specific chest problems.
- There is inadequate or insufficient evidence to determine whether there is an association between fungal exposure and the development of asthma.

Moulds, and particularly their spores, produce allergenic and toxic material in the form of mycotoxins and glucans (Gots & Pirages 2002). There are direct physiological responses to mycotoxins [American Academy of Paediatrics Committee on Environmental Health (AAPCEH) 1998], especially for individuals with a dust allergy (Hens 2003). A positive skin prick test to the mould genus *Alternaria* has been statistically significantly associated with asthma (Custovic & Woodcock 2000). In a meta-analysis, Fung & Hughson (2002) concluded that there is an association between mould, allergy and respiratory symptoms. However, Pirages (2003), from the International Centre for Toxicology and Medicine (USA), stated that mould concentrations commonly found in homes would not cause any negative health effect.

Zureik *et al.* (2002) indicated a strong association between mould sensitization and the severity of an adult's asthma, although sensitization to mould in isolation was unusual. The results suggested that mould had a greater influence on severity than cat allergen or pollen for existing asthmatics. Ross *et al.* (2000) found an association between mould and self-reported emergency treatments, Dales *et al.* (2000) also found the same association in a quantified study. The lack of robust evidence relating mould to specific health issues reduces the impetus for governments and local authorities to promote the remediation of mould (Burr 2001).

Environmental control

There are few studies on the effect of remedial actions reducing mould, and none were found on how remediation might affect asthma (NAS 2000). There are no standards for the presence of mould in homes. Many people recognize mould in their homes by sight or smell but fail to combat the problem, mainly because they are unaware of how to remove mould or what is causing it – a structural fault or condensation. Although visible mould is easy to record, research suggests that airborne mould levels must be quantified and qualified to prevent biased reporting (Ren *et al.* 2001) and misdiagnosis of a mould problem (Fradkin *et al.* 1987). Portnoy *et al.* (2001), found that self-reported illnesses and indoor problems linked with mould can be corroborated with a standardized assessment protocol.

A pilot study conducted by the Canadian Housing and Mortgage Corporation and Health Canada, found that, in some houses, even the combination of a ventilation system and dehumidifier did not prevent the recurrence of mould (Fauteux 2000). Fauteux (2000) has suggested that, where severe contamination is present, to have any effect, mould needs to be physically removed (including its root system) and sources of moisture.

Pitten *et al.* (2001) have researched the effect of polyurethane encasings (impermeable to particles > 3 μm) vs. cotton covers, and found that the polyurethane encasings statistically significantly reduced the amount of mould in mattresses after 1 year. The moulds most frequently found in mattresses were *Penicillium* spp. and *Aspergillus* spp. This suggests that allergen-impermeable encasings used to reduce dust mite allergens may also reduce exposure to toxic mould by-products. More research is required to determine if the results from Pitten's study came about because fewer skin cells and organic material reached the interior of the mattress, thereby reducing the food supply for mould, or because the mattress was less humid, thereby restricting the proliferation of mould.

The ingress of mould spores from outdoors can be reduced in homes with filtered mechanical ventilation, as the filters will arrest spores (Tovey 1997). If windows are shut, there is little likelihood of infiltration of mould spores (NAS 2000). Bleaching surfaces or redecorating will temporarily remove surface mould but will not remove filamentous roots. To do this a systemic fungicide is required. To eradicate mould indoors permanently, actions need to be taken to remove the source of moisture, i.e. repairing structural problems, reducing condensation through insulation, ventilating out excessive humidity, and changing lifestyle.

Humidity and dampness

Properties of humidity and dampness

Humidity is measured with a hygrometer and is often expressed as relative humidity (RH) – the percentage of water vapour in the air compared with the total amount of water vapour the same air could hold at a given temperature. Absolute humidity (AH) quantifies the amount of water in g/kg (grams of water per kg of air) at a given atmospheric pressure. The most commonly-quoted limits are RH $\leq$ 45% and AH $\leq$ 7 g/kg to prevent mould and dust mite proliferation (Munir *et al.* 1995).

Dampness is used in this paper to refer to structures and furnishings that contain excessive moisture. The differentiation between dampness and humidity is often blurred. Dampness is moisture absorbed into objects or condensation on cold surfaces, whereas humidity is water vapour suspended in the air. Dampness occurs because of high indoor humidity causing condensation, poor building design or structural deficiencies allowing moisture to enter through capillary transport of water (rising damp) from the ground into the building (NAS 2000). Dampness provides a breeding ground for mould and dust mites (Øie *et al.* 1999). It has been estimated that structural dampness was present in $\sim$33% of homes, in seven countries world-wide (NAS 2000).

Health impact

There is an association between damp housing and mould and respiratory symptoms/asthma (Billings & Howard 1998) but it is difficult to determine the relationship in isolation (Fletcher *et al.* 1999). There is an association between indoor RH levels >45% and increased prevalence of respiratory problems (Fauteux 2000). The association between asthma and dampness could be because of direct exposure to mould allergens, dust mite allergen and endotoxins or direct physical stress caused by cold and damp (Billings & Howard 1998, Frank *et al.* 1999, Dharmage *et al.* 2002). Kilpeläinen *et al.* (2001) suggest that the effect of dampness or an associated factor may be synergistic and that dampness may enhance sensitization to allergens. Evans *et al.* (2000) reported that the association was probably because of a person's perceived inability to keep their home warm in winter. There is, however, a direct link between RH $\leq$ 30% and health, as dry air can cause dry skin, eye irritations and tiredness (Sundell & Lindwall 1993).

NAS (2000) concluded that:

- Damp conditions are associated with the existence of doctor-diagnosed asthma and with the presence of symptoms considered to reflect asthma (i.e. dampness may lead to asthma development).
- Symptom prevalence among asthmatics is also related to home dampness indicators (i.e. dampness may exacerbate existing asthma).
- The factors related to dampness that actually lead to the development of disease and to disease exacerbation are not yet confirmed, but probably relate to dust mite and fungal allergens.

Environmental control

No studies clearly demonstrate that dampness and humidity control will reduce symptoms or the development of asthma (NAS 2000). The lack of available data on the affect of reducing humidity on asthma has been shown by Singh *et al.* (2003), highlighting the lack of research on humidity control. NAS (2000) recommends mechanical ventilation as a retrospective control of humidity and dampness. In the South West of the UK, outdoor AH (wintertime) is often lower than indoors (median outdoors = 5·04 g/kg; indoors = 6·50 g/kg: unpublished own data, 2003, gathered over 6 years). Therefore, ventilation will reduce humidity. Howieson *et al.* (2003) installed localized MVHR units and found a clinical improvement in lung function, although there is no way to determine if this was due to reduced RH, reduced numbers of house dust mites or a reduction in other pollutants caused by the increased ventilation. Niven *et al.* (1999) showed that using a whole-house MVHR coupled with a dehumidifier could adequately control temperature and humidity but did not have any significant effect on dust mite allergen levels. Niven *et al.* (1999) suggest that the humidity was not reduced sufficiently to reduce numbers or proliferation, and additional methods may be needed to reduce reservoirs of *Der p* 1. The reduction of humidity to reduce dust mite numbers is hampered by the fact that the house dust mite's microclimate is different to ambient conditions (Crowther *et al.* 2001).

Limitations

This review has concentrated on the impact of factors found in the indoor environment but has not reviewed allergen intake through food consumption.

What is already known about this topic

- People spend more than 90% of their time indoors in an environment that is undergoing substantial changes driven by internal and external forces.
- There has been a substantial increase in respiratory illnesses over the last 40 years, especially asthma, which some researchers link to the indoor environment.

What this paper adds

- Householders need expert advice on how to mitigate indoor environmental factors affecting health, which could come from front-line healthcare professionals such as health visitors.
- Verification that the main indoor environmental factors affecting health can be dealt with by householders themselves for very little expenditure.

Discussion

Examining comprehensive literature reviews that have covered the same topics in isolation or combination has highlighted research trends and confirmed the reliability of the literature search methods employed, strengthening the conclusions of this review. Long-term analysis of the literature relating the indoor environment with asthma revealed a finite number of topical subjects, for example:

- The reduction of exposure to *Der p* 1 in bedding has only become a major issue following the discovery and development of allergen isolation techniques.
- The removal of environmental tobacco smoke in private dwellings.
- 'Fuel poverty' linked to dampness and cold (which in this context heralds microbial growth indoors) has now become an issue because of the awareness of excess 'winter deaths' and increased morbidity from respiratory illnesses.

This review has confirmed that the collective world literature on the subject of asthma is enormous and so diverse that pulling the information together to present a concise, coherent framework is complicated. The ISAAC Steering Committee (1998) highlighted this diversity in their study of 463,801 children aged 13–14-years old from 56 countries. There is a great deal of geographical and cultural diversity, even in regional studies, as demonstrated by von Mutius (1997), and von Mutius *et al.* 1997), who compared living conditions for children in East and West Germany in relation to respiratory illnesses in connection with the occurrence of 'Die Wende' in 1989. The indoor environment varies greatly between households, because of lifestyle differences, making general recommendations for remedial actions a complex issue.

There is a lack of robust trials assessing the effect of remedial actions on indoor environmental pollutant(s), possible health benefits and separating out cause and effect for a single variable. Further, because of moral and financial issues, there are limits to which actions are acceptable and feasible for a household. Researchers must take into account perceived and real difficulties for householders when suggesting remedial actions to be taken indoors. All allergen avoidance measures require some degree of lifestyle change or physical intervention.

Coupled with the difficultly in conducting studies of the indoor environment, there are also problems with the type of health data collected in a study. Usually the prerequisite for a reliable study of health outcomes is to establish a clinical measurement or some other quantifiable outcome. Qualitative studies are not often regarded as strong evidence of changes in health, therefore, despite positive results, reviewers disregard some studies. The WHO (2002) states that a person's perception of their health status can be a useful health outcome, and there is some correlation between self-reporting and other quantifiable outcomes (Wanless 2003).

Poor housing conditions and poverty are closely connected with respiratory illnesses for children (Krieger *et al.* 2000), and are confounding factors in health and environment studies. In considering, the indoor environment as a risk factor to health, it is wrong to look at the home in isolation, as the indoor environment variables discussed are also relevant to occupational settings, e.g. (nursery) school environments (Smedje & Norbäck 2001) and public buildings. Many indoor environmental problems have been acknowledged as risk factors for many years, yet regulatory bodies are only now starting to develop new standards to remedy the acknowledged difficulties (Olesen 2004). This is despite the fact that many dwellings have been built by local authorities and subsidized by the public purse. It is frustrating to read, for example, that houses need to breathe or that indoor condensation problems still occur, even when adequate technical solutions are available.

Conclusion

It might be argued that ventilation is one of the most important issues to be addressed, along with the elimination of environmental tobacco smoke and pets, when preventing the exacerbation of respiratory illnesses. Most indoor environmental problems are people-related and caused within the home. There is currently not enough evidence to prove that reducing exposure to indoor allergens and pollutants will reduce respiratory illnesses, apart from reducing exposure to dust mite allergen. There are only encouraging routes and suggestions about how to mitigate the detrimental effects from indoor allergens, especially for sensitized individuals. Healthcare professionals need to be aware of the possible effects of the indoor environment. This review provides a basis for understanding the interactions between health and the indoor environment, enabling healthcare professionals to advise clients on the actions that can be taken to reduce exposure to triggers in homes and workplaces. In particular, health visitors and other professionals who make home visits may be able to use this review to give advice on reducing triggers for the secondary and tertiary prevention of asthma symptoms. As a cautionary measure, expectant mothers could be advised on taking action to reduce house dust allergen as a primary prevention of allergies. This knowledge can be integrated into a holistic approach to respiratory health care.

Author contributions

GR, SAE and RBJ were responsible for the study conception and design, drafting of the manuscript and critical revisions; GR, collected the data; RBJ, provided statistical expertise and supervision; GR and SAE provided administrative support.

References

American Academy of Paediatrics Committee on Environmental Health (AAPCEH) (1998) Toxic effects of indoor molds. *Pediatrics* **101**(4), 712–714.

American Lung Association (2004) *Trends in Asthma Morbidity and Mortality*. American Lung Association Epidemiology and Statistics Unit Research and Scientific Affairs, New York, USA.

de Andrade A.D., Birnbaum J., Magalon C., Magnol J.P., Lanteaume A., Charpin D. & Vervloet D. (1996) *Fel d* 1 levels in cat anal glands. *Clinical and Experimental Allergy* **26**(2), 178–180.

Anyo G., Brunekreef B., de Meer G., Aarts F., Janssen N.A.H. & van Vliet P. (2002) Early, current and past pet ownership: associations with sensitisation, bronchial responsiveness and allergic symptoms in school children. *Clinical and Experimental Allergy* **32**(3), 361–366.

Arlian L.G. (1992) Water balance and humidity requirements of house dust mites. *Experimental and Applied Acarology* **16**, 15–35.

Arshad S.H., Bojarskas J., Tsitoura S., Matthews S., Mealy B., Dean T., Karmaus W., Frischer T., Kuehr J., Forster J. & the SPACE group. (2002) Prevention of sensitization to house dust mite by allergen avoidance in school age children: a randomized controlled study. *Clinical and Experimental Allergy* **32**(6), 843–849.

Ashmore I. (1998) Asthma, housing and environmental health. *Environmental Health* **106**(1), 17–24.

van Asselt L. (1999) Interactions between domestic mites and fungi. *Indoor and Built Environment* **8**, 216–220.

Asthma News (2003) *Asthma Statistics*, available at: http://www.asthma-uk.co.uk/asthma4.htm, accessed 18 August 2005.

Asthma UK (2003) *Key Facts and Statistics*, available at: http://www.asthma.org.uk/journalists/facts.php, accessed 18 August 2005.

Bahir A., Goldberg A., Mekori Y.A., Confino-Cohen R., Morag H., Rosen Y., Monakir D., Rigler S., Cohen A.H., Horev Z., Noviski N. & Mandelberg A. (1997) Continuous avoidance measures with or without acaricide in dust mite-allergic asthmatic children. *Annals of Allergy, Asthma and Immunology* **78**(5), 506–512.

Billings C.G. & Howard P. (1998) Damp housing and asthma. *Monaldi Archives for Chest Disease* **53**(1), 43–49.

de Blay F., Casset A. & Sohy C. (2002a) Cat and dog allergy: what preventative measures can be taken? *Revue Francaise d'Allergogie et d'Immunologie Clinique* **42**(6), 565–568.

de Blay F., Fourgaut G. & N'Gom S. (2002b) Architectural concepts and the reduction of allergen exposure. *Revue Francaise d'Allergogie et d'Immunologie Clinique* **42**(3), 256–262.

Boleman W.T. (2000) A look at indoor allergen environmental control. *Paediatric Asthma, Allergy and Immunology* **14**(4), 301–305.

Burr M. (2001) *A Community Based Trial of the Effects Upon Asthmatics of Remediating Moulds Within Their Homes*. Asthma UK Current Grants, Asthma UK, London.

Campbell F., Jones K. & Gibson P. (2003) Feather versus non-feather bedding for asthma (Cochrane Review). *The Cochrane Library* **3**.

Carswell F., Oliver J. & Weeks J. (1999) Do mite avoidance measures affect mite and cat airborne allergens? *Clinical and Experimental Allergy* **29**(2), 193–200.

Cats Protection League (2003) *Facts & Figures*, available at: http://www.cats.org.uk/media/facts.asp, accessed 18 August 2005.

Clark N.M., Brown R., Joseph C.L.M., Anderson E.W., Liu M., Valerio M. & Gong M. (2002) Issues in identifying asthma and estimating prevalence in an urban school population. *Journal of Clinical Epidemiology* **55**, 870–881.

Cloosterman S.G.M., Schermer T.R.J., Bijl-Hofland I.D., van der Heide S., Brunekreef B., van den Elshout F.J., van Herwaarden C.L. & van Schayck C.P. (1999) Effects of house dust mite avoidance measures on *Der p* 1 concentrations and clinical condition of mild adult house dust mite-allergic asthmatic patients, using no inhaled steroids. *Clinical and Experimental Allergy* **29**(10), 1336–1346.

Collins K. (2000) Cold, cold housing and respiratory illness. In *Cutting the Cost of Cold* (Rudge J. & Nicol F., eds), E & FN Spon Press, London, UK.

Critchley R., Howard R. & Oreszczyn T. (2000) *The Nottingham Energy, Health and Housing Study*. Nottingham Council Office Department of Health and Housing Group, UK.

Crocket A. (1993) *Managing Asthma in Primary Care*. Blackwell Scientific Publications, Oxford, UK.

Crowther D., Oreszczyn T., Pretlove S., Ridley I., Horwood J., Cox P. & Leung B. (2001) Controlling house dust mites through ventilation: the development of a model of mite response to varying hygrothermal conditions. In *Proceedings of the International Society of the Built Environment*, Dijon, France (ISBE, ed.), Ormalingen, Switzerland, 15 June 2001.

Custovic A. & Chapman M.D. (1997) Indoor allergens as a risk factor for asthma. In *Asthma* (Barnes P.J., Grunstein M.M., Leff

A.R. & Woolcock A.J., eds), Lippincott-Raven Publishers, Philadelphia, PA.

Custovic A. & Woodcock A. (2000) Clinical effects of allergen avoidance. *Clinical Reviews in Allergy and Immunology* **18**, 397–419.

Custovic A., Simpson A., Pahdi H., Green R.M., Chapman M.D. & Woodcock A. (1998) Distribution, aerodynamic characteristics and removal of the major cat allergen *Fel d* 1 in British homes. *Thorax* **53**(1), 33–38.

Custovic A., Hallam C., Woodcock H., Simpson B., Houghton N., Simpson A. & Woodcock A. (2000) Synthetic pillows contain higher levels of cat and dog allergen than feather pillows. *Pediatric Allergy and Immunology* **11**(2), 71–73.

Dales R.E., Cakmak S., Burnett R.T., Judek S., Coates F. & Brook J.R. (2000) Influence of ambient fungal spores on emergency visits for asthma to a regional children's hospital. *American Journal of Respiratory and Critical Care Medicine* **162**(6), 2087–2090.

Dharmage S., Bailey M., Raven J., Abeyawickrama K., Cao D., Guest D., Rolland J., Forbes A., Thien F., Abramson M. & Walters E.H. (2002) Mouldy houses influence symptoms of asthma among atopic individuals. *Clinical and Experimental Allergy* **32**(5), 714–720.

Douglas A.E. & Hart B.J. (1989) The significance of the fungus *Aspergillus penicilloides* to the house dust mite *Dermatophagoides pteronyssinus*. *Symbiosis* **7**, 105–117.

Eggleston P.A. (2000) Environmental causes for asthma in inner city children. The national cooperative inner city asthma study. *Clinical Reviews in Allergy and Immunology* **18**(1), 311–323.

Eriksson N.E. & Holmen A. (1996) Skin prick tests with standardised extracts of inhalant allergens in 7099 adult patients with asthma or rhinitis: cross-sensitisations and relationships to age, sex, month of birth and year of testing. *Journal of Investigational Allergology and Clinical Immunology* **6**, 35–46.

Etkin D.S. (1995) *Indoor Air Quality in Schools*. Cutter Information Corp., Massachusetts, USA.

Evans J., Hyndman S., Stewart-Browne S., Smith D. & Petersen S. (2000) An epidemiological study of the relative importance of damp housing in relation to adult health. *Journal of Epidemiology and Community Health* **54**, 677–686.

Fauteux A. (2000) Impact of a healthier home. *Soplan Review* **March 2000**, 8–9.

Fisk W.J., Faulkner D., Palonen J. & Seppanen O. (2002) Performance and cost of particle air filtration techniques. *Indoor Air* **12**(4), 223–234.

Flannigan B., McCabe E.M. & McGarry F. (1991) Allergenic and toxigenic micro-organisms in houses. *Journal of Applied Bacteriology Symposium Supplement* **70**, 61–73.

Fletcher G., Oldham L.A., Frank P., Pickering C.A.C., Niven R.McL., Francis H.C., Kay S. & Frank T.L. (1999) Reservoir levels of endotoxin in relation to damp and visible mould in a case control study of childhood asthma. In *Proceedings of 8th International Conference on Indoor Air Quality and Climate–Indoor Air '99* (Raw G.J., Aizlewood C.E. & Warren P.R., ed.), pp. 533–535.

Fradkin A., Tobin R.S., Tario S.M., Tucic-Poretta M. & Malloch D. (1987) Species identification of airborne molds and its significance for the detection of indoor pollution. *Journal of Air Pollution Control Association* **37**(1), 51–53.

Frank T.I., Pickering C.A.C., Fletcher G., Francis H.C., Oldham L.A., Kay S., Frank P. & Niven R.McL. (1999) Relationship between self reporting, visible inspection and objective measurement of damp for determining damp or mould contamination in houses. In *Proceedings of 8th International Conference on Indoor Air Quality and Climate–Indoor Air '99* (Raw G.J., Aizlewood C.E. & Warren P.R., eds), pp. 564–566.

Fung F. & Hughson W.G. (2002) Health effects of indoor fungal bioaerosol exposure. In *Proceedings of Indoor Air 2002*, 30 June to 5 July 2002, Monterey, CA, USA (Levin H., ed.), ISAQ, Finland.

Gore R.B., Bishop S., Durrell B., Curbishley L., Woodcock A. & Custovic A. (2003) Air filtration units in homes with cats: can they reduce personal exposure to cat allergen? *Clinical and Experimental Allergy* **33**(6), 765–769.

Gots R.E. & Pirages S.W. (2002) Mold as toxins. *Columns Mold* **1**(6–7), 5859.

Halmerbauer G., Gartner C., Schierl M., Arshad H., Dean T., Koller D.Y., Karmaus W., Kuehr J., Forster J., Urbanek R. & Frischer T. (2003) Study on the Prevention of Allergy in Children in Europe (SPACE): Allergic sensitization at 1 year of age in a controlled trial of allergen avoidance from birth. *Pediatric Allergy and Immunology* **14**(1), 10–17.

Hargreaves M., Parappukkaran S., Morawska L., Hitchins J., He C. & Gilbert D. (2003) A pilot investigation into associations between indoor airborne fungal and non-biological particle concentrations in residential houses in Brisbane, Australia. *The Science of the Total Environment* **312**(1–3), 89–101.

van der Heide S., Kaufman H.F., Dubois A.E. & de Monchy J.G. (1997) Allergen reduction measures in houses of allergic asthmatic patients: effects of air cleaners and allergen-impermeable mattress covers. *European Respiratory Journal* **10**(6), 1217–1223.

van der Heide S., van Aalderen W.M., Kaufman H.F., Dubois A.E. & de Monchy JG. (1999) Clinical effects of air cleaners in homes of asthmatic children sensitised to pet allergens. *Journal of Allergy and Clinical Immunology* **104**(2Pt 1), 447–451.

Hens H.S.L.C. (2003) Mold in dwellings: field studies in a moderate climate. In *Proceedings of the 24th AIVC Conference and BETEC Conference, Ventilation, Humidity Control and Energy*, 12–14 October 2003, Washington, DC, USA (Annex V. AIVC, ed.), AIVC, Brussels, Belgium.

Howieson S.G., Lawson A., McSharry C., Morris G., McKenzie E. & Jackson J. (2003) Domestic ventilation rates, indoor humidity and dust mite allergens – are our homes causing the asthma pandemic? *Building Services Engineering, Research and Technology* **24**(3), 137–147.

Htut T., Burgess I.F., Maunder J.W. & Basham E. (1996) A pilot study on the effect of one room mechanical ventilation with heat recovery (MVHR) units on house dust mite populations and *Der p* 1 levels in laboratory simulated bedrooms and on ambient conditions in an occupied bedroom in Cambridge, UK. *International Journal of Environmental Health Research* **6**, 301–313.

Institute for Environment and Health (IEH) (2001) *Indoor Air Quality in the home: Final Report on DETR Contract EPG 1/5/12 (Web Report W7)*. IEH, Leicester, UK, available at: http://www.le.ac.uk/ieh/pdf/w7.pdf, accessed 18 August 2005.

ISAAC Steering Committee (1998) Worldwide variation in prevalence of symptoms of asthma, allergic rhino conjunctivitis, and atopic eczema: ISAAC. *The Lancet* **351**, 1225–1232.

Jadad A.R., Moore R.A., Carroll D., Jenkinson C., Reynolds D.J.M., Gavaghan D.J. & McQuay H.J. (1996) Assessing the quality of reports of randomised clinical trials: is blinding necessary? *Controlled Clinical Trials* **17**(1), 1–12.

Joint Research Council (JRC) (2003) *Indoor Air Pollution: New EU Research Reveals Higher Risks Than Previously Thought*, available at: http://www.jrc.cec.eu.int/default.asp@sidz=more_information&sidstsz=press_releases.htm

Kilpeläinen M., Terho E.O., Heleniu H. & Koskenvuo M. (2001) Home dampness, current allergic diseases, and respiratory infections among young adults. *Thorax* **56**, 462–467.

Krieger J.W., Song L., Takaro T.K. & Stout J. (2000) Asthma and the home environment of low-income urban children: preliminary findings from the Seattle-King Country healthy homes project. *Journal of Urban Health* **77**(1), 50–67.

Lau S., Illi S., Sommerfield C., Niggermann B., Bergman R., von Mutius E., Wahn U. & the Multicentre Allergy Study Group (2000) Early exposure to house-dust mite and cat allergens and development of childhood asthma: a cohort study. *The Lancet* **356**, 1392–1397.

Liu A.H. (2001) Allergy and Asthma Prevention. *Allergy and Asthma Proceedings* **22**(6), 333–336.

Mihrshahi S., Marks G., Criss S., Tovey E., Vanlaar C. & Peat J.K. (2003) Effectiveness of an intervention to reduce house dust mite allergen levels in children's beds. *Allergy* **58**(8), 784–789.

Munir A.K.M., Björkstén B., Einarssson R., Ekstrand-Tobin A., Moeller C., Warner A. & Kjellman N.I.M. (1995) Mite allergens in relation to home conditions and sensitization of asthmatic children from three climatic regions. *Allergy* **50**, 55–64.

von Mutius E. (1997) Towards prevention. *The Lancet* **350**(suppl. II), 1417.

von Mutius E., Weiland S.K., Fritzsch C., Duhme K. & Keil U. (1997) Increasing prevalence of atopy in East Germany. *American J Respiratory Critical Care Medicine* **155**, A248.

NAC Australia (1992) Report on the cost of asthma in Australia. Boston Consulting Group, National Asthma Campaign. *Journal of Medicine* **328**(23), 1665–1669.

National Academy of Sciences Institute of Medicine (NAS) (2000) *Clearing the Air: Asthma and Indoor Air Exposures*. National Academic Press, Washington, DC.

Nishioka K., Yasueda H. & Saito H. (1998) Preventative effect of bedding encasement with microfine fibers on mite sensitisation. *Journal of Allergy and Clinical Immunology* **101**(1 pt 1), 28–32.

Niven R.Mc L., Fletcher A.M., Pickering A.C., Custovic A., Sivour J.B., Preece A.R., Oldham L.A. & Francis H.C. (1999) Attempting to control mite allergens with mechanical ventilation and dehumidification in British houses. *Journal Allergy and Clinical Immunology* **103**, 756–762.

Nolard N. (2001) Fungal allergies. *Mediators of Inflammation* **10**(6), 294–295.

Ochmanski W. & Barabasz W. (2000) Microbiological threat from buildings and rooms and its influence on human health (sick building syndrome). *Przegl Lek* **57**(7–8), 419–423.

Øie L., Nafstad P., Botten G., Magnus P. & Jaakkola J.K. (1999) Ventilation in homes and bronchial obstruction in young children. *Epidemiology* **10**(3), 294–299.

Olesen B.W. (2004) International standards for the indoor environment. *Indoor Air* **14**(7), 18–26.

Oosting A.J., de Bruin-Weller M.S., Terreehorst I., Tempels-Pavlica Z., Aalberse R.C., de Monchy J.G., van Wijk R.G. & Bruijnzeel-Koomen C.A. (2002) Effect of mattress encasings on atopic dermatitis outcome measures in a double-blind, placebo-controlled study: the Dutch mite avoidance study. *Journal of Allergy and Clinical Immunology* **110**(3), 500–506.

Pirages S.W. (2003) Mold and health issues. In *Proceedings of the 24th AIVC Conference and BETEC Conference, Ventilation, Humidity Control and Energy*, 12–14 October 2003, Washington, DC, USA (Annex V. AIVC, ed.), AIVC, Brussels, Belgium.

Pitten F.A., Scholler M., Kruger U., Effendy I. & Kramer A. (2001) Filamentous fungi and yeasts on mattresses covered with different encasings. *European Journal of Dermatology* **11**(6), 534–537.

Popplewell E.J., Innes V.A., Lloyd-Hughes S., Jenkins E.L., Khdir K., Bryant T.N., Warner J.O. & Warner J.A. (2000) The effect of high-efficiency and standard vacuum-cleaners on mite, cat and dog allergen levels and clinical progress. *Pediatric Allergy and Immunology* **11**(3), 142–148.

Portnoy J.M., Flappan S. & Barnes C.S. (2001) A procedure for evaluation of the indoor environment. *Aerobiologia* **17**(1), 43–48.

Ren P., Jankun T.M., Belanger K., Bracken M.B. & Leaderer B.P. (2001) The relation between fungal propagules in indoor air and home characteristics. *Allergy* **56**(5), 419–424.

Rijssenbeek-Nouwens L.H., Oosting A.J., de Bruin-Weller M.S., Bregman I., de Monchy J.G. & Postma D.S. (2002) Clinical evaluation of the effect of anti-allergic mattress covers in patients with moderate to severe asthma and house dust mite allergy: a randomised double blind placebo controlled trial. *Thorax* **57**(9), 784–790.

Ross M.A., Curtis L., Scheff P.A., Hryhorczuk D.O., Ramakrishnan V., Wadden R.A. & Persky VW. (2000) Association of asthma symptoms and severity with indoor bioaerosols. *Allergy* **55**(8), 705–711.

Schou C. (1993) Defining allergens of mammalian origin. *Clinical and Experimental Allergy* **23**(1), 7–14.

Sedlbauer K. (2001) *Vorhersage von Schimmelpilzbildung auf und in Bauteile*. Dissertation Universitaet, Stuttgart, Germany.

Sieger T.L., Fiore M.C., Anderson H.A., Ziarnik M.E., Bush R.K., Dopico G.A., Hanrahan L.P. & Guzik J. (1987) The health effects and environmental assessment of "tight" homes. In *Proceedings of the 80th Annual meeting of APCA*, 21–26 June 1987, New York, USA (APCA, ed.), APCA, Pittsburgh, USA.

Singh M., Bara A. & Gibson P. (2003) Humidity control for chronic asthma (Cochrane Review). *The Cochrane Library* **3**.

Smedje G. & Norbäck D. (2001) Irritants and allergens at school in relation to furnishings and cleaning. *Indoor Air* **11**(2), 127–133.

Sporik R., Holgate S., Platts-Mills T.A.E. & Cogswell J. (1990) Exposure to house dust mite allergen (*Der p* 1) and the development of asthma in childhood: a prospective study. *New England Journal of Medicine* **323**, 502–507.

Sporik R., Chapman M.D. & Platts-Mill T.A.E. (1992) House dust mite exposure as a cause of asthma. *Clinical and Experimental Allergy* **22**, 897–906.

Sporik R., Hill D.J., Thompson P.J., Stewart G.A., Carlin J.B., Nolan T.M., Kemp A.S. & Hosking C.S. (1998) The Melbourne house dust mite study: long-term efficacy of house dust mite reduction strategies. *Journal of Allergy and Clinical Immunology* **101**(41), 451–456.

Strachan D.P. (2000) The role of environmental factors in asthma. *British Medical Bulletin* **56**(4), 865–882.

van Strien R.T., Koopman L.P., Kerkhof M., Oldenwening M., de Jongste J.C., Gerritsen J., Neijens H.J., Aalberse R.C., Smit H.A. & Brunekreef B. (2003) Mattress encasings and mite allergen levels in the prevention and incidence of asthma and mite allergy study. *Clinical and Experimental Allergy* **33**(4), 490–495.

Sundell J. & Lindwall T. (1993) Indoor air humidity and sensation of dryness as risk indicators of SBS. *Indoor Air* **3**, 382–390.

Tovey E.R. (1997) Environmental control. In *Asthma* (Barnes P.J., Grunstein M.M., Leff A.R. & Woolcock A.J., eds), Lippincott-Raven Publishers, Philadelphia, PA.

Tsitoura S., Nestoridou K., Botis P., Karmaus W., Botezan C., Bojarskas J., Arshad H., Kuehr J. & Forster J. (2002) Randomized trial to prevent sensitisation to mite allergens in toddlers and preschoolers by allergen reduction and education: one-year results. *Archives of Paediatrics and Adolescent Medicine* **156**(10), 1021–1027.

US Environmental Protection Agency (EPA) (1994) *Indoor Air Pollution: An Introduction for Health Professionals*. US Environmental Protection Agency, available at: http://www.epa.gov/iaq/pubs/hpguide.html.

Voorhorst R., Spieksma F.T.H.M. & Varekamp N. (1969) *House Dust Mite Atopy and The House Dust Mite Dermatophagoides pteronyssinus*. Stafleu's Publishing, Leiden.

Wanless D. (2003) *Securing Good Health for the Whole Population: Population Health Trends*. HMSO, London, UK.

Woodcock A., Forster L., Matthews E., Martin J., Letley L., Vickers M., Britton J., Strachan D., Howarth P., Altman D., Frost C. & Custovic A. (2003) Control of exposure to mite allergen and allergen-impermeable bed covers for adults with asthma. *New England Journal of Medicine* **349**(3), 225–236.

World Health Organization (WHO) (1988) Dust mite allergen and asthma: a worldwide problem. *Bulletin of the World Health Organisation* **66**(6), 769–780.

World Health Organization (WHO) (2002) *European Health for all Database*. WHO, Geneva.

Zureik M., Neukirch C., Leynaert B., Liard R., Bousquet J. & Neukirch F. (2002) Sensitisation to airborne moulds and severity of asthma: cross-sectional study from European Community respiratory health. *British Medical Journal* **325**, 411.