Ventilation rates and moisture-related allergens in UK dwellings

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Abstract

Recent studies show that the UK is one of the countries with the highest asthma prevalence worldwide. It has been suggested that the trend towards the reduction of domestic ventilation rates for energy-efficiency reasons has resulted in poor indoor air quality and may represent a causal factor for the high asthma prevalence in the UK.

This study firstly aims to assess whether a link exists between asthma and low ventilation rates in housing. Secondly, the study aims to establish the minimum ventilation rate required in a dwelling in order to control levels of moisture-related pollutants (dust mites, mould) and therefore reduce the number of respiratory hazards. The work was funded by the UK Government's Building Regulations Research Programme.

An extensive review was performed of the UK and overseas published information on the links between asthma and domestic ventilation rates. The study also included an analysis of existing UK data sets where respiratory health, mould growth and housing characteristics were surveyed. In addition, the study involved theoretical modeling of a typical UK dwelling, to predict the impact that changes in ventilation rates will have on house dust mite (HDM) in a bed and on mould growth.

The literature review has highlighted that most existing data is inadequate for conclusions to be drawn regarding the *direct* association between ventilation rates and respiratory problems. For moisture-related pollutants the literature offers *some* advice on the minimum ventilation rates required to reduce pollutants levels. The analysis of

existing UK data sets has not revealed any significant direct links between ventilation, respiratory health and moisture-related pollutants. The results of the theoretical modeling indicate that in most cases 0.5 ach^{-1} is required to avoid mould growth but a significantly higher ventilation rate (0.8 ach^{-1}) may be required to control mites' growth.

Most current guidance on domestic ventilation is based on the assumption that if adequate ventilation is provided for avoiding mould growth, then other IAQ problems will be contained. This study indicates that this may not be the case. In order to fully evaluate the direct link between asthma and low ventilation rates in the UK, a large scale prospective study is needed, where indoor pollutants, respiratory health indicators, air-tightness and ventilation rates are all adequately measured.

1.0 Introduction

Recent surveys show that the UK is one of the countries with the highest prevalence of respiratory symptoms and asthma worldwide, both for children and adults (Janson C. *et al.*, 2001; ISAAC Steering Committee, 1998). A number of studies indicate that between the mid-1960s and the mid-1990s there was an increase in asthma prevalence in the UK of approximately 5% per year (Devereux G. *et al.*, 2003). Some authors even refer to an "epidemic of asthma and allergy" (Holgate S.T., 2004). However, subtle methodological differences in the survey studies may have played a role in the observed increase in allergies prevalence. For example, Anderson *et al.* (2004) compared the results of the International Study of Asthma and Allergies in Childhood (ISAAC) corresponding to the 1995 survey and the 2002 survey. They concluded that 'the most likely explanation for the paradoxical increase in prevalence of the label of asthma is that it is applied to increasingly milder disease'.

Several hypotheses have been formulated in order to explain the rise in the prevalence of asthma and allergies in developed countries. Some theories relate to changes in lifestyle, particularly dietary changes or changes in children's exposure to microbes as a consequence of the 'Westernized lifestyle' (the 'hygiene hypothesis', von Hertzen L.C. and Haahtela T., 2004). Another hypothesis relates to an increase in exposure to allergens such as those produced by house dust mites and moulds. The increased exposure is attributed to a combination of several factors: carpet use, warmer houses, more time spent indoor and decreased housing ventilation due to energy efficiency concerns.

Depending upon occupants' numbers and habits, lower ventilation rates can result in higher indoor moisture levels, which in turn may lead to the proliferation of moisture-related pollutants: house dust mites (HDM) and moulds. Exposure and sensitisation to HDM allergens is a major risk factor for asthma in most parts of the world (Custovic A. *et al.*, 1998). Some studies also suggest that mite allergens are associated with eczema and perennial allergic rhinitis (Raw G.J. *et al.*, 2001). As regards indoor moulds, the most common health effect caused by them is an allergic reaction in sensitized individuals, which can trigger allergic asthma or allergic rhinitis (ACOEM, 2002). At present, it is not possible to produce any reliable threshold limit values for exposure to moulds. Some threshold limit values for HDM have been suggested (Platts-Mills T.A., et al., 1997), but not all authors agree on them (Peat J.K. et al., 1998).

It is unlikely that increased exposure to indoor allergens alone may have caused an "allergy epidemic". However, several recent studies have found a link between damp buildings and adverse health effects. For example, in a multidisciplinary review of the literature on the health effects of dampness and mite exposure in buildings, Bornehag C.G. *et al.* (2004) concluded that dampness in buildings is a risk factor for health effects among atopics and non-atopics both in domestic and in public environments. However, no conclusions could be drawn on the causative agents.

This paper firstly aims to assess whether a link exists between asthma and low ventilation rates in housing. Secondly, the study aims to establish the minimum ventilation rate required in a dwelling in order to control levels of moisture-related pollutants (dust mites, mould) and therefore safeguard its occupants' respiratory health. The work was funded by the UK Government's Building Regulations Research Programme.

2.0 Methodology

An extensive review was performed of the UK and overseas published information on the links between moisture-related pollutants, domestic ventilation rates and respiratory health. The study also included an analysis of existing UK data sets where respiratory health, mould growth and housing characteristics were surveyed. In addition, the study involved theoretical modeling of a typical UK dwelling, to predict the impact that changes in ventilation rates will have on HDM in a bed and on mould growth.

3.0 Literature Review

3.1 Evidence of a Direct Link Between Residential Ventilation and Respiratory Problems

UK and overseas published information was reviewed in order to assess the links between moisture-related pollutants, domestic ventilation rates and respiratory health. The results of the literature review were recently published (Davies *et al*., 2004). The review highlighted that there are very few studies addressing the *direct* link between respiratory health and ventilation in housing. Most existing data are inadequate for conclusions to be drawn whether ventilation rates directly cause respiratory problems.

The EUROVEN group recently reviewed the scientific literature relating to the effects of ventilation on health, comfort and productivity in non-industrial environments (Wargocki *et al.,* 2002). The study concluded that there is a strong association between ventilation and health. However, the study also noted that more information is required on the links between ventilation rates and health in homes. Another recent study (Emenius e*t al.,* 2004) examined the impact of building characteristics and indoor air quality on recurrent wheezing in infants. They found that whilst building-related exposures appear to have a major impact on children's health, this was not primarily explained by differences in ventilation systems, air change rate or HDM infestation.

A workshop held in 1999 by the National Academy of Sciences, USA (Committee, 2000) concluded that 'existing data are inadequate for conclusions regarding the association between ventilation rates or ventilation system microbiological contamination and either the exacerbation of asthma symptoms or asthma development ... Airtight building envelopes and low rates of ventilation have been cited as factors that may contribute to asthma incidence or symptoms or may explain recent increases in asthma; however, very few relevant data are available'.

Although few studies address the direct link between housing ventilation and respiratory health, a number of studies exist on the links between ventilation and moisture-related pollutants.

3.2 House Dust Mites and Ventilation in Housing

At present there is some evidence of the impact of low ventilation rates in housing and mite infestation. However, further work is needed on mite survival rates in transient conditions, and on the links between housing ventilation and the mite microclimate.

Harving *et al*. (1993) found a positive correlation between air humidity and mite concentration and an inverse correlation between HDM concentration and air-exchange rate. Sundell *et al.* (1995) found that elevated concentrations of HDM allergen in mattress and floor dust were associated with the difference in absolute humidity between indoor and outdoor air, as well as with low air-exchange-rates of the home, especially the bedroom. Sundell *et al.* concluded that in regions with a cold winter climate there is a correlation between infiltration and mite infestation, but air-flow rates related to number of people in the home appears a stronger indicator of HDM infestation than air-flow rates related to home volumes.

Modelling studies indicate that at high internal temperatures, mite infestation problems appear likely to occur only at ventilation rates significantly less than 0.5 ach^{-1} (Lowe R, 2000; Crowther D, 2002). The importance of housing ventilation is also highlighted by Berry *et al.* (1996), who found that houses which rarely or never opened windows had higher mean yearly average mite counts taken from the bedroom carpet. This was not observed with counts obtained from the living room carpet, when the degree of opening the living room window was examined.

Several studies have been carried out where mechanical ventilation with heat recovery (MVHR) and/or dehumidifiers were utilised in order to reduce indoor relative humidity levels in winter and consequently mite concentrations. However, although the use of MVHR appears to have proven quite successful in Scandinavian countries (Emenius *et al*., 1998; Harving *et al*., 1994), such an approach has caused some conflicting results in the UK (Niven *et al*., 1999, Howieson *et al.,* 2003; Htut *et al*., 1996; Stephen *et al.*, 1997; McIntyre, 1992).

3.3 Mould and Ventilation in Housing

Although there is some evidence of the links between ventilation and presence of mould in housing, at present the actual health risk from mould in buildings has yet to be quantified.

In order to avoid mould growth, a general room RH of less than 70% is recommended, provided the building has no serious cold bridges (Ridley *et al.*, 2003). Modelling (*ibid.*) shows that an air-infiltration rate below 0.5 ach^{-1} leads to an indoor RH greater than 70% in fuel rich dwellings (0.7 ach^{-1} for fuel poor dwellings).

A number of studies have been conducted investigating mould growth in relation to housing characteristics, including ventilation. However, in most cases the latter was not quantitatively measured. Garrett M.H. *et al.* (1998) found that 'uncontrolled ventilation through cracks in the cladding and through the foundation of the house may increase indoor total spore concentrations, while controlled ventilation through open windows may reduce spore concentrations'. These findings are confirmed by Dharmage S. *et al.* (1999), whose study concluded that although there is a major impact of outdoor fungi on the levels of indoor airborne fungal propagules, the overall effect of natural ventilation on indoor fungal exposure is beneficial.

A study by the UK Building Research Establishment (1990) revealed that recently built one bedroom and bedsit homes in the UK had significant condensation problems, which could lead to mould growth and proliferation. The study indicated that factors such as ventilation, air movement, heating and insulation were more important than occupant behaviour and energy consciousness and the most important occupant characteristics were the number and age of occupants.

3.4 Literature Review: Conclusions

It can be concluded that there is general consensus that a link exists between ventilation rates in dwellings and respiratory hazards (for example HDM). There is also general consensus of a link between these respiratory hazards and respiratory problems, but it is not clear to what extent hazards cause ill-health. Most existing data are inadequate for conclusions to be drawn whether ventilation rates directly cause respiratory problems.

4.0 Theoretical Modelling

4.1 Theoretical Modelling: Methodology

Modelling was carried out to predict the impact that changes in ventilation may have on the occurrences of mould growth on the internal surfaces of a dwelling and the risk of house dust mite populations in a typical bed. The modelling uses a base case dwelling that complies with the current UK Building Regulations. The ventilation rate, moisture production rate, level of insulation, heating set point and schedule, heating system efficiency and geographical location are then varied to assess how such changes impact on the risk of mould growth and the population of house dust mites in the dwelling. The

British Standard 5250 (BSI 2002) was adopted for details on typical moisture production rates, as a function of occupant numbers and behaviour.

The models used for this analysis are Condensation Targeter II (Oreszczyn *et al.,* 1999) and its house dust mite population module BED3 (Crowther *et al.,* 2001). Condensation Targeter II is a monthly steady state model, based on the Bredem 8 (Henderson G *et al.,* 1986 and Shorrock *et al.,* 1994) algorithm, that predicts monthly mean indoor air temperature and relative humidity in two zones, zone 1 being the living room area and zone 2 being the rest of the dwelling (including the bedrooms), and surface temperatures and surface relative humidities in each zone. The model also calculates the energy consumption of the dwelling.

In the model a Mould Index (MI) measures the risk of mould occurring on the coldest surfaces within the dwelling each month of the year. If the MI is zero or below, then the predicted relative humidity at the coldest surface will be a minimum of 80% and therefore mould is predicted to occur. The more negative the value of MI, the greater the probability and severity of mould occurring. The higher the MI the lower the surface relative humidity and the smaller the predicted risk of mould growth occurring. The modelling has assumed that there are no cold bridges in the dwellings. Future analysis could investigate mould growth on cold bridges.

A Mite Population Index (MPI) measures the growth or decline of mite numbers within a bed for each month of the year. If the MPI is greater than 1 the population is growing, if the MPI equals 1 the population is stable, if the MPI is less than 1 then the population is in decline. Given a starting population of mites the monthly MPI can be used to calculate how the population of HDM changes throughout the year. Note that although the modelling uses the latest theoretical techniques and the best available data regarding the environmental impacts on the house dust mite life cycle, it is currently the subject of a validation exercise (Bartlett, 2004). Key periods of population growth occur during the summer; however, the use of BREDEM models to predict the summer operation of buildings is less well understood. Therefore there is some uncertainty in the predictions of the BED3 model.

4.2 *Theoretical Modelling: Results*

As expected, the results clearly show that the risk of mould and HDM is strongly related to ventilation and moisture production rates. The risk of both mould and HDM increases as moisture production increases and infiltration decreases.

Table 4.1 and 4.2 illustrate the results of the mould and HDM growth, in relation to changes in ventilation rates and moisture production rates. The results suggest that the avoidance of HDM requires higher ventilation rates than those required for avoiding the risk of mould. For a 'dry' occupancy of a family of 4, having a moisture production rate of 5 kg/day, a ventilation rate of 0.4 ach^{-1} should be sufficient to avoid HDM problems. For 'moist' occupancies of 4 people HDM will be able to survive if ventilation is kept below 0.8 ach^{-1}.

Mould Growth Risk		**Moisture Production Rate (kg/day)**						
		2	**4**	**6**	**8**	**10**	**12**	**14**
Ventilation Rate (ach^{-1})	**0.2**	n	n	p	y	y	y	y
	0.4	n	n	n	n	p	y	y
	0.6	n	n	n	n	n	p	y
	0.8	n	n	n	n	n	n	n
	1.0	n	n	n	n	n	n	n

Table 4.1: *Risk of mould for the different combinations of moisture production and infiltration rate (Key: n = No mould growth at any time; y = Mould growth all year; p = Mould growth risk at certain times during the year).*

House Dust Mites Risk		**Moisture Production Rate (kg/day)**						
		2	**4**	**6**	**8**	**10**	**12**	**14**
Ventilation Rate (ach^{-1})	**0.2**	n	p	y	y	y	y	y
	0.4	n	n	p	y	y	y	y
	0.6	n	n	n	p	y	y	y
	0.8	n	n	n	p	p	p	p
	1.0	n	n	n	n	p	p	p

Table 4.2: *Risk of HDM for the different combinations of moisture production and infiltration rate (Key: n = No HDM growth at any time; y = HDM growth all year; p = HDM increase in summer/autumn but decrease in winter/spring).*

The thermal insulation analysis shows that any improvement in the level of thermal insulation leads to a reduced risk of both mould growth and HDM. In a typical dwelling, however well it is insulated, there are likely to be periods during the year when the conditions within the beds will be those required for HDM populations to increase. However, these periods are not likely to be more than a few months and HDM populations will decline during all other months. Extending the heating pattern and/or increasing the demand temperature in a dwelling leads to a reduced risk of mould growth and HDM.

The geographical location of dwellings is significant for the risks associated with mould growth and HDM populations and therefore the external climate should be taken into account when assessing this risk.

Occupancy is a significant factor affecting the risk of mould growth and HDM populations. This is primarily due to the increasing moisture production rates as a result of the greater number of occupants.

The ability of the dwelling occupants to pay for the fuel to heat the dwelling to comfortable temperatures has an impact on the risk of mould growth and HDM population. Occupants suffering fuel poverty are likely to have a significantly increased risk, particularly of HDM populations.

4.3 Theoretical Modelling: Conclusions

The modelling results relating to an adequately heated house of 80 m^2, with 6 or less occupants whose behaviour can be characterised as ‘dry’ or ‘moist’ as defined in *British Standard 5250* (BSI, 2002), show that:

- An average ventilation rate of 0.5 ach^{-1} or greater is needed to avoid mould growth;
- An average ventilation rate of 0.8 ach^{-1} or greater is needed to avoid house dust mite populations increasing annually based on modelling using the best available models (which require validation).

It should be noted that a number of assumptions were made for the modelling presented in this paper. The greatest relates to the assumption of how the system is used by the occupants. In particular the ventilation rate in a dwelling is unlikely to be constant throughout the seasons. The ventilation rate achieved in a naturally ventilated dwelling varies as a function of internal and external temperature, wind speed, direction and local terrain factors, and occupant behaviour. Computer simulation tools could be used to model the ventilation rates achieved in dwellings with different levels of air tightness and background ventilators.

Properly ventilating and heating new dwellings is one way of reducing the risk of mould growth and HDM populations. However, there are many other factors that have an impact on the environmental conditions in dwellings and in beds, some of which have been modelled as part of this project. Other issues that have been identified include the heating pattern, heating system responsiveness, geographical location, dwelling occupancy and fuel poverty. All of these can have a significant impact in a dwelling, which is properly ventilated and which has an efficient heating system installed.

5 Analysis of UK data sets on health and housing

5.1 Analysis of UK data sets: Methodology

A brief analysis was performed of the English House Condition Survey (EHCS) 1996 and 2001, where respiratory health, mould growth and housing characteristics are surveyed (DETR, 1998; ODPM, 2003). The English House Condition Survey is a comprehensive study of the English housing stock and of its occupants. The EHCS 1996 also contains information on occupants' self-reported health.

The main aim of this analysis is to examine the links between housing characteristics (in particular ventilation), moisture-related respiratory hazard (mould) and respiratory health. The data from the EHCS does not contain information on the building's air leakage or ventilation rates. However, other building characteristics such as age of property or energy efficiency rating are available in the database, which can be considered linked to air tightness. In the EHCS, a SAP rating of energy efficiency was calculated for each building, according to a standard assessment procedure (DEFRA, 2001). The EHCS also contains information on the dwelling's fitness of ventilation. The latter is intended on the basis of its definition given in Section 604 of the 1989 *Local Government and Housing Act* (HMO, 1989), which specifies the criteria for judging whether a dwelling is fit for human habitation. For example, the size and positioning of openable windows and of mechanical ventilation is one of the criteria adopted to assess the fitness of ventilation of a dwelling. In the EHCS a Mould Severity Index is also calculated for each property, on the basis of reported visible mould. However, in this paper mould presence refers to mould of any severity occurring.

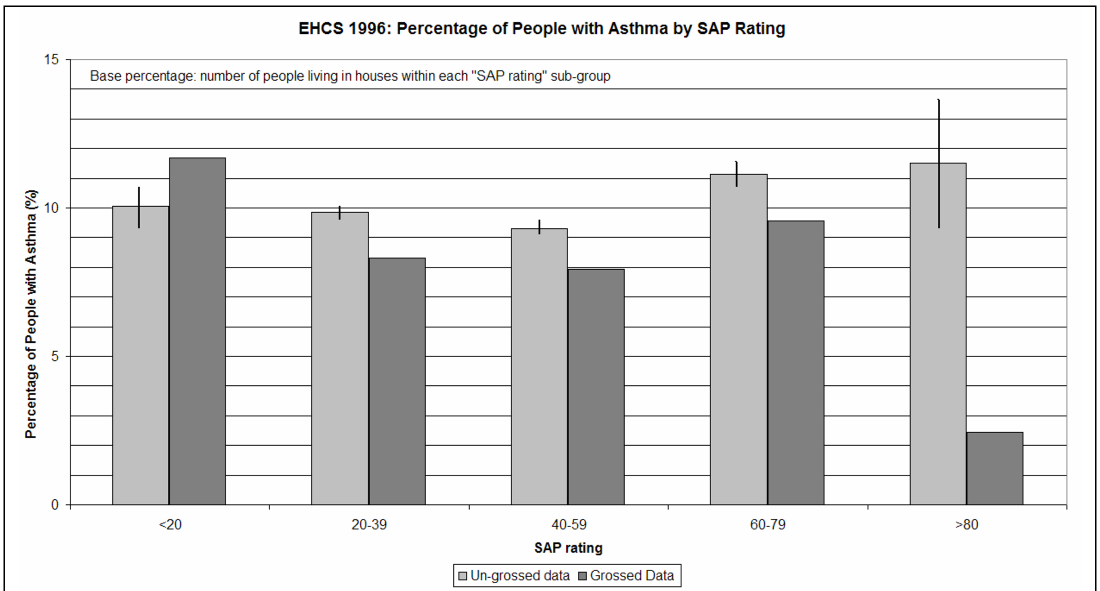
Most of the raw data from the 1996 and 2001 EHCS database was available for the purposes of this study. However, it was not possible to obtain the raw data on the Mould Severity Index for the EHCS 1996. Consequently, the information on mould and health refers to published EHCS 1996 tables (DETR, 2000).

The EHCS raw data also includes weighting factors, applied to the sample in order to gross it to the national total and to remove any biases due to sample design. It could be argued that the adoption of weighting factors is not appropriate for the purposes of this study, whose aim is to investigate the existence of possible links between asthma and housing characteristics, rather than giving a picture of the English housing stock. On the other hand, it could also be argued that any findings obtained through the use of un-grossed raw data might be affected by biases due to sample design. Consequently, in this study both grossed and un-grossed data was investigated.

For the purposes of this study, the frequency distribution of asthma sufferers or mould growth was calculated in relation to the age of the building, to its the fitness of ventilation and to its energy efficiency. The frequency distribution of mould in relation to occupancy was also considered. For each frequency distribution table, 95% Confidence Intervals were also calculated. It should be pointed out that when grossing factors are applied, the 95% confidence intervals are fairly small. This is in part due to the very large sample size obtained through the weighting process and therefore indicates a level of confidence, which is not apparent in the un-grossed data.

5.2 Analysis of UK Data Sets: Results

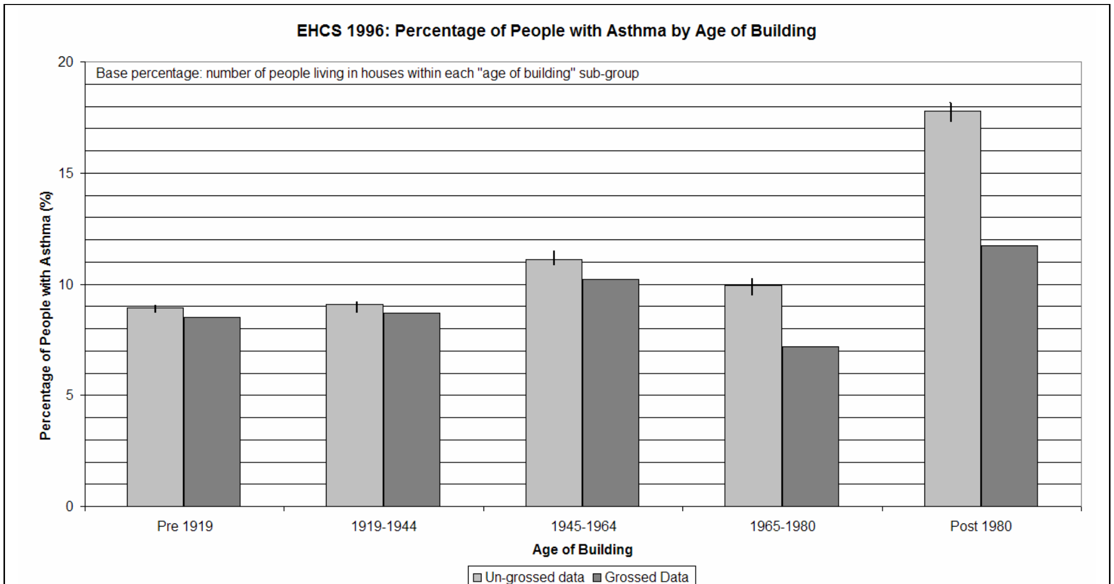
Some differences were found in the frequency distributions of asthma sufferers by SAP rating, with and without applying grossing factors (Fig. 5.1).



SAP Rating	Grossed data		Un-grossed data	
	Percentage of People with Asthma	95% Confidence Interval	Percentage of People with Asthma	95% Confidence Interval
<20	11.70	0.04	10.05	1.51
20-39	8.30	0.02	9.85	0.67
40-59	7.95	0.01	9.29	0.48
60-79	9.55	0.02	11.12	0.95
>80	2.45	0.06	11.50	3.53

Figure 5.1: *EHCS 1996. Percentage of People with Asthma by SAP Rating.*

If weighting is applied, the percentage of people with asthma is significantly lower in dwellings with a SAP rating greater than 80. However, if weighting factors are not applied, no significant association can be found between asthma occurrence and SAP rating. It should be noted that in the surveyed sample there is only a small number of dwellings with a SAP rating greater than 80, hence the greater uncertainty in the figures for the percentage of people with asthma living in dwellings with a SAP rating greater than 80.



	Grossed data		Un-grossed data	
Age of Building	Percentage of People with Asthma	95% Confidence Interval	Percentage of People with Asthma	95% Confidence Interval
Pre 1919	8.51	0.02	8.94	0.52
1919-1944	8.69	0.02	9.08	0.58
1945-1964	10.22	0.02	11.12	0.66
1965-1980	7.20	0.02	9.94	0.71
Post 1980	11.71	0.03	17.80	0.92

Figure 5.2: *EHCS 1996. Percentage of People with Asthma by Age of Building.*

Both grossed and un-grossed data show that a greater percentage of people living in dwellings built after 1980 have asthma (Fig. 5.2). No significant association could be found between fitness of ventilation and asthma occurrence. However, it should be noted that some dwellings with unfit ventilation might also be very leaky, which may counteract the effect of unfit ventilation.

The occurrence of mould growth is greater in dwellings with a lower SAP rating; recent properties have a lower prevalence of mould growth.

The occurrence of mould growth appears greater in dwellings with unfit ventilation. This might suggest that excessively airtight dwellings with poor ventilation might be more subject to mould growth. However, it should be noted that only a very small percentage (0.4%) of the 2001 EHCS dwellings has unfit ventilation. Furthermore, the fitness of ventilation does not give any indication on a dwelling's air leakage and ventilation rates. The occurrence of mould is greater in larger households and in households with a greater occupants density.

The published data from the EHCS 1996 Energy Report (DETR, 2000) shows that a higher percentage of respiratory problems occurs in cases where moderate and severe mould is present (the published information appears to refer to grossed data).

5.3 Analysis of UK Data Sets: Conclusions

No definite conclusions could be drawn on the impact of energy efficient dwellings on its occupants' health. Some differences were found in the frequency distributions of asthma sufferers by SAP rating, with and without applying grossing factors. It should be noted that energy-efficient dwellings may impact on health in a complex manner. For example, the air tightness of energy-efficient dwellings may have an adverse impact on indoor air quality, if the main polluting sources are indoor. However, higher levels of insulation also result in more comfortable, warmer indoor temperatures.

Although no conclusions could be drawn on the links between energy efficient dwellings and asthma prevalence, this study suggest that a greater percentage of people living in dwellings built after 1980 have asthma. This may be due, for example, to a combination of increased air tightness and of harmful emissions from new materials' type. Further studies should be carried out in order to confirm this result.

No significant association could be found between asthma prevalence and fitness of ventilation. However, the occurrence of mould growth appears greater in dwellings with unfit ventilation. As ventilation fitness does not represent a quantitative measurement, these results should be taken with some caution.

As already mentioned, published data suggests that there is an association between damp buildings and asthma prevalence. The analysis of the EHCS 2001 shows that there is an association between mould growth and occupants numbers, as well as SAP rating and age of property.

The occurrence of respiratory problems is determined by a number of interacting factors, both at the individual's level and at the housing characteristics level. Mould growth is also affected by several variables. Multiple-variable analysis might highlight the presence of correlations, which were not found in this study.

6.0 Conclusions

The review of literature on the links between ventilation rates in dwellings and moisture-related respiratory hazards revealed a general consensus on the link between ventilation rates in dwellings and respiratory hazards (for example HDM). There is also general consensus of a link between these respiratory hazards and respiratory problems, but it is not clear to what extent hazards cause ill-health. Most existing data are inadequate for conclusions to be drawn whether ventilation rates *directly* cause respiratory problems.

It must be noted that there are real difficulties in attempting to study the relationship between housing ventilation and respiratory health. In order to examine a causal relationship, studies involving a large number of participants should be conducted. Ventilation rates and exposure levels to all common indoor pollutants should be measured. However, the number of participants is restricted by the large number of variables to be measured. Respiratory symptoms that may be attributed to housing are common and difficult to standardise; and so also are the various factors suggested to cause them. Furthermore, measurements of exposure levels can be very expensive; sampling of some pollutants can be complex and has yet to be standardised. Also, sampling is very dependent on the methods used. Many studies on indoor mould and health refer to reported visible mould. However, some studies (Garrett M.H. *et al.*, 1998) have found that measurements of specific fungal spore genera concentrations predict health outcomes better than total spore concentrations, reported dampness or observed dampness. Furthermore, the presence of visible mould/dampness may indicate that the indoor environmental conditions are favorable for mite growth.

It should be noted that it is relatively difficult to measure ventilation in housing: current techniques can only be undertaken on a small number of dwellings at a time, due to expense and complexity. Furthermore, ventilation is not the only parameter affecting indoor hygrothermal conditions. A number of other parameters should also be taken into account: heating patterns, building fabric, occupants' habits, etc. In addition, low ventilation rates are not necessarily always undesirable, if outdoor air is heavily polluted.

A number of studies appear to indicate that a link exists between ventilation in housing and moisture-related pollutants. However, further work is necessary in order to better assess the relationship between housing ventilation and HDM or mould microenvironments. Also, more work is needed on the impact of transient hygrothermal conditions on HDM and mould growth. At present, more work is also needed on sensible exposure threshold limit values, particularly for mould.

The analysis of the EHCS database suggests that mould growth is related to occupancy levels, energy efficiency and age of the property. The analysis also revealed a trend for a higher asthma prevalence in dwellings built after 1980. Further studies are required in order to confirm and interpret these findings.

Most current guidance on domestic ventilation is based on the assumption that if ventilation levels are sufficient to avoid mould growth, then other IAQ problems will be contained as well. The modeling work outlined in this paper suggests that this may not be the case.

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