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Will drivers for home energy-efficiency harm occupant health?

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Abstract

The UK Government has committed to an 80% reduction in carbon emissions by 2050, with housing accounting for 27% of total current emissions. There are several drivers both to reduce emissions from homes and to reduce fuel poverty, promoting a range of building and behavioural measures in homes. The health benefits of warmer homes in winter have been described, but there has been less consideration of the potential negative impacts of some of these measures.

We examine the changes in our homes, and the possible consequences for health. The main concerns for health surround the potential for poor indoor air quality if ventilation is insufficient, and the possible risks of over-heating in heatwave conditions. We note a limited evidence base and the need for further research on the health effects of energy-efficient homes, particularly with regard to ventilation.

Keywords

Health, Homes, Energy efficiency, Indoor Air Quality, Heatwave

Introduction

The indoor environment is a significant determinant of population health. People in industrialised countries spend approximately 80% of their time indoors[1,2]. Those at extremes of age or in poor health are likely to spend considerably more time at home than others; they may be particularly affected by changes to the indoor environment. The health sector has an important role in ensuring healthy indoor environments for all.

Three main drivers are promoting the building and refurbishing of homes to make them more energy efficient. Firstly, housing accounts for 27% of current carbon dioxide (CO_2) emissions in the United Kingdom (UK)[3]. Home energy-efficiency is seen as a key part of the UK Government's commitment to an 80% reduction in carbon emissions from 1990 levels by 2050[4]. Secondly, the national Fuel Poverty Strategy incorporates home energy efficiency as part of its framework to eradicate fuel poverty in vulnerable households by 2010 [5]. Lastly, the current financial crisis may encourage householders to contain energy costs by making their homes more energy efficient. Given the impact of the recent recession on the building industry, now is an opportune time to examine whether there is sufficient information on the impact on occupant health of existing building policy, guidance and practice.

The UK has one of the highest rates of excess winter mortality in Europe, with currently about 25,000 excess winter deaths each year [6]. These deaths are at least partially related to poor housing [7]. Much of the research and policy emphasis to date has been on exploring how energy efficiency measures may benefit health through improved indoor temperatures in winter. However, it is important that we also consider and mitigate any potential hazards to health. Chief among our concerns is the impact on indoor air quality (such as levels of radon, products of combustion, pollutants released by furnishings, building materials and consumer products, environmental tobacco smoke, mould and house dust mites), and the potential risk of over-heating during heatwave conditions. Both hazards may have a significant impact on occupant health and well-being.

Changes in our homes

Traditional UK housing has low thermal performance and high levels of air permeability. An estimated 15% of all UK homes (3.4 million) fail the thermal comfort criteria for a 'decent home'[8]. The changes recommended to save energy and improve the thermal comfort of our homes include improved standards of insulation and air tightness, high efficiency boilers, double-glazing, and behaviour change (e.g. switching appliances off at the wall).

In the UK, new-build and structural change in existing homes must comply with Building Regulations to ensure the health and safety of those in and around the building. The Building Regulations set out the requirements with which individual aspects of building design and construction must comply. There are 14 Parts that cover aspects such as structure, access, fire safety, electrical safety, waste disposal, energy use, ventilation etc.[9]. 'Approved Documents' provide guidance on how each part of the Building Regulations may be achieved. To reduce emissions from residential buildings, a progressive tightening of Building Regulation Part L (Conservation of Heat and Power) is underway. Part F (Ventilation) is being revised in tandem, aiming to ensure that increased air tightness does not compromise indoor air quality. The intention is that by 2016 all new homes will be 'zero carbon'. This is to be achieved by 2015 for social housing funded under the National Affordable Housing Programme.

Alongside the Building Regulations is the 'Code for Sustainable Homes (CSH) 2007', against which, from 2008, it has been mandatory for all new homes to be rated[10] (table 1). The CSH is an aspirational framework for the design and construction of new homes, and indicates the likely direction of travel of the Regulations[11]. By 2010, 2013, and 2016 all new homes should achieve 'Code 3, 4 and 6' respectively. A CSH rating provides valuable information to homebuyers and provides a means by which housebuilders may differentiate themselves. 'Health' is included as one of the nine categories against which new homes are rated, but its characterisation is limited to sound insulation, good daylighting, private outdoor space, and 'lifetime homes' (homes that are accessible and adaptable). Indoor air quality is not directly addressed. Most weight in the rating is given to easily definable measures of energy and water usage, rather than health benefit. At present, there are less than 100 homes in the UK rated against the CSH, although nearly 200,000 have been registered for future construction[12].

A whole house ventilation rate of between 0.5 and 1.0 air changes per hour is considered to usually represent adequate ventilation[13]. At this level of air change, relative humidity is unlikely to exceed 70% for prolonged periods, thus preventing condensation and mould growth. At present, ventilation is mostly achieved by air infiltration of the building structure and window opening. As houses become increasingly airtight, less reliance can be placed on a building's air permeability to provide adequate ventilation. 'Purpose-provided' ventilation will need to be increased – either using natural/passive or mechanical (forced flow) systems.

In very air tight homes, such as CSH Code 5 and 6, mechanical systems are likely to be required. Mechanical ventilation has the advantage that it is more easily controllable than natural systems, and if equipped with an efficient heat recovery system will help save energy and maintain indoor temperatures. However, it represents a step-change in building design and system use for the UK. Mechanical systems need correct commissioning, installation, and maintenance, and there is, at present, no dedicated trade body or accredited training for the installation and servicing of mechanical ventilation systems in the UK. The ability of these systems to achieve the recommended ventilation rates post occupancy is rarely measured. Mechanical systems also require energy to operate and may be noisy, with the attendant risk that occupants may not use them or interfere with their operation. Several studies have demonstrated a lack of occupant awareness and understanding of the ventilation system in their homes[14,15,16]. Also, a reliance on mechanical systems raises concerns for health because of the risk of failure, which may be aggravated by poor maintenance (e.g. through not replacing filters).

However, natural ventilation systems do not avoid the problem of poor installation or use, with anecdotal reports of occupants sealing air bricks and trickle ventilators supplied with double glazing. Occupants may not open windows because of external noise and air pollution, or because of security/safety fears. Homes also risk being over-ventilated with unnecessary heat loss, because of the lack of control available with natural systems.

There is some evidence to support the hypotheses that newer homes may be under-ventilated or have poorer indoor air quality. A national survey of UK homes found that levels of formaldehyde and VOCs were highest in very new homes, but did not assess ventilation[17]. A later study of 37 new UK homes built since 1995 showed that 38% had ventilation rates in winter below the recommended level and that trickle vents were only fully open in four of the homes[18]. Mean concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), formaldehyde and volatile organic compounds (VOCs) were within typical ranges for UK homes, with VOC levels higher in those with lowest ventilation. Elsewhere in Europe, experience from Sweden has demonstrated that following a national programme to upgrade homes, 80% of single family houses and 50% of multi-family houses were found to be under ventilated[19]. Those living in multi-family homes built since 1976 were more likely to report symptoms such as hoarseness and dryness of the skin than those living in older homes. The difficulties of ensuring adequate ventilation using either mechanical or natural systems illustrate some of the challenges inherent in revising part F (ventilation) of the Building Regulations.

Although there has been progress to improve the energy efficiency and thermal comfort of new-build, housing stock turnover is low (<1% annually)[3]. It is estimated that 70% of the housing stock of 2050 has already been built[20]. If the 80% emission reduction target for 2050 it to be met from the housing sector, up to 500,000 existing homes need to be appropriately refurbished every year[21]. Refurbishment to existing homes that does not involve structural change is generally outside of Building Regulation requirements, and performed without scrutiny. There are a variety of policies and programmes encouraging energy efficiency measures in existing homes, which may be installed on a professional or 'do-it-yourself basis', depending on the intervention involved. Ventilation requirements are rarely considered, although it has been shown that it is possible to substantially reduce air permeability in existing homes with measures such as insulation and draught stripping[22,23]. An additional risk is that existing ventilation measures e.g. air bricks or flues from combustion appliances may be inappropriately sealed.

Health impacts

The relationship between housing and health is complex and difficult to measure – e.g. measurement of exposure, multiple confounding factors, and the need for long-term follow-up for important health outcomes. As a result there is a lack of robust evidence on the health impacts of housing interventions[24] and some debate about whether energy-efficient homes are more or less beneficial for occupant health.

The available evidence suggests that energy-efficiency measures have a largely positive effect on the physical and mental health of occupants through improving winter indoor temperatures and reducing fuel poverty[25,26, 27], although many of these studies also incorporate heating upgrades. In broader global health terms, a reduction in carbon emissions and the consequent improvement in outdoor air quality and mitigation of climate change are expected to achieve important public health gains[28]. Wilkinson et al have recently modelled the likely health impacts under five scenarios of household intervention to improve energy efficiency[29]. All scenarios, with important caveats, resulted in an overall benefit to health, but with some negative effects relating to specific environmental factors.

Nevertheless, there are concerns about the impact on occupant health of increased air tightness in the absence of adequate ventilation. Insufficient ventilation increases levels of indoor pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), formaldehyde, volatile organic compounds (VOCs), environmental tobacco smoke (ETS), radon - all of which may be harmful to health.

If energy efficient homes incorporate appropriately maintained mechanical ventilation systems with filtration of fine particles ($PM_{2.5}$) in the incoming air there could be benefits to population health from reduced exposure to ambient particles[30]. Leech et al have demonstrated improvements in symptom scores for throat irritation, cough, fatigue and irritability amongst those moving into new air tight homes with mechanical ventilation and heat recovery (HRV) systems, compared with those moving into standard new homes[16.] Nevertheless, only 76% of the occupants in the energy efficient houses operated their HRVs throughout the winter, 58% throughout the summer, and 10% did not even realise they had an HRV installed.

High levels of relative humidity promote the growth of mould and the proliferation of house dust mites – both of which are implicated in the development and worsening of asthma. Raising winter indoor temperatures through better insulation should reduce levels of relative humidity and condensation, but if ventilation is insufficient relative humidity will increase causing a potential worsening of respiratory conditions. The absence of condensation and mould is considered indicative of adequate ventilation[31]. However it is not clear whether this remains a safe assumption with improved thermal insulation and warmer indoor temperatures - there may be less mould but levels of other pollutants will remain the same or increase.

The impact of energy saving on the incidence of carbon monoxide poisoning is hard to predict. On the one hand, poor overall or appliance specific ventilation because of poorly implemented efforts to save energy will increase the risk of carbon monoxide poisoning. On the other, a reduced reliance on fossil fuel burning in the home will reduce risk by removing some sources of the gas.

Radon is estimated to cause more than 1000 lung cancer cases per year[32]. Radon is usually drawn in from the soil because of pressure differences that occur between the ground and the internal atmosphere of buildings. The relationship between indoor radon levels and the installation of energy saving measures is complex. These measures may both increase indoor radon levels by improving air tightness (double-glazing of all windows was estimated to increase indoor radon levels by 55%, full draught-proofing by 9%[33]) and decrease radon levels by reducing ingress from the ground (sealing unused chimneys reduces the stack effect, underfloor insulation may reduce radon entry). It is now clear that the risk of lung cancer extends below the current UK 200 Bqm^3 Action Level[28]. In May 2008, the Health Protection Agency recommended that all new build, extensions and refurbishments regardless of area should be fitted with basic radon protective measures e.g. fitting a gas-tight membrane into the floor of the building [34]. This is rarely practicable in an existing home, and alternative measures need to be considered if a home is identified as being above the current radon Action Level.

It is also important to consider how energy efficiency measures are likely to affect occupant health in our anticipated near-future climate. In the UK, milder winters and warmer, wetter summers are expected. More frequent and more intense heatwaves are likely and it is estimated that by 2050 every second summer will be similar to the summer of 2003 when there were over 2000 extra deaths in the UK[6]. Whilst insulation may reduce such risks by keeping heat out of the home, if heat is allowed to enter e.g. through unshaded double-glazed windows, thermal insulation may prevent it escaping thus increasing heat related health risks. These include an increased risk of illness and death from a wide variety of conditions, most commonly respiratory and cardiovascular disease. In hot weather, the importance of nocturnal ventilation becomes particularly pronounced, and there is some doubt about the effectiveness of mechanical ventilation systems in achieving the recommended eight air changes per hour required for effective cooling in these circumstances. Passive measures to reduce over-heating need to be incorporated in the design and refurbishment of buildings now to avoid a future reliance on use of air conditioning units to cool homes.

The warmer summers of the future may well be associated with higher outdoor levels of the irritant gas ozone and this will impact the indoor environment. Ozone reacts with material surfaces and with other components of the air and therefore indoor concentrations in the absence of an internal source are normally lower than outdoors. However there is some concern that the products of the chemical reactions could themselves be a health risk and further research is required[35].

What is needed?

At present, evidence on the impacts on health of highly energy efficient homes in the UK is insufficient[36]. Yet the drivers promoting the take-up of energy efficiency are likely to become more pressing, and to require more stringent measures. Policy makers need to ensure energy is saved, whilst not undermining health, but the evidence base with which to inform policy is limited.

Many of the potential hazards to health associated with energy saving in homes depend upon whether or not sufficient ventilation is provided. Whilst there is evidence to link ventilation to indoor air pollutants, and indoor air pollutants to health, there is less information about the direct links. There has never been a comprehensive study on the role of home ventilation for ensuring health; of ventilation rates achieved in practice in UK homes; or a definitive assessment of a safe minimum level of ventilation (although 0.5 air changes per hour is widely recommended). It is also notable that most published studies of energy efficient homes use a limited definition of occupant health, focussing on thermal comfort and occupant satisfaction. There is a real need for large scale, longitudinal studies to assess the relationships between energy efficiency, ventilation, indoor air quality and health, and to model the relationships under different climate change scenarios.

As buildings become more airtight, there will be a greater reliance on mechanical ventilation systems. We urgently need a better understanding of the performance of these products post-occupancy as well as guidance for those commissioning, installing, maintaining and using such products. Anecdotal information suggests that there is a low level of public understanding about the importance of, and the best way to achieve, appropriate ventilation. Research should be undertaken to gain a better understanding of the public's knowledge, behaviour and attitudes with regard to ventilation.

We should also take the opportunity to learn from the experience of those colleagues in other countries with experience in the design and construction of airtight buildings, whilst acknowledging the importance of UK specific factors in relation to housing type, building practice, climate and occupant behaviour. Several countries now have standards or packages to assure indoor air quality in sustainable homes (e.g. the US Environmental Protection Agency Energy Star Indoor Air Package). The European Commission is supporting an initiative to harmonise the existing voluntary schemes for labelling of low emitting construction products that aim to reduce the risk of poor air quality[37,38]. There are currently no requirements in the CSH for selection of low emitting products and a scheme based on the experience of other European countries should be adopted.

Climate change is described as the biggest threat to public health in the 21^{st} Century[39]. Energy saving and other measures to make homes more sustainable offer a significant opportunity to make homes healthier. However, in order to maximise the health benefit from these policies it is imperative that we assess all of the impacts on health, and take action to limit the harm to occupants from any hazards identified.

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References

[1]Farrow A, Taylor, H and Golding J. Time Spent in the Home by Different Family Members, *Environmental Technology* 1997;18:605-13.
[2] Mccurdy T and Graham SE. Using human activity data in exposure models: Analysis of discriminating factors. *J Expo Anal Environ Epidemiol* 2003;13:294-317.
[3] Communities and Local Government. Building a Greener Future: Policy Statement. 2007. 07 HC04748/a. Available online at: http://www.communities.gov.uk/publications/planningandbuilding/building-a-greener (accessed 15th August 2009).
[4] United Kingdom Climate Change Act. 2008. Available online at: http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf (accessed 15th August 2009).
[5] United Kingdom Fuel Poverty Strategy. 2001. Available online at: http://www.berr.gov.uk/files/file16495.pdf (accessed 15th August 2009).
[6] Department of Health. Health and Winter Warmth Bulletin - Summer 2008. Available online at http://www.warmerhealthyhomes.org.uk/media/PDF/health%20bulletin%20summer%2008.pdf (accessed 15th August 2009).
[7] Wilkinson P, Landon M, Armstrong B, Stevenson S, and McKee M. Cold Comfort: the social and environmental determinants of excess winter deaths in England 1986-1996. York, Joseph Rowntree Foundation, 2001.
[8] Communities and Local Government. English House Condition Survey Headline Report, 2007. Available online at: http://www.communities.gov.uk/documents/statistics/pdf/1133548.pdf (accessed August 13th 2009).
[9] Communities and Local Government. The Building Regulations Explanatory Booklet. Available online at: http://www.communities.gov.uk/publications/planningandbuilding/buildingregulationsexplanatory (accessed 13th August 2009).
[10] Communities and Local Government. The Code for Sustainable Homes Technical Guide May 2009 version 2. Available online at: http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf accessed 15 August 2009
[11] Communities and Local Government. Code for Sustainable Homes. Setting the Standard in sustainability in new homes. 2008. Available online at: http://www.communities.gov.uk/documents/planningandbuilding/pdf/codesustainhomesstandard.pdf (accessed 15 August 2009).
[12] Parliamentary Question. Response by Communities Minister Iain Wright to a written question by Grant Shapps, April 2009. Available online at: http://www.parliament.the-stationery-office.co.uk/pa/cm200809/cmhansrd/cm090429/text/90429w0023.htm (accessed 15th August 2009).
[13] DETR. Energy efficient ventilation in housing: a guide for specifiers on the requirements and options for ventilation. Good Practice Guide 268. Department of Environment, Transport and the Regions, London, 2002.
[14] Aizlewood C, Dimitroulopoulou C. The HOPE project: The UK experience. *Indoor and Built Environment* 2006;**15**:393-409.
[15] Ezratty V, Duburcq A, Emery C, and Lambrozo J. Residential Thermal Comfort, Weather-Tightness and Ventilation: Links With Health in a European Study (LARES). Proceedings of the 5th Warwick Healthy Housing Conference. 17th-19th March 2008, Warwick University, United Kingdom: 2008.
[16] Leech J, Raizenne M and Gusdorf J. Health in occupants of energy efficient homes. Indoor air 2004; 14:169-173.

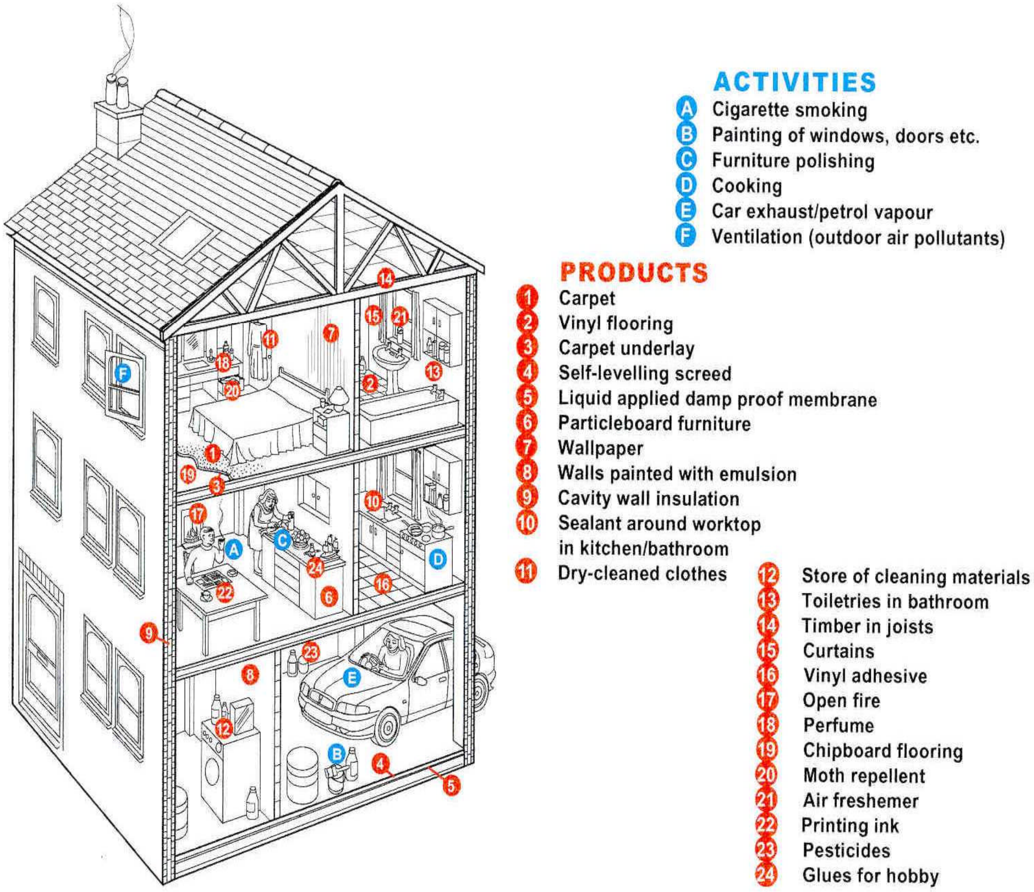
[17] Coward SKD, Llewellyn JW, Raw GJ, Brown VM, Crump DR, and Ross D. Indoor air quality in homes in England. BRE report BR 433. London: CRC Ltd, 2001.
[18] Dimitroulopoulou C, Crump DR, Coward SKD, Brown B, Squire R, Mann H, et al. Ventilation, air tightness and indoor air quality in homes in England built after 1995. BRE report BR 477. BRE, Garston, 2005.
[19] Norlen U and Andersson K. The Indoor Climate in the Swedish housing stock. Swedish Institute for Building Research. 1993.
[20] Office of Climate Change Household Emissions Project. Analysis pack Sept 2007. Available online at :http://www.occ.gov.uk/activities/emissions/Household%20emissions%20report%20-%20analysis%20pack%2028March2007.pdf (accessed 13th August 2009).
[21] Kelly MJ. CLG's Primary Responsibilities concerning Climate Change- a personal view. Meeting the carbon reduction targets – how can the energy efficiency of the existing building stock be increased? Proceedings of Improving the Energy Efficiency of the Existing Building Stock. Foundation of Science and Technology 4th June 2008. Available online at: http://www.foundation.org.uk/events/pdf/20080604_Kelly.pdf (accessed 15th August 2009).
[22] Hong SH, Ridley, I, Oreszczyn, T, and The Warm Front Study Group. The Impact of Energy Efficient Refurbishment on the Airtightness in English Dwellings. Proc.Air Infiltration & Ventilation Centre (AIVC) Conference, September 15-17, Prague . 2004.
[23] Ridley I, Mumovic D, Davies M, and Oreszczyn, T. Impact of Replacement Windows on IAQ of Occupied Dwellings Project. Building Research Technical Report 8/2005. Office of the Deputy Prime Minister, 2006.
[24] Thomson H, Petticrew M, Morrison D. Health effects of housing improvement: Systematic review of intervention studies. *British Medical Journal* 2001;**323**:187-90.
[25] Barton A, Basham M, Foy C, Buckingham K, Somerville M. The Watcombe Housing Study: The short term effect of improving housing conditions on the health of residents. *J Epidemiol Community Health* 2007;**61**:771-7.
[26] Green G and Gilbertson J. Health Impact Evaluation of the Warm Front Scheme. Sheffield Hallam University. 2008. Available online at: http://www.shu.ac.uk/_assets/pdf/cresr-WF_final+Nav(2).pdf (accessed 15th August 2009).
[27] Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T *et al*. Effect of insulating existing houses on health inequality: Cluster randomised study in the community. *British Medical Journal* 2007; **334**:460-4.
[28] Wilkinson P, Smith KR, Beevers S, Tonne C, Oreszczyn T. Energy, energy efficiency, and the built environment. *Lancet* 2007;**370**:1175-87.
[29] Wilkinson P, Smith KR, Davies, M, Adair H, Armstrong BG, Barrett M et al. Health and Climate Change 1. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *Lancet* 2009: 374; 1917-1929
[30] Hänninen OO, Palonen J, Tuomisto JT, Yli-Tuomi T,. Seppänen O, Jantunen MJ. Reduction potential of urban PM2.5 mortality risk using modern ventilation systems in buildings. *Indoor Air* 2005; 15: 246–256
[31] Ridley I, Pretlove, S EC, Ucci M, Mumovic D, Davies M, and Oreszczyn T. Asthma/Dust Mite Study - Final Report - Sensitivity of Humidity and Mould Growth to Occupier Behaviour in Dwellings Designed to the New Air Tightness Requirements. Building Research Technical Report 7/2005. Office of the Deputy Prime Minister, 2006.
[32] The Independent Advisory Group on Ionising Radiation. Health effects of radon exposure. *Radiation and Pubic Health* RCE II 2009.
[33] Gunby JA, Darby SC, Miles JC, Green BM, Cox DR. Factors affecting indoor radon concentrations in the United Kingdom. *Health Phys* 1993;**64**:2-12.

[30] Health Protection Agency. HPA Advice on Radon Protective Measures in New Buildings. Health Protection Agency Board Meeting 21st May 2008. Enclosure 08/054. Available online at: http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1210922348305 (accessed 15th August 2009).
[35] Carslaw N, Langer S and Wolkoff. P New Directions: Where is the link between reactive indoor air chemistry and health effects*? Atmospheric Environment* 43 (2009) 3808–3809.
[36] Crump D., Dengel A., Swainson M. Indoor air quality in highly energy efficient homes – a review. NHBC Foundation Report NF18, July 2009.
[37] European Collaborative Action . Harmonisation of indoor material emissions labelling systems in the EU – inventory of existing schemes. European Collaborative Action – Urban air, indoor environment and human exposure, report no. 24, 2005.
[38] Crump D. Harmonisation of material labelling schemes in the EU. Proceedings of the twelfth annual UK review meeting on outdoor and indoor air pollution research, Cranfield University, 20-21 April 2009.
[39] Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R et al. Managing the health effects of climate change. *Lancet* 2009*; **373:** 1693—733.*

Table 1: The Code for Sustainable Homes (adapted from[10])

Code level	Minimum reduction in house emission rate over target emission rate[39] (%)	Minimum indoor water consumption per person per day (l)	Comparison with other standards	Year when Building Regulations expected to require standard
1	10	120	• Above regulatory standards • A similar standard to BRE's EcoHomes© PASS level • A similar standard to EST's Good Practice Standard for energy efficiency	
2	18	120	• A similar standard to BRE's EcoHomes© GOOD level	
3	25	105	• Broadly similar standard to BRE's EcoHomes© VERY GOOD level • Similar to EST's Best Practice Standard for energy efficiency	2010
4	44	105	• Current exemplary performance	2013
5	100	80	• Exemplary performance with high standards of energy and water efficiency	
6	'Zero Carbon'	80	• Aspirational standard based on zero carbon emissions for the dwelling and high performance across all environmental categories	2016

Figure 1 – Factors affecting indoor air quality†



† Crump D. Maintaining good air quality in your home. BRE IP 9/04. 2004.