**MAIN TEXT**

Cold housing and fuel poverty appear to be determinants of winter- and cold-related ill health in the UK and other settings.[1](#_ENREF_1) Actions to improve home energy efficiency are therefore assumed to have the potential to improve public health, while also being important for meeting climate change abatement targets.[2](#_ENREF_2) Indeed, in most settings, greenhouse gas emissions reduction and other environmental considerations are the primary motives for home energy efficiency programmes. Recent reviews of health impacts related to housing quality and energy efficiency have suggested modest beneficial effects for general health, respiratory health and mental health.[3](#_ENREF_3), [4](#_ENREF_4) However, those reviews were not targeted specifically at interventions to reduce exposure to cold in the home. To support guidance on this topic (published in March 2015),[5](#_ENREF_5) the UK’s National Institute for Health and Care Excellence (NICE) commissioned a review of evidence, part of which was aimed at determining the extent to which home energy efficiency and heating interventions reduce the health risks associated with cold.[6](#_ENREF_6" \o "Milner, 2014 #76) Further elements to the work considered aspects of vulnerability,[7](#_ENREF_7) implementation and delivery,[8](#_ENREF_8) and an economic modelling assessment.[9](#_ENREF_9)

The systematic literature review was based on a wide range of databases and grey literature sources and was performed during September and October 2013. Studies were considered eligible for inclusion if they (i) reported quantitative primary research evidence on home energy efficiency or heating interventions aimed at reducing the risks of winter- and cold-related mortality/morbidity, (ii) were performed in countries which are members of the Organization of Economic Cooperation and Development (OECD), and (iii) were published in the English language since 1993. Quality appraisal was made using the criteria and processes for assessing intervention studies outlined by NICE.[10](#_ENREF_10) Further details of the review process can be found in an electronic appendix to this paper (see eAppendix 1, Supplementary Digital Content).

Evidence on the health impacts of increasing home energy efficiency and/or winter heating

Twenty one intervention studies were identified that reported quantitative associations (see eFigure A1 in eAppendix 1, Supplementary Digital Content, which shows a flow diagram of the review process). Most studies reported interventions to increase energy efficiency, with a minority providing evidence on improving heating systems (sometimes in combination with improved energy efficiency). Studies included randomized controlled trials (RCTs), before-after comparisons, observational studies of natural experiments, and experimental studies. The included studies are described in more detail in the electronic appendix (see eTable 1 in eAppendix 2, Supplementary Digital Content, which presents the characteristics of each study). In summary:

* Six studies from the UK[11-14](#_ENREF_11) and New Zealand[15](#_ENREF_15), [16](#_ENREF_16) provided evidence about symptoms in children or adults relating to asthma;
* Six papers, including five from the UK[17-21](#_ENREF_17) and one from Canada,[22](#_ENREF_22) examined the impact of housing interventions on general respiratory health;
* Nine studies addressed effects on mental well-being, including an RCT from New Zealand,[15](#_ENREF_15) seven studies from the UK,[12-14](#_ENREF_12), [17](#_ENREF_17), [18](#_ENREF_18), [21](#_ENREF_21), [23](#_ENREF_23), and a German before-after study;[24](#_ENREF_24)
* Eight studies considered various measures of general health and wellbeing, including two RCTs from New Zealand,[15](#_ENREF_15), [16](#_ENREF_16) an RCT from Japan,[25](#_ENREF_25) and five studies including RCTs from the UK;[17](#_ENREF_17), [18](#_ENREF_18), [23](#_ENREF_23), [26](#_ENREF_26), [27](#_ENREF_27)
* Seven studies provided quantitative evidence about changes in contacts with the health service (either hospital admissions or GP consultations);[12](#_ENREF_12), [14-16](#_ENREF_14), [26](#_ENREF_26), [28](#_ENREF_28), [29](#_ENREF_29)
* RCTs from the UK[11](#_ENREF_11) and New Zealand,[30](#_ENREF_30) and an observational study from the UK[20](#_ENREF_20) provided quantitative evidence about housing interventions and absence from school.

Overall, the evidence was suggestive, though not conclusive, that interventions which improve home energy efficiency and/or home heating are generally beneficial for health. It suggested that home energy efficiency can improve respiratory outcomes for some children or adults with asthma and related conditions, with the strongest evidence coming from the larger scale RCTs in New Zealand[15](#_ENREF_15), [16](#_ENREF_16), [30](#_ENREF_30) and the UK.[11](#_ENREF_11), [13](#_ENREF_13), [26](#_ENREF_26) There was also evidence that housing interventions may improve various measures of mental well-being, at least in the short term, although evidence reporting in some studies has been selective.[13](#_ENREF_13) Evidence (largely from New Zealand) about possible reductions in health service contact was mixed, and there was limited evidence that housing interventions may reduce school absences for children with asthma.[20](#_ENREF_20), [30](#_ENREF_30)

While there are now a number of good RCTs, the evidence from these studies is heterogeneous, disappointingly mixed in quality, and somewhat difficult to interpret – including the evidence from the RCTs themselves. For example, the CHARISMA (Children's Health in Asthma: Research to Improve Status through Modifying Accommodation) study was primarily an analysis of a specific ventilation intervention for asthma sufferers and only a small subset of the study population received the heating intervention,[11](#_ENREF_11) while an otherwise sound RCT by Osman et al. (2010) had appreciable cross-contamination of its intervention arms and its effective sample size was small.[26](#_ENREF_26)

Research in this field presents a number of challenges which have contributed to the difficulty of evidence interpretation. With housing intervention studies, it is generally impossible to blind recipients (and sometimes researchers) to the intervention. In circumstances in which many of the recorded outcomes are based on patient- or parent-reported symptoms, there is evident potential for bias, especially where intervention recipients receive an upgrade in the quality of their dwelling at no direct cost to themselves. Some studies did include more ‘objective’ outcomes, including Peak Expiratory Flow Rate (PEFR)[30](#_ENREF_30) and blood pressure,[25](#_ENREF_25), [31](#_ENREF_31) doctor records of consultations and diagnoses,[15](#_ENREF_15), [16](#_ENREF_16) as well as measures of days off work or school,[11](#_ENREF_11), [15](#_ENREF_15), [16](#_ENREF_16) and instrument-based measures of mental well-being.[13](#_ENREF_13), [17](#_ENREF_17), [18](#_ENREF_18), [23](#_ENREF_23) However, longer term consequences of intervention were generally not studied, nor impacts on ‘hard’ endpoints such as mortality or hospital admissions, mainly for reasons of time lag and required sample size. With a few exceptions, individual studies were comparatively modest in size and understandably well below the very large population sizes needed to assess changes in outcomes such as cold-related mortality. The fact that most studies also measured multiple outcomes adds further complexity to interpretation, especially when similar outcome measures (or different dimensions of a measure) gave different patterns of results, as occurred for example with the different dimensions of psychosocial well-being assessed in the Warm Front evaluation.[23](#_ENREF_23) It is important to note that no single study has thus far captured a comprehensive range of potential health impacts, including those that relate to the long-term effects of exposures, and especially those relating to changes in the ventilation characteristics of dwellings. In consequence there remain uncertainties about some potentially negative longer-term (and hence usually unmeasured) consequences of home energy efficiency interventions.[32](#_ENREF_32)

Other limitations of our review include the fact that it was restricted to English language and OECD countries, while it is likely that many of the important factors relating to housing and health are specific to the local context (such as the local climate and housing quality). The heterogeneity of studies, especially the diversity of study designs and settings, makes it difficult to draw firm conclusions, and interpretation is also made more complex by changes over time that may appreciably alter the context in which interventions in housing and other sectors occur.

Nonetheless, despite these substantial cautions, the balance of the limited pool of evidence points clearly to net beneficial effects for health of home energy efficiency interventions, especially for selected population groups such as the elderly and those with certain illnesses. This conclusion is broadly consistent with previous related reviews,[3](#_ENREF_3), [4](#_ENREF_4) and supported by qualitative evidence that has identified a number of pathways for psychosocial well-being relating to energy efficiency improvements.[14](#_ENREF_14), [33](#_ENREF_33) Recent studies have also suggested that home energy efficiency upgrades are cost-effective, at least in part due to the benefits for health.[34-37](#_ENREF_34) The overall economic assessment of the interventions is likely to depend in large measure on how health and non-health costs and benefits are counted, with home energy efficiency interventions being more likely to be justified economically once a wider range of benefits are considered (including probable environmental and social benefits).[9](#_ENREF_9)

**Implications for public health policy**

The conclusion of usually net beneficial effects for health of home energy efficiency and heating improvement has important implications for public policy. Specifically, it strengthens arguments, perhaps crucially so in some cases, for more widespread and accelerated action to improve the energy efficiency of the housing stock in the UK and elsewhere for health as well as environmental reasons. When an integrated view is taken that considers impacts on health alongside those on greenhouse gas emissions, energy security and household fuel costs, the case for action would appear generally compelling.

However, with any widespread programme it is important to understand the full spectrum of positive and negative health effects of energy efficiency upgrades to ensure that interventions are appropriately tailored to maximize the positive benefits and minimize unintended adverse consequences.[38](#_ENREF_38) There is a need for further research. This is especially so given that the influence of housing quality on health may be very context specific so that extrapolation of results from one country to another should be done with caution. Specific research needs include:

* Studies that evaluate as wide a range of outcomes as possible, including mortality, hospital admissions and outcomes that may be affected over the longer term by changes in indoor air quality. Studies need to be of sufficient scale and to employ methods of objective measurement;
* Studies of the effect of fuel prices and fuel poverty on health, whose assumed influence has not been adequately quantified through high quality empirical research;
* Studies of the policy environment and operational factors to determine how policies may be justified and aligned to support health, environmental and other objectives simultaneously.

There is now also increasing evidence of economic benefits due to home energy efficiency and heating interventions, for example the evaluation of the “Warm Up New Zealand: Heat Smart” programme.[39](#_ENREF_39) Whether home energy efficiency can be justified in cost-benefit terms as a purely health intervention remains unclear, though it may have a specific role for selected people with temperature-sensitive conditions. However, given that there is a compelling rationale for improving the energy efficiency of the vast majority of the housing stock in the UK and elsewhere to meet other public policy objectives, the identification of the opportunity to improve health through home energy efficiency could be an important factor in helping to prioritize action.

In conclusion, evidence on interventions that may help reduce the multiple factors contributing to excess winter- and cold-related mortality/morbidity remains limited and heterogeneous. However, there is now a suggestive body of evidence that energy efficiency and heating interventions in housing may improve the health of some population groups, notably those with respiratory and other chronic diseases.[15](#_ENREF_15), [26](#_ENREF_26) Positive effects on health may include improvements in respiratory symptoms and the symptoms of other chronic illnesses, improved mental well-being, reduced contacts with the health service and fewer days of absence from school or work. For some key target groups, such as children with asthma, housing intervention may be sufficiently justified in its own right as a means of helping to manage the clinical condition.[11](#_ENREF_11), [16](#_ENREF_16), [20](#_ENREF_20), [30](#_ENREF_30) However, the evidence base remains limited, and there is potential for unintended adverse consequences of some forms of energy efficiency upgrade over the longer term, principally in relation to changes in the ventilation characteristics of dwellings. This is an area in which there is particular lack of hard empirical evidence and more research is needed. For lower risk target groups the health benefits are less pronounced but such actions may be more readily justified if the health effects are considered alongside other social, environmental and economic consequences. The urgent need to tackle climate change already provides powerful motivation for improving the energy efficiency of the housing stock in countries such as the UK. The strengthening evidence for probable health benefits makes the case for the widespread acceleration of such investment even more forceful.

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References

1. Webb E, Blane D, de Vries R. Housing and respiratory health at older ages. J Epidemiol Community Health, 2013; 67(3): 280-5

2. Wilkinson P, Smith KR, Davies M, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet 2009; 374(9705): 1917-29

3. Maidment CD, Jones CR, Webb TL, Hathway EA, Gilbertson JM. The impact of household energy efficiency measures on health: a meta-analysis. Energy Policy 2014; 65: 583-93

4. Thomson H, Thomas S, Sellstrom E, Petticrew M. Housing Improvements for Health and Associated Socio-Economic Outcomes. Cochrane Database of Systematic Reviews, 2013.

5. NICE. Excess Winter Deaths and Illness and the Health Risks Associated with Cold Homes. NICE Guidance. London, UK: National Institute for Health and Care Excellence (NICE), 2015.

6. Milner J, Chalabi Z, Wilkinson P, et al. Evidence review and economic analysis of excess winter deaths. Review 2: Interventions and economic studies. London, UK: National Institute for Health and Care Excellence (NICE), 2014.

7. Milner J, Chalabi Z, Wilkinson P, et al. Evidence review and economic analysis of excess winter deaths. Review 1: Factors determining vulnerability to winter- and cold-related mortality/morbidity. London, UK: National Institute for Health and Care Excellence (NICE), 2014.

8. Milner J, Chalabi Z, Wilkinson P, Duffy S, Jones L, Petticrew M. Evidence review and economic analysis of excess winter deaths. Review 3: Delivery and implementation of approaches for the prevention of excess winter deaths and morbidity. London, UK: National Institute for Health and Care Excellence (NICE), 2014.

9. Milner J, Hamilton I, Chalabi Z, et al. Evidence review and economic analysis of excess winter deaths. Economic modelling report. National Institute for Health and Care Excellence (NICE): 2014.

10. NICE. Methods for the Development of NICE Public Health Guidance (Third Edition). London, UK: National Institute for Health and Care Excellence, 2012.

11. Woodfine L, Neal RD, Bruce N, Edwards RT, Linck P, Mullock L, Nelhans N, Pasterfield D, Russell D, Russell I. Enhancing ventilation in homes of children with asthma: pragmatic randomised controlled trial. Br J Gen Pract 2011; 61(592): e724-32

12. Walker J, Mitchell R, Petticrew M, Platt S. The effects on health of a publicly funded domestic heating programme: a prospective controlled study. J Epidemiol Community Health, 2009; 63(1): 12-7

13. Barton A, Basham M, Foy C, Buckingham K, Somerville M, Torbay Healthy Housing Group. The Watcombe Housing Study: the short term effect of improving housing conditions on the health of residents. J Epidemiol Community Health, 2007; 61(9): 771-7

14. Shortt N, Rugkasa J. "The walls were so damp and cold" fuel poverty and ill health in Northern Ireland: results from a housing intervention. Health Place, 2007; 13(1): 99-110

15. Howden-Chapman P, Matheson A, Crane J, et al. Effect of insulating existing houses on health inequality: cluster randomised study in the community. BMJ 2007; 334(7591): 460

16. Howden-Chapman P, Pierse N, Nicholls S, et al. Effects of improved home heating on asthma in community dwelling children: randomised controlled trial. BMJ 2008; 337: a1411

17. Green G, Gilbertson J. Warm Front, Better Health: Health Impact Evaluation of the Warm Front Scheme. Sheffield, UK: Centre for Regional Economic and Social Research, Sheffield Hallam University; 2008.

18. Critchley R, Gilbertson J, Grimsley M, Green G. Living in cold homes after heating improvements: Evidence from Warm-Front, England’s Home Energy Efficiency Scheme. Applied Energy 2007; 84(2): 147-58

19. Richardson G, Barton A, Basham M, Foy C, Eick SA, Somerville M, Torbay Healthy Housing Group. The Watcombe housing study: the short-term effect of improving housing conditions on the indoor environment. Sci Total Environ, 2006; 361(1-3): 73-80

20. Somerville M, Mackenzie I, Owen P, Miles D. Housing and health: does installing heating in their homes improve the health of children with asthma? Public Health 2000; 114(6): 434-9

21. Hopton J, Hunt S. The health effects of improvements to housing: a longitudinal study. Hous Stud 1996; 11(2): 271-86

22. Leech JA, Raizenne M, Gusdorf J. Health in occupants of energy efficient new homes. Indoor Air 2004; 14(3): 169-73

23. Gilbertson J, Grimsley M, Green G. Psychosocial routes from housing investment to health: evidence from England's home energy efficiency scheme. Energy Policy 2012; 49(1): 122-33

24. Braubach M, Heinen D, Dame J. Preliminary Results of the WHO Frankfurt Housing Intervention Project Copenhagen: World Health Organization, 2008.

25. Saeki K, Obayashi K, Iwamoto J, Tanaka Y, Tanaka N, Takata S, Kubo H, Okamoto N, Tomioka K, Nezu S, Kurumatani N. Influence of room heating on ambulatory blood pressure in winter: a randomised controlled study. J Epidemiol Community Health, 2013; 67(6): 484-90

26. Osman LM, Ayres JG, Garden C, Reglitz K, Lyon J, Douglas JG. A randomised trial of home energy efficiency improvement in the homes of elderly COPD patients. Eur Respir J, 2010; 35(2): 303-9

27. Heyman B, Harrington B, Heyman A. A randomised controlled trial of an energy efficiency intervention for families living in fuel poverty. Hous Stud 2011; 26(1): 117-32

28. Jackson G, Thornley S, Woolston J, Papa D, Bernacchi A, Moore T. Reduced acute hospitalisation with the healthy housing programme. J Epidemiol Community Health, 2011; 65(7): 588-93

29. El Ansari W, El-Silimy S. Are fuel poverty reduction schemes associated with decreased excess winter mortality in elders? A case study from London, U.K. Chronic Illness 2008; 4(4): 289-94

30. Free S, Howden-Chapman P, Pierse N, Viggers H, The Housing Heating and Health Study Research Team. More effective home heating reduces school absences for children with asthma. J Epidemiol Community Health, 2010; 64(5): 379-86

31. Lloyd EL, McCormack C, McKeever M, Syme M. The effect of improving the thermal quality of cold housing on blood pressure and general health: a research note. J Epidemiol Community Health, 2008; 62(9): 793-7

32. Milner J, Shrubsole C, Das P, et al. Home energy efficiency and radon related risk of lung cancer: modelling study. BMJ 2014; 348: f7493

33. Gilbertson J, Stevens M, Stiell B, Thorogood N, Warm Front Study Group. Home is where the hearth is: grant recipients' views of England's home energy efficiency scheme (Warm Front). Soc Sci Med, 2006; 63(4): 946-56

34. Chapman R, Howden-Chapman P, Viggers H, O'Dea D, Kennedy M. Retrofitting houses with insulation: a cost-benefit analysis of a randomised community trial. J Epidemiol Community Health, 2009; 63(4): 271-7

35. Clinch JP, Healy JD. Cost-benefit analysis of domestic energy efficiency. Energy Policy 2000; 29(2): 113-24

36. Edwards RT, Neal RD, Linck P, et al. Enhancing ventilation in homes of children with asthma: cost-effectiveness study alongside randomised controlled trial. Br J Gen Pract 2011; 61(592): e733-41

37. Fenwick E, Macdonald C, Thomson H. Economic analysis of the health impacts of housing improvement studies: a systematic review. J Epidemiol Community Health, 2013; 67(10): 835-45

38. Hamilton I, Milner J, Chalabi Z, et al. Health effects of home energy efficiency interventions in England: a modelling study. BMJ Open 2015; 6: e007298

39. Grimes A, Denne T, Howden-Chapman P, et al. Cost-Benefit Analysis of the Warm Up New Zealand: Heat Smart Programme Wellington, New Zealand: Report for the Ministry of Economic Development, 2011

**List of Supplementary Digital Content**

Supplementary Digital Content. Electronic appendix containing a brief description of the literature review method (eAppendix 1) and a summary of the results (eAppendix 2). pdf