Published in final edited form as:
BMJ. 2022 May 09; 377: e069435. doi:10.1136/BMJ-2021-069435.

Home energy efficiency under net zero: time to monitor UK indoor air

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The urgent need to reduce greenhouse gas emissions and the probable consequences of failing to do so are well established.[1] In response, several countries have pledged to reach net zero greenhouse gas emissions by 2050.[2] Achieving this target requires action in all sectors, including housing, which contributed a fifth of UK carbon dioxide emissions in 2020.[3] The International Energy Agency expects “immediate and rapid improvements in energy efficiency in buildings, mainly from large-scale retrofit programmes.”[2]

Because the escape of heated air is an important source of energy loss,[4] energy efficiency measures aim to reduce “unintended” ventilation. However, empirical evidence on the health effects of these interventions is limited. In particular, large scale longitudinal studies to assess the relations between energy efficiency, ventilation, indoor air quality, and health are lacking.[5] Evidence from seven European regions suggests that people spend on average 56-66% of their time at home,[6] a figure that almost certainly increased during the covid-19 pandemic. Personal exposure to air pollutants indoors may thus be greater than outdoors,

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Giorgos Petrou and colleagues *argue for systematic large scale monitoring of indoor air to avoid unintended harms to health from home energy efficiency programmes*

Contributors and sources: This article was conceptualised through group discussions among all authors. GP coordinated the manuscript development and led the drafting, together with AM, HM, RP, PS, EH, MD, and PW. GP collated and analysed data on home energy efficiency uptake, together with HSC. PW and JM estimated the health effects and developed the physical model. The project investigators are PW and MD. All provided comments on the manuscript drafts. All reviewed and approved the final manuscript.

Public and patient involvement: Members of the public contributed their views in a webinar organised by our research team on understanding the impact of home energy efficiency measures on indoor air quality.

Competing interests: We have read and understood BMJ policy on declaration of interests and have no conflicts of interest to declare.

and changes in overall exposure resulting from home energy efficiency measures may have important implications for health.[7]

In 2019, the UK became the first major economy to set a legally binding target of reaching net zero emissions by 2050,[8] with an interim target of reducing UK territorial emissions by 78% compared with 1990 levels by 2035.[9–11] Improvements to the building envelope, such as wall and loft insulation, double or triple glazing, and improved airtightness, are expected to account for a substantial portion of the reductions in energy use for heating homes. New homes are to be built to a high standard of thermal efficiency and airtightness, and a “fabric first” approach will prioritise improvements in existing homes that fall below the government’s energy standard,[10] rapidly accelerating the installation of home energy efficiency measures. With a projected global retrofit rate of 2-2.5% a year, over 85% of existing buildings will be highly energy efficient by 2050.[2]

We argue that the scale of changes in home energy efficiency requires a concomitant campaign to monitor indoor air quality to identify potential health hazards and guide policy and regulation. Although we primarily focus on the UK, where a major transformation of poorly insulated and leaky housing stock is much needed,[9 10 12] similar considerations are likely to apply to many countries, especially those heavily reliant on domestic heating.

Health effects of indoor air pollution

Improved energy efficiency of housing will be important for health. Increased insulation makes homes warmer in winter, especially for fuel poor households, which can reduce winter mortality and morbidity burdens.[13] While such benefits are important, particularly in countries with colder climates like the UK, reducing any component of ventilation, whether intended or not, lowers the exchanges of air between inside and outside (box 1). Although this can reduce the ingress of pollutants from outdoors, it can also increase the accumulation of internally generated pollutants.[16–18] The levels of a wide range of indoor air pollutants may be affected by energy efficiency measures (box 2),[19 20] although the exact changes and their consequences for health will vary by setting.

Clear epidemiological evidence exists that fine particulate matter ($PM_{2.5}$) is associated with a wide range of effects on health, including cardiorespiratory outcomes, lung cancer, and adverse birth and developmental effects.[21] For populations where the majority of time is spent indoors, fine particulate exposure in the indoor environment can make a larger overall contribution to personal pollutant exposure than in the outdoor environment.[22] The health risks of secondhand tobacco smoke and mould are also well understood,[23 24] and the importance of air dispersion in exposure to infectious agents has been brought into focus by covid-19, which is substantially more transmissible in indoor environments than outdoors.[25] Furthermore, the hazards of indoor radon are becoming clearer: exposure to radon at home was estimated to account for 1 in 516 deaths in the UK in 2006.[26] On the other hand, although volatile organic compounds have been linked to respiratory and carcinogenic effects,[27] the risks for individual compounds at typical concentrations arising from household sources such as furnishings and cleaning products remain uncertain.

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The precise health effect of reduced air exchange resulting from energy efficiency measures is unknown, but if energy efficiency retrofits were to increase the concentration of indoor sourced pollutants by 50% across the UK's housing stock—a figure that is plausible based on radon measurements[17]—this would be likely to increase mortality and morbidity substantially. Increased mortality would mainly be attributable to the accumulation of fine particulate matter of indoor origin (partly offset by the reduced ingress of outdoor particles), with smaller contributions from radon, secondhand tobacco smoke, and other pollutants.[13]

Changes in exposure to indoor air pollution that occur from more airtight buildings will shift population health means. Additional health burdens are most likely to reflect changes in a large number of homes with moderate increases in personal exposure, rather than the small proportion of homes that will have very high increases in indoor pollutants—an example of Rose's prevention paradox.[28] Taking radon for example, most additional cases of lung cancer are expected to be in homes well below the UK radon action level of 200 Bq/m^3.[26,29] As with many ubiquitous environmental exposures, including outdoor air pollution, the risks to health for any individual or household are relatively small, but as exposure is widely distributed, the population burden can be substantial. Furthermore, the burden may be greater for lower income households as they are more likely to experience poor indoor air quality[30] and less able to afford remedial work to improve their home's indoor air quality. A key challenge for home energy efficiency programmes is, therefore, to reduce unintended ventilation without increasing indoor air pollution.

Build tight, ventilate right

Building codes aim to limit heating losses by reducing unintended ventilation and attempt to ensure good indoor air quality through adequate intentional ventilation, or air change. Figure 1 shows the importance of air change for indoor air pollution using a simple model of a hypothetical, internally produced pollutant for which ventilation is the only mechanism of dispersal. Internally produced pollution concentrations are inversely related to the number of air changes an hour and increase rapidly as this number decreases towards zero. The limited available evidence suggests that most UK dwellings have air change rates below 1 per hour, with more energy efficient dwellings being closer to or below 0.5/h.[31,32] This places most UK dwellings in the steep part of the curve (fig 1), where indoor air pollution concentrations are most sensitive to relatively small changes in air exchange. Although air chemistry and deposition processes (settling on internal surfaces such as floors and furniture) are also important for some pollutants, dispersal through ventilation remains an important, if not the dominant, way that concentrations of most indoor pollutants are reduced.

Ensuring good indoor air quality following the installation of energy efficiency measures might require provision of additional ventilation (box 1), and the most airtight homes may need a mechanical system.[14,33] Problems arise when the need for intentional ventilation is not recognised, or when it does not perform as intended. Factors responsible for worse than expected performance include poor design, installation, and maintenance of the ventilation system and certain occupant actions (for example, keeping trickle vents closed or switching the mechanical ventilation system off).[18,31,34] A mechanical ventilation system that recovers heat from mechanically exchanged (and usually filtered) air is a promising solution that is popular in Scandinavian countries, but barriers such as high capital cost and spatial constraints limit its widespread adoption elsewhere.[33] While studies suggest that mechanical ventilation results in higher ventilation rates and lower concentrations of internally produced pollutants in energy efficient homes,[16 18] concerns about underventilation remain even in countries where such systems are common.[16 31]

Building codes in several countries recognise the problem of energy efficiency and ventilation.[33] In England, government approved guidance on ventilation exists for new and retrofitted homes (box 3).[14] But although the guidance considers occupants' health as crucial, currently the guidance is not based on or informed by quantified health risks. Additionally, suboptimal ventilation performance has been identified in homes built according to the 2010 guidance.[32] Although this is probably partly the result of poor compliance with the guidance, it is unclear whether correct implementation would guarantee adequate air quality indoors.[32]

In the case of retrofitting existing homes, it is not known whether the government guidance on ventilation—which was updated in December 2021—can mitigate the effect of energy efficiency changes on ventilation and indoor air quality. Although the adage "build tight, ventilate right" expresses a good principle, the extent to which it is achieved in practice is unclear.

Need for monitoring

Changes made to the housing stock will likely remain in place for many years, even decades, and so will lock in effects on indoor air, whether good or bad. For these reasons, monitoring the effect of such ambitious actions on indoor air is crucial to detect adverse effects at an early stage, protect health, guide and adapt policy, and minimise remediation costs.

The UK government's covid-19 response included the deployment of 300 000 carbon dioxide monitors in English schools to monitor ventilation levels.[35] Similar urgent action is needed to understand what home energy efficiency measures will mean for the wider range of health risks related to indoor air pollution. Continuous and large scale monitoring of indoor air quality in newly built and existing homes before and after retrofitting is required, covering a range of dwelling types, settings, and household characteristics that determine variations in exposure and risk.

This would likely require monitoring thousands of dwellings, ideally for multiple pollutants, at several locations within each home for at least a year. However, the cost of monitoring would be small compared with the enormous investments expected in the housing stock. The increasing availability of low cost sensors with adequate accuracy and reliability makes large scale monitoring feasible. Local outdoor air pollution should also be monitored. Monitoring should be accompanied by surveys on the dwelling characteristics, evaluation of compliance with the building codes, and research on occupant behaviour to examine links to indoor air quality and how it might change after energy efficiency measures. If the right steps are taken and studies are thoughtfully designed and carefully carried out, data collected over the next few years could help ensure that the benefits of energy efficient homes are maximised and the unintended negative health consequences minimised.

Acknowledgments

The authors' research is funded by the National Institute for Health Research (NIHR) Health Protection Research Unit in Environmental Change (NIHR200909), a partnership between the Health Security Agency and the London School of Hygiene and Tropical Medicine, University College London, and the Met Office. The views expressed are those of the authors and not necessarily those of the NIHR, the Health Security Agency, or the Department of Health and Social Care.

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Box 1

Disentangling ventilation[14 15]

Ventilation—The supply and removal of air (by natural or mechanical means) to and from a space or spaces in a building. It comprises a combination of intentional and unintended ventilation (infiltration). It is often measured in air changes per hour—the rate of ventilation (volume per hour) divided by the volume of the ventilated space.

Intentional (purpose provided) ventilation—Ventilation that is provided by devices designed into the building (eg, windows, background ventilators, extraction fans, or mechanical ventilation). Such systems may be further separated into those with continuous or intermittent operation and systems that are mechanical or natural.

Unintended ventilation (infiltration)—The uncontrolled exchange of air between the inside and outside of a building through gaps and cracks on the building's envelope.

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Box 2

Principal pollutants and biological agents of indoor air with known or probable adverse effects on health[19 20]

- Particulate matter of indoor origin (including from cooking)
- Nitrogen dioxide (primarily from cooking)
- Carbon monoxide (from combustion appliances)
- Second hand tobacco smoke
- Volatile organic compounds (from building materials, furnishings, cleaning and personal hygiene products, etc)
- Other chemicals from cleaning products, including ammonia
- Radon (from the rocks or soil under the dwelling)
- Mould* and biological agents (including house dust mites, pet dander)
- Viral particles and other infectious agents

* Change depends on balance of temperature, humidity, and air change

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Box 3

Guidance on adequate means of ventilation in English homes

Building regulations in England require that new and retrofitted dwellings have a high level of energy efficiency, while also ensuring that "adequate means of ventilation" are provided.[4 14]

For the most airtight homes, compliance can be achieved only by using continuous mechanical ventilation systems. One prominent solution is mechanical ventilation with heat recovery, which can supply fresh filtered air while retaining part of the heat from the extracted air.[12 14]

For less airtight dwellings compliance can be achieved using non-mechanical (natural) ventilation systems.[14]

An important addition in the updated guidance, taking effect in June 2022, is a method of assessing whether further means of ventilation are needed after a home energy efficiency retrofit based on the type of measure installed.[14] Although this is a step forward in the efforts to ensure adequate ventilation after a retrofit, the efficacy of this method needs to be evaluated.

Key messages

As part of the UK's climate change mitigation strategy, the energy efficiency of millions of homes will need to be improved over the next few years

Energy efficiency measures have the potential to alter indoor air quality and affect health, although the full spectrum of health effects is not yet understood

Large scale empirical data on indoor air need to be collected to assess and understand the consequences arising from energy efficiency retrofits and avoid locking in unintended adverse health effects in millions of homes

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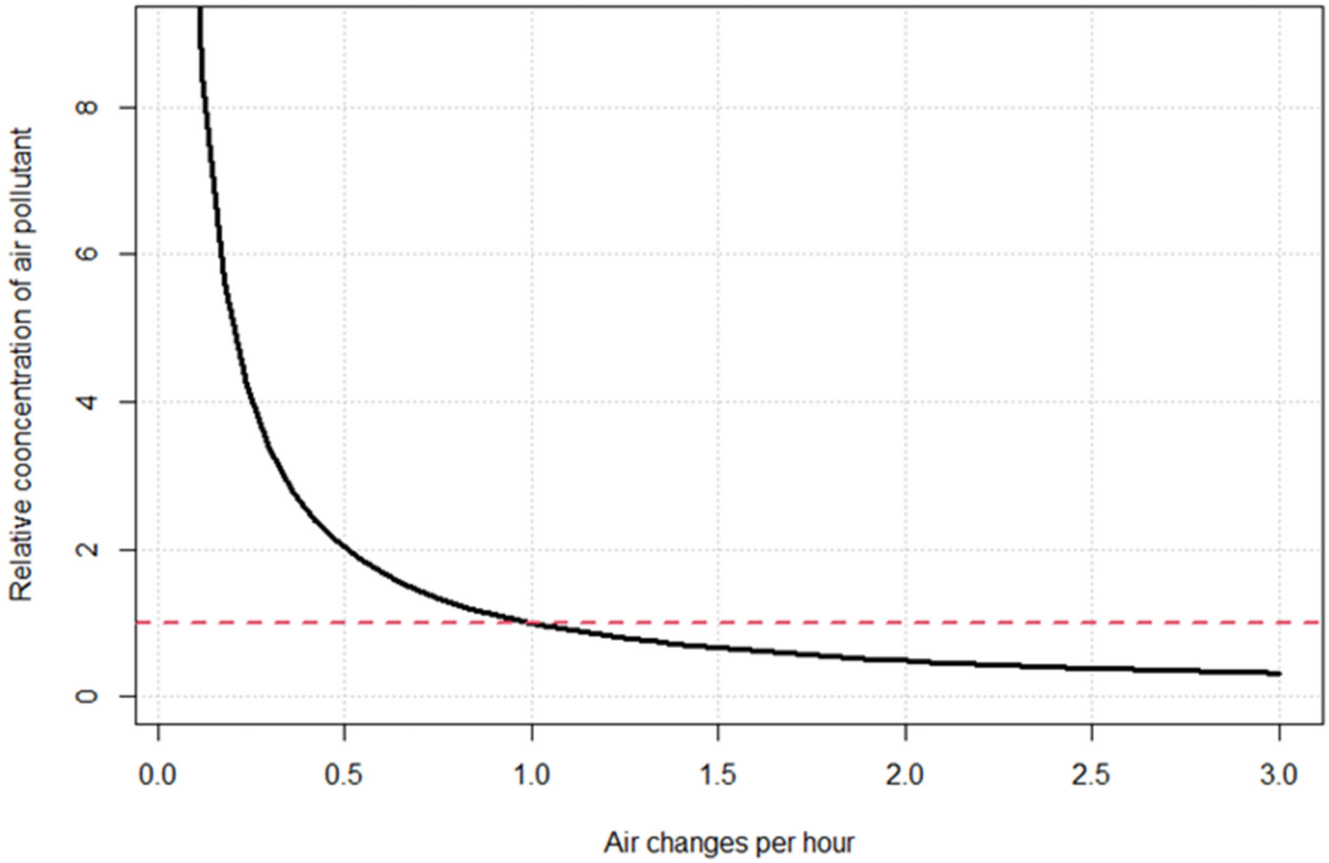

Fig 1.
Change in indoor pollutant concentration as a function of air exchange rate. Relative pollutant concentration=1 at 1 air change per hour (broken line)