Retrofitting technology to real homes: assessing the multiple impacts of solar-powered ventilation

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Abstract
Retrofitting technologies and systems into existing houses is far more complex and technically challenging than integration into new build. The multiple priorities driving retrofit, the complexity of the existing stock itself and the diverse needs of the residents that inhabit it require multifaceted and sensitive solutions.

This paper draws on the findings of one project designed to address multiple targets of energy and CO_2 reduction, fuel poverty alleviation, health and wellbeing improvement. It presents the monitoring results and lessons learned from a project installing ventilation and energy efficiency measures into homes in Northern Ireland and the Republic of Ireland (McLean et al 2007). The intention of the project was to enhance indoor air quality, reduce domestic energy consumption and bills and improve the health and wellbeing of the householders. The focus was on the fuel poor, who made up 78% of the 120 households.

Monitoring showed improvements in the indoor environment and reported self identified health benefits. It is not clear from the results whether or not use of the ventilation systems led to a reduction in energy consumption and associated CO_2 emissions.

In addition to the monitoring findings, this paper draws lessons from the project management and evaluation design on critical issues and considerations around the treatment of existing homes. The paper reveals the importance of demonstration or technology test projects, the difficulties in assessing cost-effectiveness of measures with multiple priorities and the importance of partnerships for holistically addressing these priorities.

Introduction
The importance of buildings in the low carbon agenda has been well recognised. Increasingly, recognition of the importance of the existing UK housing stock, which accounts for 99% of the housing stock each year with only 1% being replaced or added each year by new build (SDC, 2006) is being acted upon.

Retrofitting technologies and systems into existing houses is far more complex and technically challenging than integration into new build. The multiple priorities driving retrofit, the complexity of the existing stock itself and the diverse needs of the residents that inhabit it require multifaceted and sensitive solutions. Within these situations, the role of technologies needs to be considered carefully. Technologies provide an intervention point but should not be allowed to reduce complex environments or problems to simple linear solutions.

This paper draws on the findings of one project designed to address multiple targets of energy and CO_2 reduction, fuel poverty alleviation, health and wellbeing improvement. It presents the monitoring results and lessons learned from a project installing ventilation and energy efficiency measures into homes in Northern Ireland and the Republic of Ireland (McLean *et al* 2007). The subjects of ventilation in the context of energy efficiency and healthy indoor air quality have not been widely covered in the eceee Summer Study to date (see Hermelink & Huber, 2003 and Gullberg *et al,* 2007 for studies on ventilation).

The paper reveals the importance of demonstration or technology test projects, the difficulties in assessing cost-effectiveness of measures with multiple priorities and the importance of partnerships for holistically addressing these priorities.

Background

POLICY FOCUS ON EXISTING HOMES

Policy focus and practical action on new build homes has firmly placed energy efficiency and carbon emissions reduction at the top of the priority list. The Code for Sustainable Homes[1], whilst outlining a range of environmental, natural resource and sustainable lifestyle measures that can be introduced in the design of new homes, sets its only mandatory minimum standards for energy and water consumption. Only for energy efficiency have time-based targets for reaching increasingly stringent levels outlined in the Code been set.

The drive to reduce CO_2 emissions, and energy efficiency's part in this, clearly extends to the larger part of the housing stock that is taken up by existing homes. However, policy focus to date has revealed a more complex set of priorities to be considered when addressing the existing stock. The most positive action taken to date in the UK on retrofitting existing homes has been channelled through fuel poverty reduction targets and the provision of social housing that meets Decent Homes Standards. These policies prioritise assistance to those on low incomes, receiving benefits, living in particularly energy inefficient or hard to treat homes and those in social housing. Social welfare therefore sits alongside carbon reduction as a main priority when addressing the existing stock. These dual, some say conflicting, goals sit on top of a complex set of environmental, economic and social issues, uniquely experienced by each community or policy target group.

The priority groups for the retrofit of existing homes are characterised by a complex set of issues and needs and existing homes, particularly hard to treat homes, also present a complicated set of challenges.

THERMAL EFFICIENCY AND VENTILATION

As around 60% of the energy used in the home is used for space and water heating (EST, 2009) a main priority for improving energy efficiency is often improving thermal efficiency. Measures to improve thermal efficiency, like draft exclusion and insulation, increase air tightness. Whilst fulfilling the goals of reducing energy consumption and fuel bills, these measures can exacerbate or introduce indoor air quality and excessive humidity problems (Hermelink & Huber, 2003 and Gullberg *et al*, 2007) that are directly related to health and wellbeing.

Common indoor air pollutants created by cigarette smoke, gas fires and cookers, household products and construction materials build up in a poorly ventilated environment. Benzene, nitrogen dioxide and formaldehyde from these sources can cause irritation to the eyes, nose and throat as well as more serious impacts, such as cancer, at higher concentrations (Howieson, 2005; WHO, 2000). Inadequate ventilation can also result in the build-up of moisture in the home. A build up of moisture (e.g. from washing or cooking) will result in high indoor humidity, which can lead to mould growth and also promotes optimal conditions for house dust mites, the faeces of which are highly allergenic and have been linked to asthma (Howieson, 2005).

The importance of indoor air quality alongside thermal comfort for health and wellbeing has been well documented. Cold, damp and mouldy houses have also been linked to multiple adverse health effects, including increased blood pressure and risk of stroke, deterioration of arthritis, increased risk of accidents at home, increased social isolation, deterioration of mental health, adverse effects on children's education and adverse effects on nutrition (NIFPAG, 2006). Indirect links have also been found between poor indoor environmental quality and reduced performance and attendance at school (Mendell and Heath, 2005).

Indoor environmental quality is particularly important as a typical adult in work will spend 60% of their time at home, while older people, young children and their mothers and vulnerable people spend much more of their time at home (WHO, 1999; Breysse *et al*, 2004; Brunekreef, 2004). Therefore exposure to indoor pollutants can play a major role in the health and wellbeing of the population.

The reduction of natural air infiltration from improved air tightness in a retrofitted home needs to be compensated for by a low energy demand ventilation system. Installation of a ventilation system can provide several potential benefits, including:

- A warmer, drier home free from condensation and mould;
- Improved air quality;
- Improved health and wellbeing of occupants;
- Reduced energy consumption, fuel bills and CO2 emissions from a reduction in need to use fossil fuel heating and cooling sources.

This paper provides an example of a project that addresses energy efficiency, social welfare and health goals through the installation of technologies to improve energy efficiency, thermal comfort and the indoor environment. The findings of the project and lessons learned highlight some of the pertinent and complex issues around the retrofit of existing homes for energy efficiency.

CLEVER Homes project

The CLEVER Homes project (Comfortable Living Environment and Energy Reducing Homes) involved the installation of two types of solar powered ventilation systems, Nuaire Drimaster Ecosmart[2] and Sunwarm[3] into homes in Northern Ireland and the Republic of Ireland. Conventional insulation measures such as cavity wall insulation and/or top-up loft insulation were also installed, where necessary, as part of the project. Solar ventilation systems were chosen because they utilise a renewable energy source and can provide warm air to homes during the

1. Applicable to England and Wales. Versions for Scotland and Northern Ireland are under development.

2. Product now known as 'Sunwarm Roof'

3. PIV systems were chosen as the most effective ventilation system for existing homes, improving on the performance of conventional extraction fans by providing heat recovery and energy saving (EST, 2006)

heating season, reducing energy demand for space heating compared to ventilating with cold air.

PROJECT MANAGEMENT

The project was delivered by an innovative, multidisciplinary partnership involving lead partners Bryson Charitable Group (through their project Northern Ireland Energy Agency) and Sustainable Energy Ireland. Other project partners were made up of the Northern Ireland Housing Executive, the Department for Social Development, Northern Ireland Electricity, the Department of Enterprise, Trade and Investment and the Department of Health, Social Services and Public Safety.

VENTILATION SYSTEMS USED

Both the Ecosmart and Sunwarm systems use positive input ventilation to gently supply tempered, filtered air into the home, and replace old, contaminated, vapour-laden air. The main difference between the two systems is that the Sunwarm system has two roof-mounted solar collectors installed that enable the Sunwarm system to provide solar water heating.

Both systems have a ventilation unit that is installed in the loft and draws in fresh air that is then filtered to prevent external pollutants from entering the home. Air can be drawn from within the roof space or from beneath the roof tiles (Ecosmart) or through the solar panels (Sunwarm). The filtered air enters the home through a single diffuser, which is positioned on the ceiling in a central location. In the heating season, the Ecosmart system draws fresh air from within the roof space or from beneath the roof tiles, where it is normally warmer than the outside ambient air. The Sunwarm system draws external air through the solar panels, as well as utilising warm air in the loft space. During the summer (cooling season), both systems can draw in cool air at night. However, the Sunwarm system draws this air through the solar panels for extra cooling. A control panel allows the user to select the temperature of the air entering their home by adjusting the dial.

HOUSEHOLDS INVOLVED

The CLEVER Homes project installed ventilation systems into 120 homes. In the selection of project participants, the focus was on fuel poor households, which made up 78% of the participants (94 homes). The remaining 22% of participants (26 homes) were selected from the able-to-pay sector, so as not to limit the applicability of the project's findings. The selection criteria also prioritised households with members suffering respiratory illness and homes with condensation or mould problems.

MONITORING

Twenty-two per cent of participant households (26 homes) were monitored before and after installation of the systems for changes in temperature, humidity and air pollutants (benzene, formaldehyde and nitrogen dioxide [NO_2]). Only installations in existing homes were included in the monitoring. There were three periods of monitoring: pre-installation, one month post-installation, and six months post-installation.

In addition, changes in energy consumption were assessed by sending a questionnaire to all of the monitored homes asking for records or estimates of heating fuel consumption before and after installation of the ventilation system. Electricity records were also provided by Northern Ireland Electricity for the monitored homes.

Almost all participants were surveyed prior to and after installation to assess health and wellbeing impacts of the systems and impacts on energy consumption. A final questionnaire was sent to all participants to assess their level of satisfaction with the project and its components.

Results

There were no significant differences in results between the two systems so results are presented for both systems together.

POLLUTANTS

Air quality improved in all of the monitored homes, with a significant reduction in both benzene and formaldehyde levels following installation of the ventilation systems. Formaldehyde levels went from being above WHO guidelines pre-installation to safe levels post-installation indicating positive health impacts. There is no safe level of exposure for benzene because it is carcinogenic and therefore any decrease in benzene is beneficial for the health of occupants. However, there was still scope for further reductions in benzene in monitored homes. NO_2 levels were not reduced post-installation, however initial levels were not high enough to present a health risk.

TEMPERATURE AND RELATIVE HUMIDITY

Monitored homes maintained indoor temperatures at or above the 16°C temperature recommended by health guidelines both before and after installation of the ventilation systems. From the survey responses more households were happy with the temperature of their home post-installation.

The humidity data showed that use of the ventilation systems did not provide indoor relative humidity at sufficiently low values to avoid growth of house dust mites and in a few cases, relative humidity might also be high enough to support the growth of moulds. Despite this, the ventilation systems have been effective in reducing mould growth, condensation and damp for the majority of households, as evidenced by the results of the health surveys.

Overall, the surveys showed an increase in perceived thermal comfort and reduction in damp.

HEALTH

Results from the health surveys suggest that the ventilation systems have led to improved mental and physical health of participants and their children, with a significant reduction in householders suffering from asthma, asthma attacks and wheezing or whistling in the chest. There was also a significant reduction in visits to the doctor by participants and their children following installation of the systems.

ENERGY USE AND CO_2 EMISSIONS

According to the manufacturer, the Ecosmart and Sunwarm systems have the potential to save 830 kWh/year and 3300 kWh/year respectively. An additional solar heat exchanger installed in the Sunwarm system provides domestic hot water, providing up to 50% of a household's annual hot water needs and accounting for the higher savings estimated. The systems reduce the need for householders to use other forms of heating

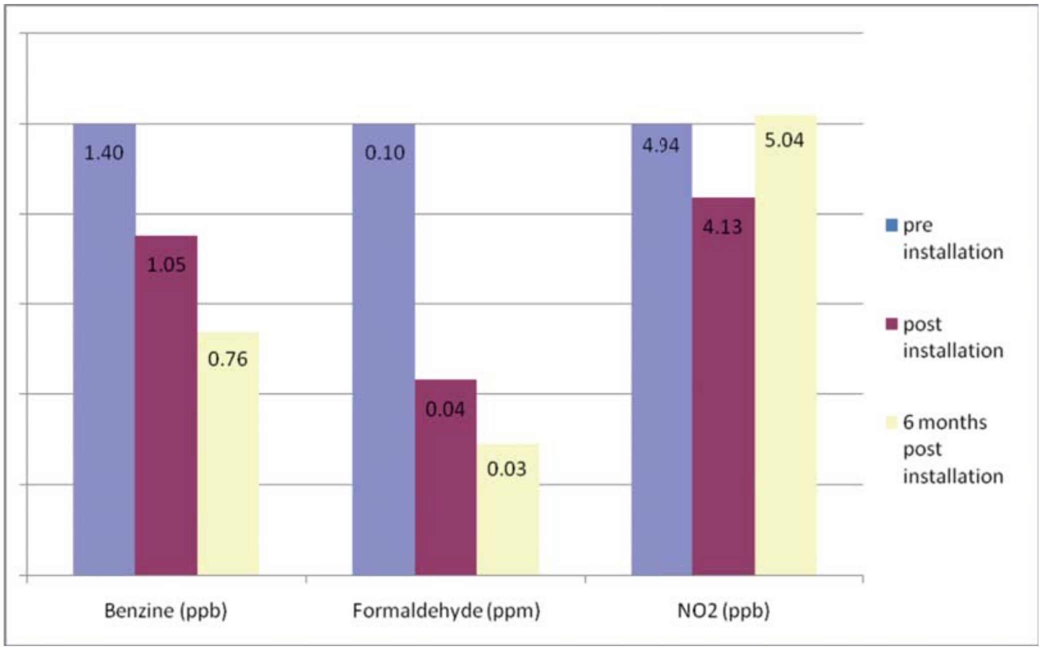

Figure 1: Relative change in pollutant levels in monitored homes from pre-installation to six months post installation. Averaged results for two ventilation systems installed. Results shown relative to pre-installation levels and with real values in ppm or ppb in air shown as figures.

and cooling, which usually would have been supplied by more carbon intensive fuels.

It is not clear from the results whether or not use of the ventilation systems led to a reduction in energy consumption and associated CO_2 emissions. However, the health surveys found that fewer households were worried about the cost of heating (32% post installation vs. 74%) and fewer households had gone without heating due to cost (8% as opposed to 22%), following installation of the ventilation systems. This suggests that participants were 'comfort-taking'[4] in response to the new systems. As 78% of the participants were deemed to be fuel poor it is unsurprising that comfort is taken before energy savings.

CLEVER HOMES MONITORING RESULTS SUMMARY

Overall, improvements were seen in all homes in benzene and formaldehyde pollutant levels, though not in NO_2. Self-identified benefits were also noted in indoor temperature, humidity and health. Actual reductions in energy use were not evident.

Triangulation with other assessments

A review of monitoring studies on the effectiveness and benefits of ventilation systems reveals that very few schemes installing positive input ventilation systems like the Ecosmart and Sunwarm systems included monitoring of the effectiveness, costs or benefits of the systems. Of those schemes that did undertake monitoring, the majority installed and monitored systems in new build homes making their results largely incomparable with the CLEVER Homes project results. Three studies have been identified that study the effect of positive input ventilation systems in existing buildings.

First, National Energy Action (NEA) installed three Sunwarm systems in community buildings in the South of England to test the potential for this system to be integrated in existing buildings (NEA, 2007). NEA was interested in the potential improvement to indoor air quality from the system because of the positive impact this could have on the health of people with respiratory problems. The NEA study found that the Sunwarm system produced excellent benefits in terms of minimising condensation and improving building users' health by creating a cleaner indoor environment. However, it was found that the potential energy savings of 50% claimed by the manufacturers was extremely optimistic for existing buildings. The study concluded that the cost of the system was very high compared to the level of energy saved and that the cost would have to be reduced to make this product suitable as a fuel poverty tool. In this regard, it was suggested that the Sunwarm system is more suitable for new-build where it is easily integrated and can help meet stringent carbon index targets.

Second, a study conducted by the Building Research Establishment (BRE) (1998) installed positive input ventilation systems (made by the Sunwarm and Ecosmart manufacturer) in 16 homes in Merthyr Tydfil and Aldershot in the UK. Temperature and humidity levels were monitored, and occupants were asked about ventilation and condensation conditions before and after the installation. The performance of the system was also tested in an unoccupied, very airtight, BRE test house, with controlled heating and water vapour production. For the occupied homes, the study found that the ventilation system did not consistently reduce relative humidity but was more effective in the more humid houses than in the drier houses. For the test house, relative humidity was reduced by around ten

4. Comfort-taking refers to a situation where although a measure is installed that effectively decreases the amount of energy required to adequately heat a home, there may not be a corresponding decrease in energy consumption if the household chooses to use more energy to achieve a higher level of comfort than experienced previously. This is particularly common in fuel poor households, who often cannot afford to heat their homes to an adequate level.

per cent. Feedback from occupants on the effectiveness of the ventilation system was more positive than would be expected given the humidity results. There were even some occupants who claimed relief from severe respiratory illness, but these claims could not be substantiated as part of this project.

Finally, Htut *et al* (2001) conducted a study in the UK to determine if steam and heat treatment of home furnishings, both alone and in combination with the installation of a positive input ventilation system by the Sunwarm and EcoSmart manufacturer, reduced the severity of asthma in householders and lowered levels of house dust mite allergens. The study found that reductions in mite allergen levels produced by the heat-steam treatment, which caused a significant reduction in the severity of asthma in householders, were sustained for longer (a period of 12 months) in homes with the ventilation system installed. The study concluded that improvements in ventilation may be effective in preventing reinfestation of house dust mites if the allergen load is first reduced.

When triangulated with these three broadly comparable studies, the CLEVER Homes project results are largely supported. All studies confirm a perceived improvement in health of the residents or in the case of the Htut *et al* study, health improvements were sustained for longer with the use of the ventilation system . The NEA study and the CLEVER Homes results revealed improvements in humidity and related indoor environmental conditions, although the BRE study found inconsistent results amongst its study homes with significant improvements achieved only in damper homes. Both NEA and CLEVER Homes found that energy saving resulting from the use of the ventilation systems was below expected levels.

Conclusions

The findings and lessons learned in this technology test case study highlight some important issues and considerations particular to energy efficiency technology improvements in existing homes.

IMPORTANCE OF MONITORING AND DEMONSTRATION PROJECTS

Firstly, the importance of technology test and demonstration projects like the CLEVER Homes project cannot be underestimated. The literature review revealed a dearth of comparable studies and therefore a dearth of information on the expected impacts of these technologies in existing homes. The lack of homogeneity in the existing stock, the challenges presented by old, low quality and hard to treat sections of it, and the needs of communities that inhabit it all make outcomes and impacts hard to guarantee. Therefore, post-installation monitoring of the kind carried out in this project provides important experiential lessons for future installations and an evidence base to promote confidence and stimulate housing refurbishment.

The lack of post-installation monitoring of the impacts of technologies on those using them, in favour of technology effectiveness modelling or testing in un-occupied environments, is revealing of an over-emphasis on the technology rather than its use or purpose. Although information on optimal efficiencies can be a useful benchmark to guide user interaction with the technology, these models become less and less relevant when the peculiarities of existing homes and the needs and preferences of their occupiers come into play.

The impact of occupier behaviour on the performance of the technologies was also found to be significant in the CLEVER Homes project. Ongoing engagement through monitoring can provide a powerful information bridge between technology supplier and end user. The CLEVER Homes project found that misconceptions on how the new technology operates with existing systems (like boilers) and incompatible behaviours could be identified and addressed through the ongoing engagement. The experience of this project re-highlights the well-established importance of information, education and behaviour alongside technology measures.

The qualitative evidence on non-energy benefits enjoyed by residents (like improved health and comfort) also provides useful information on hooks or drivers for individuals that are not engaged by energy saving alone. These findings will be useful for future projects in addressing the problem of participant recruitment that the CLEVER Homes project encountered (McLean *et al* 2007: p.22-23). This problem of recruitment is synonymous with the wider problem of engagement in the home owner/occupier sector.

MULTIPLE PRIORITIES ADDRESSED THROUGH PARTNERSHIP

Forming partnerships and cooperation was crucial to the success of the CLEVER Homes project. The project involved remarkable cooperation between governing departments, the health sector, the housing sector and the voluntary sector. This wide-ranging partnership, to which each member brought its own different but complimentary priorities and goals, provides an example of a management structure that facilitated a highly holistic approach to addressing multiple sustainability priorities in the existing stock.

The diversity of the partnership members and their interests is good indication of the breadth and complexity of the intervention and multiplicity of the outcomes. Within this intervention, the installation of a technology acted as a tool, not as end in itself. Therefore, although this project practically tested the effect of a technology, the monitoring was designed to capture impacts on the users as well as environmental outcomes. This makes the study inestimably more relevant in the context of existing homes and communities and the priorities that drive interventions.

Wiltshire and Jones (1999) provide a useful review of partnerships between energy conservation and health authorities in the UK. This project and other innovative partnerships provide important management models for replication.

ASSESSING COST-EFFECTIVENESS

Projects like this one, focussing on the existing housing stock and existing communities, are driven by multiple drivers, address multiple needs and often involve multiple measures. Therefore, the way in which cost effectiveness is measured needs to be given careful consideration.

If this project's success had been valued on energy savings (the only monetarily quantifiable goal), cost effectiveness would have been impossible to achieve. The modelled energy savings claimed for the technologies were far from met in either the CLEVER Homes or NEA studies. For projects that are part of the zero carbon or low carbon agenda and concentrate on the existing stock, the cost effectiveness calculation needs to encompass non-monetary and qualitative impacts. The single issue agenda of energy use reduction undervalues projects that deliver social or non-energy impacts to existing communities.[5]

It can be inferred that a continued reliance on modelling and controlled environment testing of technologies reinforces the single issue agenda of energy reduction, as energy is the only easily modelled factor in the complex building-technology-user interaction. Evaluation of success needs to refocus from the technology to the user.

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5. See, for example, McClain *et al* (2007) for an assessment of non energy benefits in the commission of public buildings