# Assessment of MVHR systems and air quality in zero carbon homes

Primary research

NHBC Foundation

Housing research in partnership with BRE Trust

Zero Carbon Hub

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# About NHBC Foundation

NHBC Foundation was established in 2006 by NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy technologies and the earlier investigation of what zero carbon means to homeowners and house builders.

NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from NHBC Foundation can be found at www.nhbcfoundation.org.

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# About the Zero Carbon Hub

The Zero Carbon Hub was established in the summer of 2008 to support the delivery of zero carbon homes from 2016. It is a public/private partnership drawing support from both Government and the industry and reports directly to the 2016 Taskforce.

To find out more, please visit **www.zerocarbonhub.org**. If you would like to contribute to the work of the Zero Carbon Hub, please contact **info@zerocarbonhub.org.**

# Foreword

It is clearly important that new homes are comfortable and healthy places and that changes to meet higher standards of energy performance do not, unintentionally, compromise the internal environment. NHBC Foundation has been concerned for some years at the risks, which a move towards higher standards of airtightness, could present to indoor air quality. Alongside the increased risk of overheating, it is one of our main concerns in relation to the zero carbon homes agenda.

Soon after the introduction of routine airtightness testing and the Government announcement of the zero carbon policy, NHBC Foundation commissioned a desktop study to identify existing research, which was reported in *Indoor Air Quality in Highly Energy Efficient Homes – A Review* (NF 18). That report helped us to understand the variety of pollutants present in homes and also their potential implications for health. It also raised concerns about the effectiveness of mechanical ventilation and heat recovery (MVHR) in maintaining healthy indoor environments.

Since the report was published, further research on this topic has been undertaken by the Ventilation and Indoor Air Quality task group of the Zero Carbon Hub. Its work reinforced these concerns and highlighted the need for further evidence. Given the view of the task group that MVHR will increasingly become a standard feature of new homes, the need for this additional evidence and information is pressing. The research covered in this report was undertaken in order to provide some of this additional evidence and information.

This report is based on the experience of MVHR systems in 10 homes built by Scottish and Southern Energy (SSE) at Greenwatt Way, Chalvey. Achieving Code for Sustainable Homes Level 6, these homes provided a perfect test bed for the detailed evaluation of MVHR systems in practice. As well as looking at design, specification, installation, and commissioning issues, the research has very importantly gauged the use of these systems by some typical home occupants.

A large number of issues were identified during the life of the project, and this tends to confirm the validity of the evidence identified in *Indoor Air Quality in Highly Energy Efficient Homes – A Review* (NF 18). It seems that there exists a widespread lack of familiarity with, and understanding of, MVHR and that there is considerable scope for problems to arise at all stages of the project, including design, specification, installation, commissioning, operation and maintenance.

Given the risk to indoor air quality if adequate ventilation is not provided, and the potential associated health issues, we must learn lessons from this valuable project to influence the future implementation of MVHR in the UK. This is necessary in order that the interests of home occupiers are protected and unintended consequences are avoided. I am encouraged that NHBC is currently completing the development of its own Standards guidance for MVHR, informed by the findings of this project.

We are indebted to SSE for allowing us the opportunity to undertake this valuable research and for the helpful cooperation of the Greenwatt Way tenants over the past two years.

**Rt. Hon. Nick Raynsford MP**
Chairman, NHBC Foundation

# Executive summary

This primary research report presents the findings from a two-year research project carried out by BRE entailing assessment and monitoring of 10 zero carbon Code for Sustainable Homes Code (CSH) Level 6 homes at Scottish and Southern Energy's (SSE's) Greenwatt Way development at Chalvey, near Slough, Berkshire.

Thanks to the cooperation and level of engagement from SSE it was possible to study the homes to some extent during construction and then to monitor them for a period of almost two years post-occupancy. As well as inspection, testing and monitoring work it was possible to obtain occupant feedback and gauge perceptions of living in the zero carbon homes by use of questionnaires, walk-through interviews and focus groups. In addition to continuous monitoring of temperature, humidity and power consumption by the mechanical ventilation and heat recovery (MVHR) systems, periodic testing of indoor air quality and airtightness was carried out. Towards the end of the project a study was undertaken in one of the homes in which air quality was monitored during gas and electric cooking, with the ventilation system on and off.

The project was conceived in response to concerns highlighted through *Indoor Air Quality in Highly Energy Efficient Homes – A Review*[1] regarding the possible adverse consequences of increased airtightness in energy efficient homes on the quality of the indoor environment. In the case of homes built to high levels of the CSH, where energy reduction requirements are onerous, it is widely held that MVHR systems will be used to an increasing extent.

For the reasons described above, a substantial part of the research carried out in the homes at Greenwatt Way involved assessment and evaluation of MVHR systems, taking in design, procurement, installation, commissioning, performance, maintenance and occupant perceptions. After approximately one year of occupation, nine of the MVHR fan units were recommissioned and changes made to room inlet air valves and air filters. In one home the MVHR fan unit was replaced and changes were made to sections of ductwork and its insulation. As a result of pre- and post-monitoring these interventions provided more insights into operation of MVHR systems in airtight homes.

The main findings in connection with MVHR systems at Greenwatt Way are as follows:

- It is critical that the overall ventilation strategy is taken into consideration during the design stage when intending to use MVHR systems in homes.
- During the procurement process it is important to seek technical input from the supplier and installer of MVHR systems.
- MVHR systems should be installed by trained and experienced ventilation system installers.
- Commissioning of MVHR systems must be fit for purpose.
- Factors likely to adversely affect the power consumption by MVHR fan units during operation must be considered.

- Factors likely to adversely affect the thermal performance of MVHR systems in operation must be considered.
- Successful measures may be taken to increase the performance of MVHR systems and to reduce noise levels associated with their operation.

Occupant feedback regarding living in the homes and general comfort has been mainly positive, with levels of satisfaction tending to increase over time as the homes and their MVHR systems became more familiar. Much of the negative feedback associated with ventilation, thermal comfort and internal noise could be attributed to MVHR systems, including issues with perceived lack of control, temperature differences between storeys, experiences of draughts from cool air dumping and levels of mechanical noise. Levels of occupant satisfaction on these particular issues generally improved as a result of the remedial works carried out on MVHR systems after one year of occupancy. However, it is fair to say that the Greenwatt Way occupants will have been better informed than the average householder, and have benefited from the interventions carried out as part of this research project. In the wider world there would seem to be every possibility that, where MVHR systems are not designed, installed and operated correctly, house occupants may take radical steps in response to problems with their indoor environment – such as turning the MVHR system off.

Recommendations for further research are given in the final section of the report.

# 1 Background

At present housing accounts for around 30% of the UK's total energy use[2] and 27% of its carbon dioxide ($CO_2$) emissions[3]. Government policy to combat the effects of climate change has included the intention that all new homes will be zero carbon by 2016, and a progressive tightening of the energy efficiency aspects of the Building Regulations in advance of that target date. The changes to the Building Regulations have been complemented by the inception of the Code for Sustainable Homes (CSH) which measures the sustainability of a new home against nine categories of sustainable design and construction.

Following changes to Approved Document L1A (AD L1A) of the Building Regulations 2006[4], the airtightness of homes made a near step change from generally leaky (air permeability of >10 $m^3/h/m^2$) to most homes being close to 5 to 6 $m^3/h/m^2$, and many being significantly below 5 $m^3/h/m^2$ (Figure 1). Following the introduction of the CSH in April 2007, homes built with public funding or on land previously owned by the public sector were required to meet at least Code Level 3 by April 2008. This represented a target of 25% energy reduction against that achieved according to AD L1A, which led developers to seek means of reducing energy use to below that required by the current Building Regulations. In the case of homes built to Code Level 4 and above, where the levels of energy reductions required by the CSH are even higher, it is widely held that mechanical ventilation with heat recovery (MVHR) systems will increasingly be used. Apart from their energy efficiency advantage, MVHR systems help to achieve an acceptable indoor climate in very airtight homes. MVHR involves installation and use of a multi-room ducted system which provides both supply and extract ventilation (Figure 2). Fresh air is supplied to habitable rooms having been pre-warmed with recovered heat from air extracted from wet rooms such as bathrooms and kitchens.

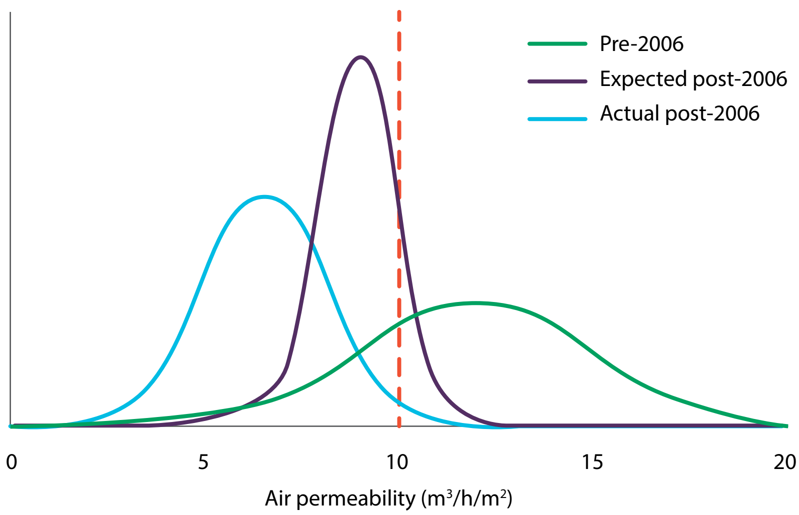


Figure 1 Changes in airtightness predicted and achieved across the 2006 changes to AD L1A[5]

Due to the trend towards building highly airtight, energy efficient homes and the use of MVHR systems to ventilate them, there is a need to assess whether or not MVHR systems available on the market are able to maintain acceptable indoor air quality (IAQ) throughout the year.

If ventilation provision in homes is not sufficient, the lack of air infiltration (through minor gaps in the fabric) could lead to poor air quality because stale indoor air is not replaced at a sufficient rate by fresh outdoor air. This would in turn result in a build-up of concentrations of pollutants in the indoor air that have been released through normal household activities, by building materials, furnishings, consumer products, as well as from people and their pets. Associated with this is the risk of high humidity and condensation, with the attendant risks of mould growth and proliferation of house dust mites (both of which can lead to exacerbation of respiratory complaints) and damage to structures.

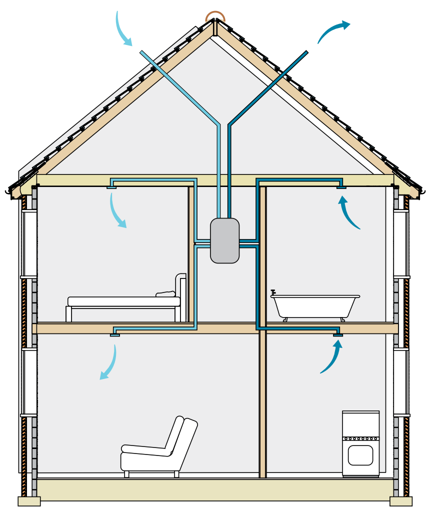

Figure 2 Continuous mechanical supply and extract with heat recovery. (Source: *Mechanical Ventilation with Heat Recovery in New Homes*. Interim report[6])

Moving from largely passive ventilation in most new homes to a 'sealed' fan unit relying on mechanical systems is a large step change in terms of culture, and requires an understanding of the operation of the systems employed to ensure good performance. To facilitate this change, it is important that developers and ventilation system manufacturers render use of such systems intuitive and straightforward, and provide adequate user information and guidance.

If systems do not operate satisfactorily, there is the possibility that occupants would seek to counteract poor air quality or lack of the feel of 'freshness' by opening windows on a regular basis, and thereby offset the inherent benefits of a structure built to standards of high energy efficiency fitted with a continuously operating MVHR system. This, and other potential occupant interventions (caused by concerns regarding noise and elevated energy costs, as well as air quality issues), could result in poor IAQ with consequent risk of condensation, mould growth, dust mite infestation and elevated concentrations of volatile organic compounds (VOCs); all of which could pose health risks and wellbeing issues to occupants, since people typically spend up to 80% of their time indoors. Health problems such as asthma and other respiratory conditions may be exacerbated, particularly in the most vulnerable population groups (the young, elderly and infirm).

Research carried out by NHBC Foundation in 2008, *Zero Carbon: What Does it Mean to Homeowners and House Builders?*[7] highlighted the concerns of homeowners and builders about the possible adverse consequences of increased airtightness for the energy efficient structures on the quality of the indoor environment. A more recent NHBC Foundation-funded review undertaken by BRE led to publication of the NHBC Foundation report *Indoor Air Quality in Highly Energy Efficient Homes – A Review* in July 2009[1]. This review concluded that there remained an urgent need for research into the performance of highly energy efficient homes in the UK with respect to the quality of the internal environment, the type of ventilation systems used, and the impact of health and wellbeing of occupants. In general it was recommended that two broad but interrelated topics required further research and investigation:

- Design and performance of products
- Evaluation of IAQ and ventilation.

Concerned about these issues, in 2010 the Zero Carbon Hub set up its Ventilation and Indoor Air Quality task group in order to bring together a wide range of stakeholders to review the current state of play regarding these important topics. The headline recommendations from this group's research study interim report *Mechanical Ventilation with Heat Recovery in New Homes*[6] are the need to:

1. Build a better base of evidence on the installed performance of MVHR systems.
2. Develop a robust approach to MVHR systems (including system design, type of fan unit, location of fan unit, noise, controls, installation, commissioning and user advice).
3. Improve control of air pollutant emissions at source.

This NHBC Foundation research study assessed and monitored the specification, installation and use of MVHR systems in a development consisting of 10 CSH Level 6 homes and is aimed at responding to the first of those three recommendations.

# 2 Introduction

This report is based on an NHBC Foundation-funded monitoring project carried out by BRE at Greenwatt Way, a development of 10 CSH Level 6 homes built in Chalvey, near Slough, Berkshire for Scottish and Southern Energy (SSE).

SSE originally conceived the study of the Greenwatt Way zero carbon homes to investigate the overall energy consumption of CSH Level 6 homes, the use of various renewable technologies, and how occupants use energy within zero carbon homes. In addition to these core themes, SSE wished to engage in collaborative research with a number of partner organisations into other aspects of the zero carbon homes in occupation, including a study of the indoor environments provided by using MVHR systems.

BRE proposed an 18-month monitoring project at Greenwatt Way to help give the house-building industry a better understanding of the impact of airtight homes on IAQ and its potential implications for health, so that effective solutions could be developed to improve energy efficiency while at the same time reducing the potential for airtight homes to adversely affect occupant health and wellbeing. The main objectives of the initial 18-month monitoring project were as follows:

- To evaluate the design, construction, installation, commissioning and system operation issues with the MVHR systems to be installed in the homes, including inspection of systems and continuous monitoring of their power consumption in order to assess performance.
- To evaluate the effects of the MVHR systems as a means of ventilation provision on temperature and thermal comfort, humidity and condensation, ventilation rate and IAQ in the homes.

- To study occupant behaviour and experience in the homes, including comfort and wellbeing, operation of the MVHR systems across a range of seasons, acceptance of such systems, and steps taken to modify temperature and air quality levels experienced within the homes.
- To investigate the implications on energy use connected with the MVHR systems installed in occupied low energy homes.

Construction at Greenwatt Way commenced in late 2009, and the installation of MVHR ductwork was inspected during the build phase. Following completion of construction and fit out during September 2010 the site was officially opened by the Secretary of State for Energy, and nine of the homes were occupied soon after. One home has been retained as a show home.

Figure 3 Greenwatt Way in Chalvey, near Slough, Berkshire

In the course of the 18-month monitoring project additional research (as detailed below) was commissioned by NHBC Foundation and SSE, which is also relayed in this report.

- Due to the findings of monitoring of the homes during the first 12 months of occupation, in October/November 2011 the MVHR systems in all 10 homes were recommissioned and certain components adjusted or replaced. In one of the homes the MVHR fan unit itself was replaced.
- To coincide with these interventions, background noise levels in most of the rooms of the homes were measured before and after the remedial work.
- Monitoring of temperature and humidity in the homes and power consumption by the MVHR system was continued after the expiry of the original 18-month monitoring period in March 2012 in order to further inform the MVHR investigations.
- Finally, in July 2012 a study of the effects of gas and electric cooking on IAQ in the show home was carried out with and without the MVHR system in operation.

Clearly when undertaking post-occupancy evaluation of homes it is important to complement physical testing and monitoring with studies relating to occupant perceptions and behaviour. Therefore three rounds of occupant studies were carried out in February 2011, September 2011 and April 2012, by means of questionnaires, interviews in the show home and focus groups. The key findings from the occupant studies are reported in Section 3.3 General occupant feedback, Section 4.9 Occupant feedback on noise and the ventilation system, Section 5.4 Occupant feedback, and in Section 6 Conclusions and recommendations.

# 3 General assessment of the homes and occupancy

## 3.1 Characteristics of Greenwatt Way

The Greenwatt Way development is situated adjacent to the SSE depot in Chalvey, near Slough, Berkshire. It comprises a mixture of flats and houses of timber frame and masonry construction as follows:

Home 1 Three-bedroom detached house (timber frame)
Home 2 Two-bedroom end of terrace house (timber frame)
Home 3 Two-bedroom mid-terrace house (timber frame)
Home 4 Two-bedroom end of terrace house (timber frame)
Home 5 One-bedroom first floor flat (masonry)
Home 6 One-bedroom first floor flat (masonry)
Home 7 Three-bedroom end of terrace house (masonry) – show home
Home 8 Three-bedroom mid terrace house (masonry)
Home 9 Three-bedroom end of terrace house (masonry)
Home 10 Three-bedroom detached house (masonry).

The development also includes an 'energy centre' which houses a mini-district heating system serving all of the homes and where monitoring data is collected. The energy centre is powered using any one of four renewable technologies: solar thermal panels, an air source heat pump, a ground source heat pump and a biomass boiler. In addition, renewable electricity is supplied from solar photovoltaic (PV) tiles which cover the whole roof area of each home.

In addition to the homes, meeting room facilities, communal cycle racks and refuse facilities are housed in the same building as Homes 5 and 6. Nine of the homes have been rented to a mixture of SSE staff and local people. As a condition of tenancy, occupants agreed to cooperate with the monitoring and research being undertaken. Home 10 has been retained as a show home, and this is occupied at times by SSE staff and visitors.

Figure 4 Greenwatt Way (Homes 5 and 6) shown during construction

Figure 5 Homes 2 to 4 (left), energy centre (middle) and Home 5 (right) shown on opening day

As well as being constructed and insulated in order to achieve a very high level of airtightness (with a target air permeability of $<2\ m^3/h/m^2$) the Greenwatt Way homes have several features and systems which improve energy efficiency and encourage tenants to waste less energy and water. In addition to the MVHR system, all homes have smart metering, solar PV roofs, triple glazed windows and energy efficient water appliances and white goods. Some of the homes also have an innovative greywater recycling system which uses recycled bath and shower water to recover waste heat and flush toilets; rainwater harvesting systems collect rainwater which is stored and used to flush toilets.

The wider SSE project combined measurement of energy use with studies around occupant perceptions, the use of various renewable technologies and the operation of the small community energy system provided by the Greenwatt Way energy centre. Inspection, testing and monitoring activities were undertaken by BRE over a two-year period in liaison with SSE and their tenants.

## 3.2 Fabric testing

Although the focus of the monitoring project was on the MVHR systems and quality of the indoor environments, some testing of fabric performance was carried out as part of the project. Airtightness testing was performed on three separate occasions, each time with an air leakage audit using smoke pencils. Extensive thermal imaging of all 10 homes (both internal and external) was carried out in December 2010.

### 3.2.1 Airtightness testing and air leakage audits

Airtightness testing was first undertaken in September 2010 during the finishing stage of construction. The homes were shown to have air permeability values in the range 2.6 to 5.7 $m^3/h/m^2$. Main air leakage paths were identified and visualised using a smoke pencil during the pressurisation phase of airtightness testing. As expected air leakage paths were limited, although common ones were seen throughout the homes – such as around doors, through electrical wall sockets, around service pipe penetrations and light fittings (Figure 6).


Figure 6 Typical air leakage paths in Greenwatt Way homes (a) under back door (b) through wall sockets (c) through gap behind bathroom basin

Subsequent airtightness tests in July 2011 and March 2012 showed that in the case of all homes, except Home 5, the level of airtightness increased over the first 18 months of occupation (Table 1).

Table 1 Summary of airtightness results

| Home no. | Air permeability ($m^3/h/m^2$ at 50 Pa) | | |
|---|---|---|---|
| | September 2010 | July 2011 | March 2012 |
| 1 | 4.5 | 3.7 | 3.2 |
| 2 | 4.1 | 4.6 | 2.7 |
| 3 | 2.6 | 2.8 | 2.5 |
| 4 | 2.9 | 3.1 | 2.5 |
| 5 | 4.4 | 8.6 | 8.1 |
| 6 | 4.6 | 5.2 | 3.9 |
| 7 | 5.0 | 6.5 | 3.8 |
| 8 | 5.7 | 4.9 | 2.9 |
| 9 | 4.9 | 3.2 | 3.0 |
| 10 | 4.4 | 3.2 | 2.1 |

It is worthy to note that the increase of airtightness levels over the 18-month period were generally greater in the masonry houses (Homes 7 to 10). It is also interesting that the general trend towards the homes of both construction types to become more airtight over time (which confirms the findings of earlier research by NHBC Foundation)[8]. Air permeability testing is subject to measurement accuracy and can be affected by the prevailing weather conditions, and this may account for some of the differences between results.

The air leakage audits carried out in July 2011 and March 2012 highlighted the same common areas of leakage in all homes, particularly underneath the external doors, and around the roof lights above the staircases in the houses.

### 3.2.2 Infrared thermography

An infrared thermographic survey of all homes was carried out on 9 December 2010, when there was sufficient cloud cover throughout the day to prevent solar gain on external surfaces and there was a temperature differential of at least 10°C between inside and outside the homes.

In general the homes were shown to be good from the point of view of the thermographic study undertaken and there were no obvious signs of heat loss through the external façade of the homes (Figure 7). The main heat loss paths in all home types appeared to be through gaps around windows and in particular the front entrance doors and rear patio windows (Figure 8). The other weak areas seen to be common in all of the houses were the poorly insulated roof lights above the staircases. On internal thermal images it was also possible to see signs of cold air ingress through gaps around loft access hatches. In the case of the two flats, especially Home 5, it was possible to see a difference in the amount of heat being lost between the internal area of the flat and the sloping roof area (ie the loft area above the flat). There seemed to be more heat being lost from the roof area, which may suggest heat getting up into the loft area and leaking out through the external walls (Figure 9).


Figure 7 Front façade of Home 2. Corresponding thermal image shows uniform heat loss across the building façade

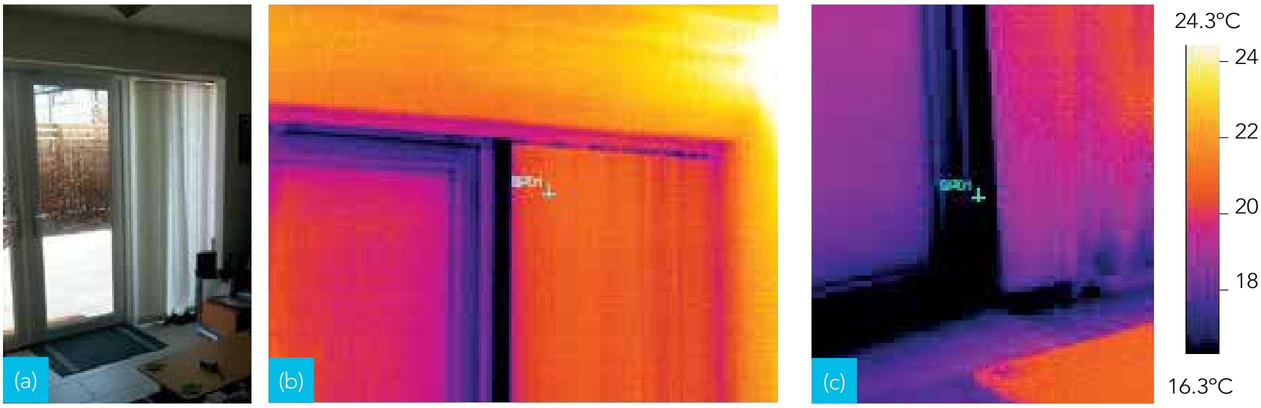


Figure 8 (a) Internal view of opening patio doors in Home 1, (b) and (c) corresponding thermal images show cold bridging around the doors


Figure 9 (a) West façade of Home 5, (b) corresponding thermal image shows some heat loss at eaves level

## 3.3 General occupant feedback

In order to gain insight into the residents' experiences of living in the Greenwatt Way homes a series of three occupant studies were carried out by the BRE Social Research team in February 2011, September 2011 and April 2012. On each occasion a detailed questionnaire was prepared with input from SSE's project team, covering the following aspects of occupancy:

- **The Home:** Learning how to use it and the experience of living in it.
- **Environmental factors:** Including temperature, ventilation and air quality, lighting, noise and water use.
- **Controls and technologies:** Issues regarding understanding and ease of use of the systems and technologies in the homes, as well as levels of satisfaction with them.
- Energy use and energy costs.
- Safety, security and privacy.

In each case there was at least one adult questionnaire respondent from each of the nine occupied homes. Following collection and analysis of each quantitative data set a focus group was run with the Greenwatt Way residents. The focus groups explored in more detail key findings from the questionnaire responses, and were held in the show home to allow occupants to physically point out any particularly good or bad aspects of the homes and systems, as well as demonstrating any issues.

Occupant feedback regarding all aspects of the MVHR system and concerning specific aspects of the indoor environment (IAQ, ventilation, thermal comfort, lighting and noise) are discussed in Sections 4.9 and 5.4 respectively. A brief summary of feedback from the residents regarding other aspects of living in the Code Level 6 homes is presented below.

**February 2011: 17 respondents**
**(6 male, 11 female) of average age 34; focus group of 10**

Six months after moving in, the occupants were generally very happy with their new homes during occupation in the initial autumn/winter period from September to February. Occupants liked the design and layout of the homes, with the open plan ground floors in the houses being highlighted as being among the best features. Taking all environmental factors into consideration, over 75% of the respondents generally found their home comfortable, and the vast majority reported feeling safe and secure within it.

On the less positive side, only 29% of respondents said they had found their home induction useful, and 75% said they referred to their user guide less than once per week, which suggests that occupants may not have known how to use the homes and their technologies in the most effective manner. Looking in more detail at the ease of control and level of understanding of the various systems in the homes, the occupant responses were interesting.

Figure 10 shows how well they felt they understood the control systems in the home and Figure 11 shows how easy occupants found it to control the systems. A significant group of respondents (30%) struggled to understand both how to control the heating system and found it difficult to use it. Some occupants found the whole house shutdown system, which is designed to save energy by cutting off the supply to most lighting and appliances when leaving the home, difficult to understand; however, they found it easy to use. Respondents generally found the electric lighting controls both easy to understand and easy to use.

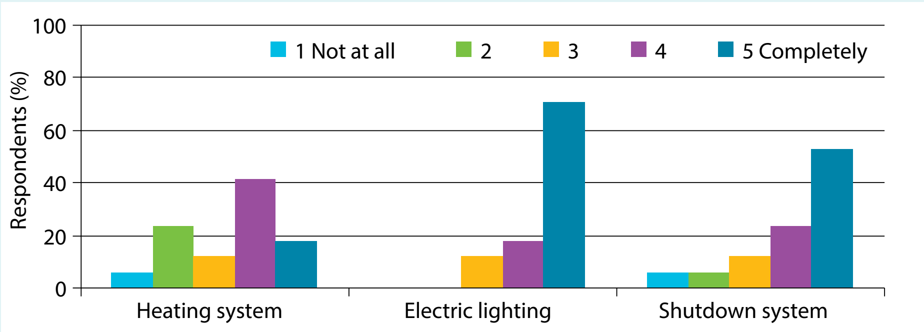


Figure 10 How well respondents understand how to control systems in their home

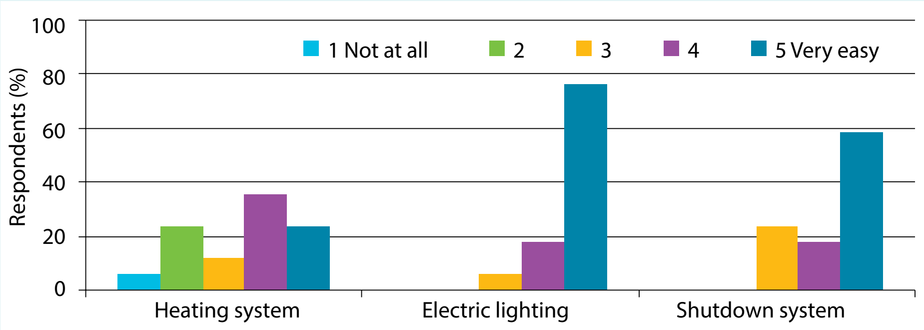


Figure 11 How easy respondents find it to use systems in their home

**September 2011: 15 respondents**
**(6 male, 9 female) of average age 38; focus group of 14**

1 year after moving in, when responding to a modified questionnaire and attending the focus group the occupants were asked to base their input on the spring/summer period of 2011. Taking all environmental factors into consideration 87% of respondents remained comfortable in their homes, and external spaces including the shared/communal garden were rated as good. House residents reported spending most of their time in the open plan ground floor area during summer due to this being cooler than other rooms.

Having become accustomed to the energy bills in their new homes the majority of respondents felt that their bills were less or much lower than those in their previous homes. Interestingly, many of the occupants said that they were far more conscious of their energy use now than they were having first moved in. Due to feedback from the provided by the SSE project team and increased transparency as to how much energy they were using from real-time displays in the homes, the occupants reported a keenness to limit energy use and to keep their energy bills as low as possible. The whole house shutdown system was reported to be used more frequently than at the time of the previous survey. Over 50% rated the performance of the PV tiles as good or very good, and the district heating and hot water systems were also rated as good or very good by the majority. However, perhaps understandably, there appeared to be limited understanding as to which technology was responsible for space heating or water heating at any given time.

**April 2012: 12 respondents**
**(6 male, 6 female) of average age 36; focus group of 10**

Eighteen months after moving in, a further survey was undertaken. Again the questionnaire was modified and occupants were asked to consider the autumn/winter/spring period of 2011 to 2012 in their responses and when attending the third focus group. Particular emphasis was placed on issues surrounding the MVHR system due to the recommissioning and remedial works carried out in November 2011 (see Section 4), although clearly this could have been due in part to the nuisance factor associated with the works. Most occupants remained content with their homes overall, with 100% now finding their home generally comfortable taking into account all environmental conditions, although comments on certain aspects such as lack of storage space emerged. All of the respondents said that their friends and family rated their house or flat as good or very good, and that they felt safe or very safe in their home.

After 18 months of occupation the majority of residents felt that they had a good or even complete understanding of how to control the heating system and electric lighting. With regard to energy use and cost, the majority of respondents felt that their winter energy bills at Greenwatt Way were lower than expected and lower than for their previous homes, although over two-thirds said they never looked at their real-time displays. The latter observation was backed up by the fact that almost half of the occupants felt less conscious of energy use than they had during the initial months of their occupation.

# 4 MVHR systems

## 4.1 Design and installation

### 4.1.1 Design

An outline design of the ventilation system for the homes at Greenwatt Way was undertaken by the M&E designers with drawings produced showing the general arrangement of the ventilation components and the intended ductwork routing. The drawings included details of the ductwork to be used for distribution within the insulated envelope, stating that flat ductwork would generally be used. The drawings also indicated that much of the ductwork was to be located in the loft space (ie outside the insulated envelope); however, no specific details of the ductwork in this location (ie type and size) were given.

The initial specification for the MVHR system was for a fan unit able to achieve an air supply rate of up to 400 $m^3/h$. It also included the facility for the supply air temperature to be boosted by a post heater (fed from the space heating system located in the supply air duct immediately after the MVHR fan unit). However, during the construction phase the specification of the MVHR system was reduced and a product that was able to supply little over 200 $m^3/h$ was identified as being suitable.

The original specification included a remote control to allow occupants to control fan speeds. The MVHR system specification also had an automatic mode of operation allowing a trigger value of relative humidity (RH) and/or $CO_2$ to be set to run the fans at boost speed, appropriate during bathing/cooking. However, the MVHR fan units actually installed had neither the facility for occupants to adjust the fan speeds, nor any integral humidity and/or $CO_2$ sensors. Although a $CO_2$ sensor was specified and supplied to site, no details of how it was to be incorporated (either physically or electrically) were available.

Also, it was noted that the air flow rates for each MVHR fan unit or the rates at each internal air valve were not specified on the outline design drawings. The only reference to an air flow rate was made on a specification document for the MVHR system stating that required nominal supply and extract air flow rates were 29 l/s.

It may be argued that the shortcomings associated with the design of MVHR systems made it very unlikely that good outcomes would be achieved post-occupancy in these homes.

### 4.1.2 Installation

The quality of the ductwork installation was assessed in May 2010 between first and second fix. At that time the ductwork was being installed on the ground floor of the houses. The work was being carried out by a team of experienced pipe fitters, without prior experience of MVHR systems. The M&E outline design specified flat ductwork in all locations within the heated envelope. However, with the floors installed it was immediately clear that the flat duct could not be fed through the metal web floor joists unless it was cut into short lengths and several bends were used to run from the risers to the air valve locations. This was questioned and the use of round ductwork suggested. The flat ductwork that had been specified can be seen in Figure 12 clashing with the webs of the floor joists making installation very hard and requiring installation of many additional bends, which would have increased air resistance significantly.

Round ductwork was subsequently procured and installed within the floor joists. Figure 13 depicts how the use of this type of duct minimised the need for any additional bends to be installed between the riser and the room valve.

Figure 12 Flat ductwork (as specified) clashing with joist webs

Figure 13 Round ductwork allowed direct runs from risers to air valves and could be installed in long lengths, minimising the number of connections

BRE visited the site again during early September 2010 when most of the ductwork had been installed in the houses. The good quality of the installation within the houses in terms of ductwork joints, supports and lack of unnecessary bends was very evident, and reflected the attention to detail the installers had taken. However, it was noted that where many of the ducts had been terminated at ceiling level the ductwork had been left open and very few had been sealed. While it is not general practice in the UK to seal ductwork on installation, dust will collect and unless removed by sweeping prior to running the MVHR fan unit, this dust will be drawn into the extract filters, resulting in them requiring early cleaning/replacement. Also dust in the supply ductwork will be blown back into the building.

The MVHR fan units had also been installed, along with the associated loft ductwork. It was immediately evident that very significant lengths of ductwork were located in the unheated loft. Inspection of the roof construction revealed that the ceiling was an off-site produced panel and no provision had been made for including horizontal ductwork runs within the panel. As no space had been made available within the insulated envelope for ductwork to run internally, the only option was for all of it to be located in the loft. The general layout of the ductwork in the loft can be seen in Figure 14, all in accordance with the outline drawings issued by the M&E designers.

Figure 14 MVHR fan unit and associated distribution ductwork in the loft

The MVHR fan units were installed on rubber feet to minimise noise transfer to the structure of the building, but no mechanical isolation (such as short lengths of flexible duct) was provided between the MVHR fan unit and the service ductwork. Omitting this separation allows vibration in the MVHR fan unit to be transferred down the ductwork and then into the structure of the building, since the ducts were mounted on solid blocks directly onto the loft floor. The insulation of the ductwork within the loft was generally of a very good standard. All ductwork was insulated with 25 mm of foil-backed mineral fibre insulation meeting the required minimum specified in the Building Regulations. All joints were taped using aluminium tape. The finished insulated ductwork can be seen in Figure 15a.

Some of the final connections between the MVHR supply and exhaust ductwork and the external valves in the loft were made in flexible duct. This is typical practice, and allows slight misalignments to be taken up. However, some of the flexible ducts were far longer than necessary, twisted, and in some cases uninsulated, which would cause extra heat loss. It was also noted that condensation traps had not been provided on the exhaust air ducts from the MVHR fan unit to outside, which could result in condensate draining back into the fan unit from the long exhaust ducts.

When the MVHR fan units were running it was noted that the post heater installed in the supply air ductwork after the MVHR fan unit had very noticeable levels of air leakage from the folded corners of the sheet metal casing. The insulation of the hot water pipework feeding these fan units was also totally inappropriate for an unheated loft location, with significant sections missing and no insulation on the connections to the second unused coil (Figure 15b). The loss of warmed air and the heat loss from both the heat exchanger's casing and associated pipework can only have a very negative effect on overall energy use for these homes.

It was also noted that all of the air valves installed throughout the homes were of the extract type. None of the supply-type air valves were installed in any of the living rooms. The difference between these two types of valve is that a supply-type air valve is designed to jet the air into a space and achieve a level of mixing of the supply air with the room air before it enters the occupied zone of the room. In this way the potential for cool supply air to result in cold draughts is minimised. Conversely, the exhaust air valve has no directional qualities, and is designed to extract air with a minimum of flow resistance.

The outline design of the system contained no details of the actual control strategy for the MVHR; although specified and supplied to the site the $CO_2$ sensors were not installed. Therefore it was evident that the fan units as installed would run at a fixed rate with no boost control provided for the occupants.


Figure 15 (a) The ductwork was insulated with 25 mm of foil-backed mineral fibre insulation; joints foil taped (b) little attention to quality of insulation on post heaters

### 4.1.3 Summary of findings

**Concept and design**

- **Design detail**: The original outline design intent for the MVHR systems, as undertaken by a third party, was never fully worked up into a detailed design. The effect of this was that many of the details that would normally be included in a detailed design were missing, including system controls sensors and strategy, wiring instructions, air flow rates for each supply and extract location. This was not picked up, as the installation was not undertaken by experienced ventilation system installers – who would have looked for this level of detail.
- **Design checking**: The manufacturer of the MVHR fan units installed offered a design service as part of the sales package. However, the fan units were purchased on a 'supply only' basis, and therefore this level of outline design checking did not occur.

**Procurement and installation**

- **Mix of trades:** The MVHR systems were installed by a selection of trades. The ductwork was installed by pipe fitters, and then the MVHR fan units were installed by electricians. Trained and experienced ventilation system installers would have been more likely to have questioned some of the details of the design and component selection, which in turn would have highlighted the lack of a fully detailed design.
- **Same MVHR system installed in all homes:** The same 'off the shelf' MVHR fan unit was installed in all homes at Greenwatt Way, from the one bedroom flats to the three bedroom detached houses. The consequence was that in many of the homes the size of MVHR fan unit deployed was not correct. This fundamental mistake would have been picked up if the design had been reviewed by the manufacturer.
- **Ductwork type:** The original ductwork procured (flat cross section) was found to be impractical to use in the homes as constructed, clashing with the webs of the floor joists – thus making straightforward installation impossible. Replacement with ductwork of round cross section allowed direct runs from risers to air valves and meant that ductwork could be installed in long lengths, thereby minimising the number of bends and connections required. There were short sections of flexible duct in some locations that created very significant restrictions to air flow due to poor installation practice.
- **Insulation of MVHR fan unit and ductwork:** As the MVHR fan units and a substantial proportion of the ductwork were located outside of the insulated envelope in the homes (currently common practice in the UK) very great attention should have been paid to the insulation on the MVHR fan unit and ductwork. Although the quality and consistency of the insulation was good and met the minimum requirements of the Building Regulations, it was expected that the overall heat loss from the ductwork would be very significant. This heat loss would also be exacerbated by the heat loss from the uninsulated MVHR fan unit (there are no requirements placed on the thermal characteristics of MVHR casing material). The post heater and associated pipework were uninsulated or very poorly insulated, and this was not appropriate for installation in an unheated location.

## 4.2 Commissioning

### 4.2.1 MVHR system inspection post-occupation (October to November 2010)

Approximately one month post-occupation BRE conducted an assessment of the MVHR system in all 10 homes at Greenwatt Way. The aim was to assess the quality of the overall installation of the MVHR system and the commissioned air flow rates.

The main findings from the site visits are summarised below:

- The commissioning sheets forwarded by the commissioning engineers stated that the design air supply/extract rate for all homes was 29 l/s. This single, consistent figure would be unlikely, since the homes differ significantly in floor area and number of wet rooms, the smallest being a single bedroom flat with kitchen and one wet room and the largest being a three bedroom detached house with kitchen and three wet rooms. The actual supply/extract air flow rates measured were 13 l/s for the one bedroom flats and up to 33 l/s for the three bedroom houses.
- All of the MVHR fan units inspected had been wired such that they were running in boost mode constantly. The measured electrical power consumption indicated that most of the installed fan units were left at near maximum fan power.
- No manual controls were installed to allow occupants to select between trickle and boost settings. Confirmation from SSE that $CO_2$ sensors were specified and supplied to site suggests that installation of a $CO_2$ control system (which adjusts fan speed depending on occupancy) may have been included in the original specification – in order to achieve user-free system control. However, there was no evidence of provision for any control sensor feeding back to the MVHR fan unit. Relative humidity controllers were later installed and linked into the MVHR fan unit to trigger boost speed operation.
- Although the insulation of the ductwork in the lofts had initially been generally satisfactory, the aluminium foil tape used on the insulation had started to fail on some of the ductwork corners after less than six months (see Figure 16a). The insulation of the ductwork in the flats was generally of a lower quality than that in the houses.
- The condensate drain lines were not insulated in any of the installations. This may result in the condensate freezing, thus preventing the removal of condensate from the MVHR fan units in cold weather. Damage to the fabric and finishes of the homes could then result.
- The filters in a few of the MVHR fan units were inspected. The exhaust air filters were found to be very dirty, suggesting that fan units had been left running after installation, when snagging and final cleaning of the homes was being undertaken (see Figure 16b). The filters should have been inspected and changed as required prior to handover. Also some of the filters were found to have been installed the wrong way round, which would have compromised their effectiveness.


Figure 16 (a) Failure of tape securing insulation (b) dirty extract filters (note that the arrow on the side of the filter indicates installation backwards)

### 4.2.2 Recommissioning of the MVHR fan units

Following work carried out on the MVHR fan units by the manufacturer and independent recommissioning of the MVHR system during January/February 2011, BRE undertook an assessment of the recommissioning.

A review of the setting of the air valves, following recommissioning, revealed that most of them had been closed in very tightly (Figure 17).The reason for this was to minimise the potential of cold supply air 'dumping' down into the rooms and causing discomfort – a situation exacerbated by the wrong types of air valve having been used for supply. Closing the valve results in the supply air jetting into the room and mixing with the room air before it enters the zone occupied by people in the room. The extract valves had been closed to near shut because the model of MVHR fan unit installed in these homes only has a single speed control for both fans. Therefore, increasing the fan speed to overcome the resistance in the supply valve results in the extract air flow rate increasing. To return the air flows to balance the extract, valves have to be closed by approximately the same amount as the supply valves. The result of having the valves nearly closed is that the fans must run at a higher speed to achieve the design air flow rate than if the correct valves had been installed and set correctly. This would have been of considerable detriment to the efficiency of the systems.

Figure 17 Supply and extract valve commissioned to near shut

### 4.2.3 Summary of findings: commissioning of systems

- **Initial round:** The lack of any questioning that the air flow rates for all the houses could be the same indicates a lack of understanding of the requirements of the Building Regulations. It is clear that this round of commissioning was wholly unsatisfactory.
- **Recommissioning round:** The design air flow rates used and the values achieved met the requirements of Part F of the Building Regulations 2006[9]. However, closing the valves to near shut, while minimising the potential of thermal discomfort, has a very significant impact on fan power and it is unfortunate that the inappropriateness of the valves installed was not noted on the commissioning sheets.

## 4.3 Performance monitoring (all homes)

Monitoring the power use of the MVHR fan units confirmed the suspicion that all were set at far too high a fan speed following the first recommissioning in late 2010.

The monthly energy use and average power data for three months (April to June 2011), shown in Table 2, indicates clearly that the MVHR fan units were running at very high fan speeds. The maximum power this model of MVHR fan unit will use is around 75 W, suggesting that even after a second round of commissioning there are two houses that are effectively running at maximum boost speed continuously.

Table 2 Monitored monthly energy use and average power for MVHR fan units

| | Home | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Energy/month (kWh) | | | | | | | | | | |
| April | 53.26 | 35.52 | 39.63 | 29.89 | 21.91 | 19.61 | 51.38 | 54.94 | 47.55 | 39.88 |
| May | 54.66 | 35.36 | 38.55 | 28.53 | 22.41 | 17.39 | 52.97 | 56.29 | 49.71 | 41.68 |
| June | 52.50 | 41.60 | 42.14 | 31.72 | 24.35 | 18.59 | 50.88 | 54.06 | 47.36 | 44.53 |
| Average power (W) | | | | | | | | | | |
| April | 71.59 | 47.74 | 53.27 | 40.17 | 29.45 | 26.35 | 69.05 | 73.84 | 63.91 | 53.60 |
| May | 75.91 | 49.12 | 53.54 | 39.63 | 31.12 | 24.16 | 73.57 | 78.19 | 69.05 | 57.88 |
| June | 70.56 | 55.92 | 56.64 | 42.63 | 32.73 | 24.99 | 68.39 | 72.66 | 63.65 | 59.86 |

A review of the laboratory test data for the MVHR fan unit installed in each of the homes (Table 3) reveals that the specific fan power for a very good installation should be less than 1 W/l/s for all of the homes on this site. Taking into account the additional 40% 'in-use factor' used to downgrade the laboratory results to more realistic site-based results, this still suggests that for the flats the power should be less than 20 W, for the two bedroom houses the power should be less than 30 W and for the three bedroom houses the power should be less than 40 W.

Table 3 Laboratory test results for MVHR fan unit installed in homes

| Exhaust terminal configuration | Fan speed setting | Specific fan power (W/l/s) |
|---|---|---|
| Kitchen + one additional wet room | 100% variable | 0.69 |
| Kitchen + two additional wet rooms | 100% variable | 0.76 |
| Kitchen + three additional wet rooms | 100% variable | 0.85 |

Overall the results clearly indicate high fan power resulting from poor system commissioning. This can be identified as the cause of the high fan power, since the installation of the ductwork was reviewed during the installation/construction process and was found to be above average, with an appropriately sized duct being used for the air flow rates being handled.

### 4.3.1 Power consumption of MVHR fan units following installation of humidity boost control

The MVHR fan unit power consumption was continuously monitored and the data from the middle of the summer to the end of September 2011 is presented in Figure 18. From this it is very clear that the MVHR fan units that were running close to boost at the beginning of this period remain at that level; the other homes, except Home 10, all increased during the summer. This resulted in Homes 5 and 6 running at significantly below boost rates, ie around 50 kWh/month (equal to approximately 70 W continuous running power) at the end of September.

In Figure 18 Home 10 appeared to have the opposite trend to Homes 1 to 9, with the energy use of the MVHR fan unit falling over the summer. However, this was identified as being due to the failure of the fan unit, which when inspected in October had totally failed with neither fan running.

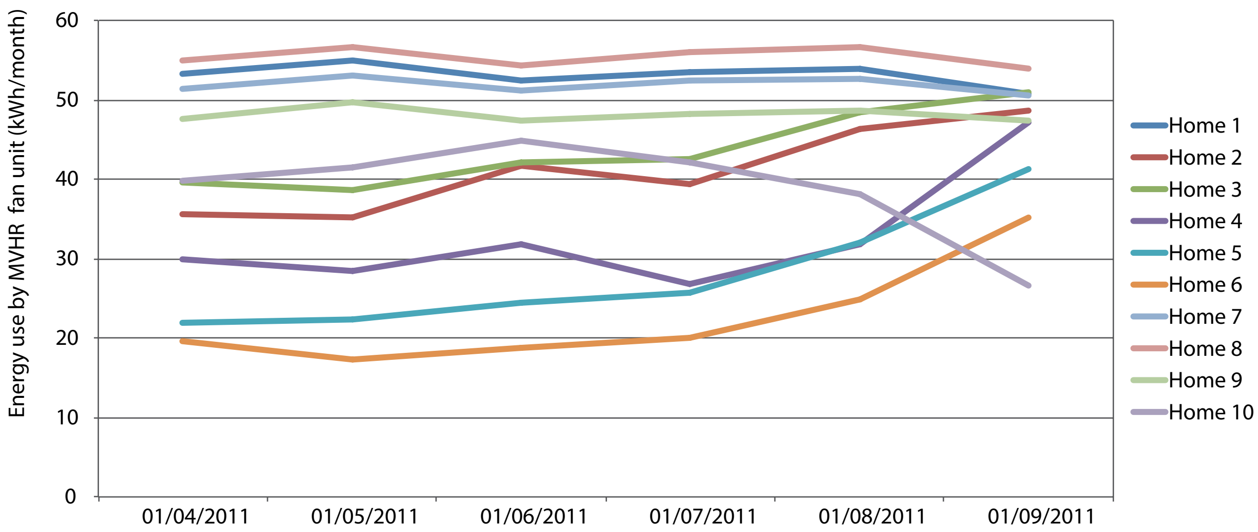


Figure 18 Monthly energy use by the MVHR fan units for Homes 1 to 10

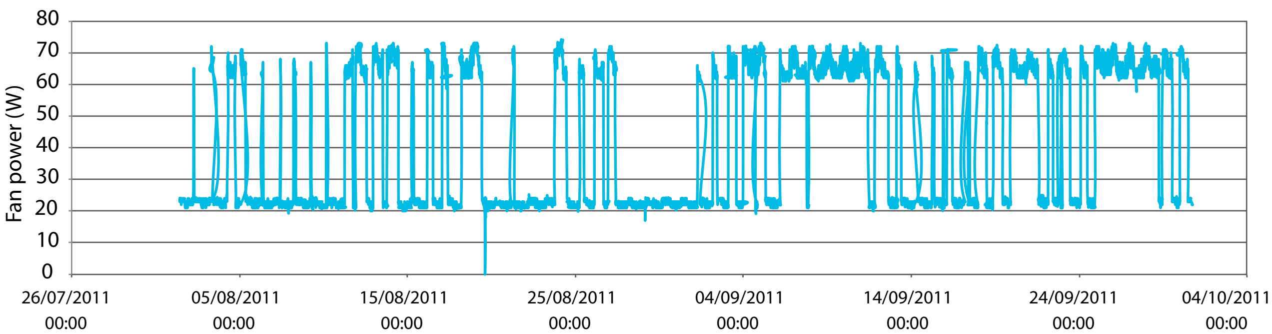


Figure 19 Instantaneous power drawn by the MVHR fan unit for Home 6

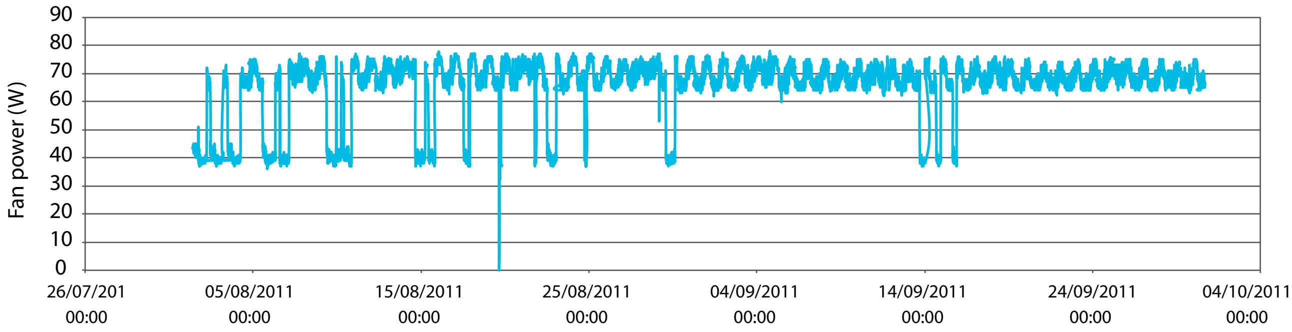


Figure 20 Instantaneous power drawn by the MVHR fan unit for Home 2

When this data is broken down to the instantaneous readings (Figure 19 and Figure 20), it is clear that there were significant periods of time when the MVHR fan unit was running on boost all day in the Home 6, and that in Home 2 the MVHR system changed to running nearly permanently on boost during September.

To assess whether the initial settings on the humidity sensors, set at 60% when installed, were causing the MVHR fan units to run continuously at boost, the measured internal air temperature and RH in the homes were assessed for the month of September. An example of the data is shown in Figure 21. The measured data shows that there is a significant period when the internal RH is greater than 60%; therefore, the sensor will trigger the fans to run at boost speed until the RH falls to 54%. However, in Home 2 the MVHR fan unit was running at boost speed continuously.

To assess whether the effect of the extract air cooling after it has passed through the building envelope, but before it reaches the MVHR fan unit, was causing it to run in boost mode continuously: the effect of a drop in temperature of 2°C on the RH was calculated. The effect of this is also shown in Figure 21. It is clear that even this small reduction in temperature of the exhaust air increases the RH above the 56% value required to switch the fan unit out of boost mode. Measurements of the temperature of air within the extract ducts show reductions in air temperature of

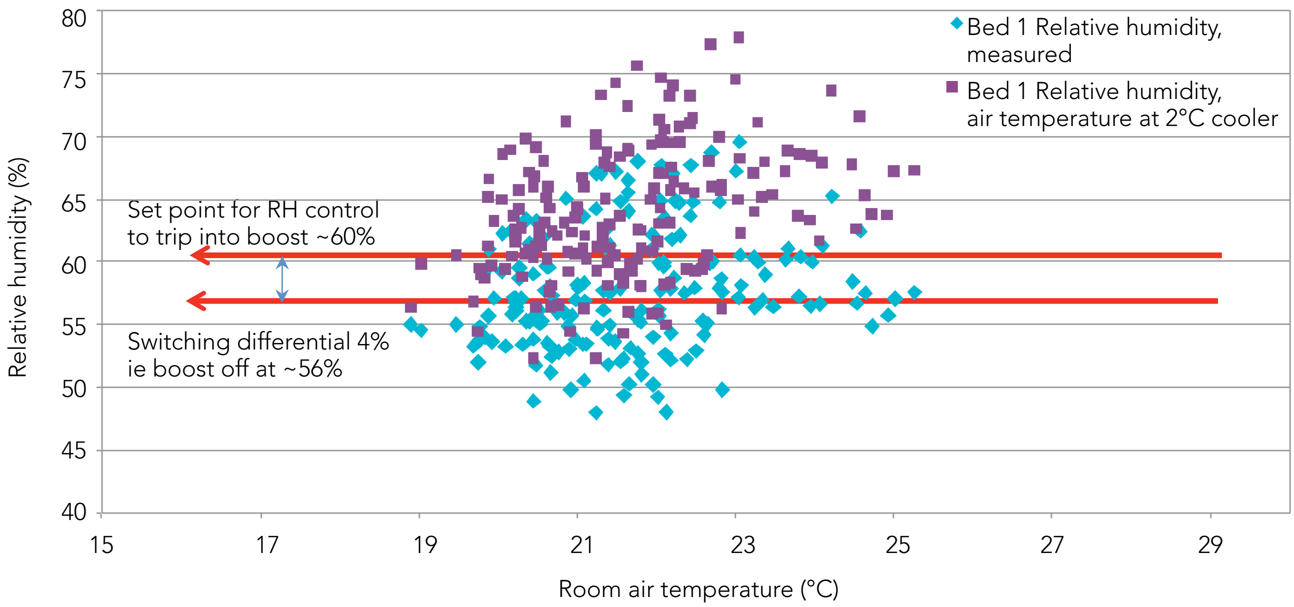


Figure 21 Room air conditions showing 'boost on' and 'boost off' relative humidity values, and the effect of reducing room temperature by 2°C on relative humidity

greater than 1°C were normal as the loft air temperature fell in autumn. Therefore it is evident that setting the RH controller to 60% was a significant factor causing the near continuous boost operation of the MVHR fan units.

### 4.3.2 Summary of findings: power consumption of MVHR fan units

- **Result of commissioning:** Although it is understandable that the commissioning engineer was trying to minimise thermal discomfort for the occupants, the consequence of having the air valves closed near to shut was that the fans had to be set at a higher speed to achieve adequate air flow rates. It should have been obvious that the wrong air valves had been installed and these should have been changed prior to occupation.
- **Heavily soiled filters:** Essential to the efficient operation of MVHR system is regular replacement/cleaning of filters which is required to maintain the design air flow rates and to minimise fan power (and energy consumption). The filters should have been clean at handover and a maintenance schedule should have been provided, recommending filter maintenance at appropriate intervals.
- **Incorrectly set controls:** The installation and setting of the RH control at a level that occurs naturally within the homes resulted in fan power being increased significantly in all the homes. When running at boost speed the fans are also relatively noisy, and this was noted by the occupants. Location and setting of the controlling sensors is critical to the correct and efficient operation of systems. It is suggested that when the extract air is cooled significantly after it has left the wet rooms, the location of the RH sensors in the MVHR fan units themselves is not appropriate, and that these should be located locally in the wet rooms.

## 4.4 Recommissioning of systems (Homes 2 to 10)

Following an assessment of the air flow rates after the independent recommissioning of the MVHR system in the homes, it was noted that the air flow rates in Home 9 were falling during September 2011. This was traced back to clogging of the fly screen in the inlet terminal, in a location within the loft space which was hard to access. The fly screen was removed and air flow rates returned to the commissioned values. However, it was decided that the fly screens in all homes should be inspected. The fouled fly screen in Home 9 had reduced the total supply air ventilation rate down from 24 l/s to below 20 l/s. When the assessment of the fly screens in the other houses was undertaken in October, they were all found to be nearly totally blocked. Figure 22 shows images of one screen as it was removed.

Figure 22 Fly screen removed from a supply air valve – almost totally blocked by build-up of debris

Prior to removing the screens in Home 6 and Home 7, the supply air flow rates were measured. In Home 6 the ventilation rate had reduced from 14 l/s to 9 l/s and in Home 7 over the same period the supply flow rate had reduced from 28 l/s to less than 5 l/s. This equated to less than 1 l/s being delivered through each of the supply air valves in the living rooms. The total exhaust air flow rate was measured as 29 l/s, a reduction of only 1 l/s over the summer. This very small reduction in exhaust air flow rate suggests that most of the make-up air was being readily supplied through fabric infiltration or doors and windows.

As a result of the high fan power caused by the incorrect supply air valves being installed and the need to remove the fly screens, it was decided that the systems would be recommissioned by BRE. The aim was to minimise the power consumption, improving the thermal comfort of the occupants, and reducing the reported noise of the MVHR system.

The agreed works were as follows:

**Replace unsuitable room inlet valves in all 10 homes**
The air valves installed in all supply locations were replaced with supply type valves and the system recommissioned to achieve the design air flow rate at minimum fan power.

**Install upgraded supply air filters in a duct mounted filter box in all 10 homes**
The MVHR fan units installed in all of the homes have supply and extract air filters included within their casing. However, access to them requires the removal of 10 screws. This makes regular checking and replacement of the filters unlikely. This was evident after only a few months' occupation, when it was noted that several of the supply air filters were very dirty. The options for installing additional filtration were: to upgrade the filters within the MVHR fan unit, possibly with a pre-filter and then a high grade final filter, or to place alternative filtration close to the supply air valve. The latter option was chosen as more practical, since it allowed an easily accessible filter to be placed in the first section of the ductwork, and required no tools for removal. To increase accessibility the approach adopted was to place filter boxes directly on the internal face of the roof space wall in the supply air duct (Figure 23). The type of filter installed was an F5, a slightly higher grade (finer) than the filters installed in the MVHR fan units. Following the remedial work the filters were to be inspected as part of routine maintenance and cleaned or replaced as appropriate.

Figure 23 Filter box installed in supply air duct inside loft

## 4.5 Thermal efficiency

### 4.5.1 Detailed monitoring of the MVHR system (Home 9)

The published results of products listed on the database used by SAP[10] are based on laboratory testing of the thermal performance of MVHR fan units. Little detailed monitoring has been undertaken of products in the field, under normal operating conditions. The opportunity at Greenwatt Way has therefore been very useful, as it has allowed the installation of MVHR systems in Code Level 6 homes (which should, by their very design, be highly thermally efficient) to be assessed in order to determine whether or not the true performance matches the predicted performance.

To gather sufficient high quality data to make a full assessment of installed performance required the installation of a range of high accuracy temperature and RH sensors into the air stream of the MVHR system in several locations. Sensors were located at each inlet/outlet (spigot) of the MVHR fan unit and at each point at which a duct passed through the building thermal envelope. Monitoring of the performance of the MVHR fan unit over a three-day period revealed a significant variation in the thermal efficiency. This can be seen in Figure 24. When the thermal efficiency is plotted against the loft air temperature, a strong correlation is evident. This can be seen in Figure 25.

The relationships for a winter period are shown in Figure 26.

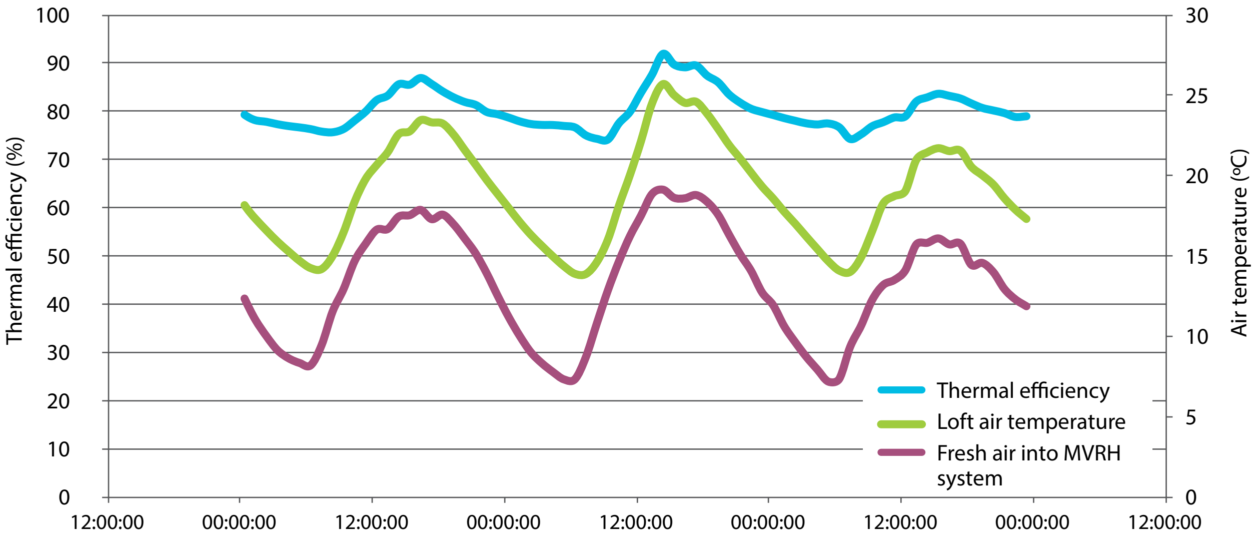


Figure 24 Variation of thermal efficiency of MVHR unit over three days (Home 9)

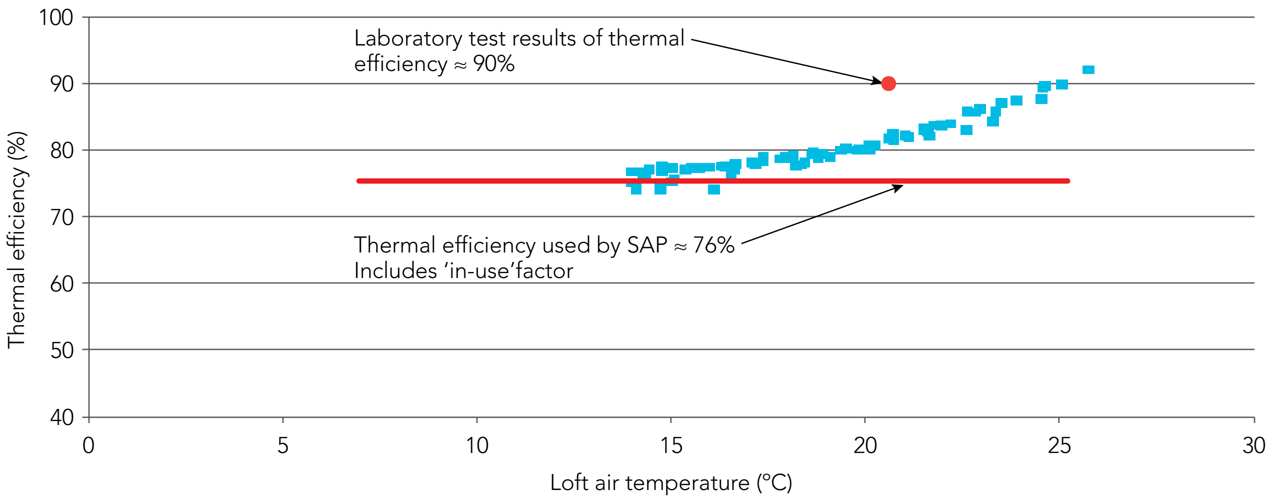


Figure 25 Variation of thermal efficiency of MVHR unit with loft air temperature (Home 9, May period)

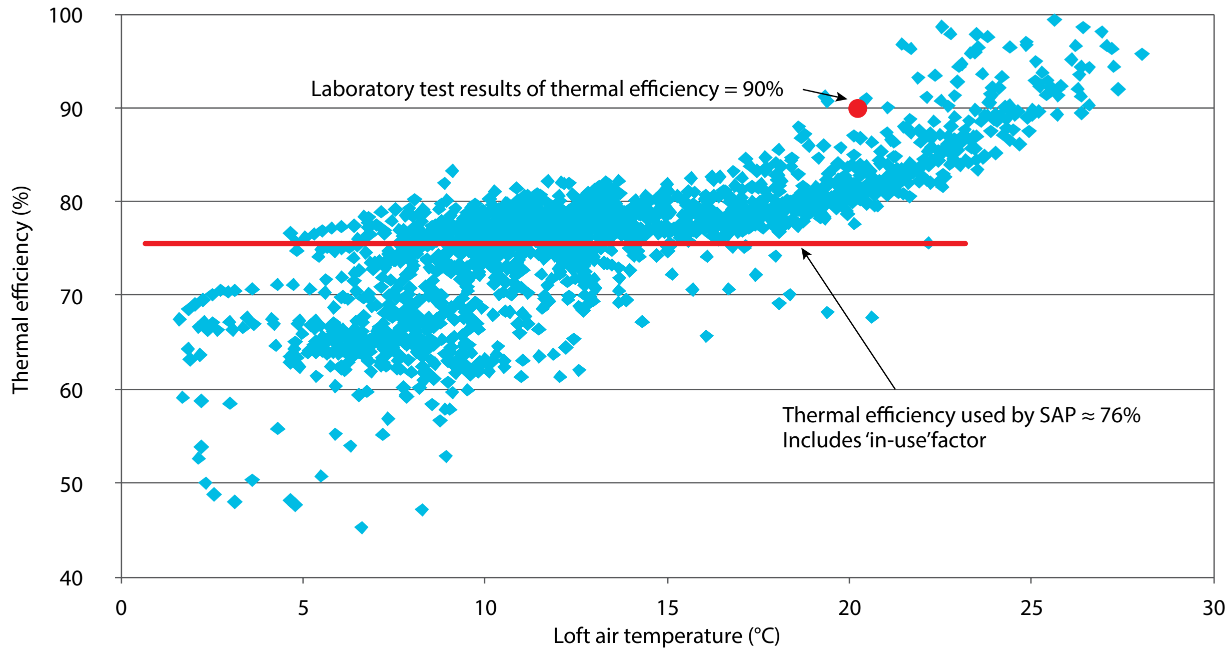


Figure 26 Variation of thermal efficiency of MVHR unit with loft air temperature (Home 9, December/January/February period)

From Figure 25 and Figure 26 it is evident that the thermal efficiency of the MVHR fan unit installed in Home 9 was directly affected by the loft air temperature. The data shows clearly that as the loft air temperature fell below 10°C, the thermal efficiency of the system fell below 70%. This compares badly with the results of the laboratory testing, which measured the efficiency at around 90%; SAP test data is shown in Table 4. To convert the laboratory test data into installed performance data the results are adjusted by an 'in-use' factor. For an MVHR system with insulated ductwork the in-use factor is -15% of the laboratory test results. That makes the predicted thermal efficiency for Home 9 around 75%.

Table 4 Laboratory test results for thermal efficiency of the MVHR fan unit

| Exhaust terminal configuration | Fan speed setting | Specific fan power (W/l/s) |
|---|---|---|
| Kitchen + one additional wet room | 0 to 100% | 92 |
| Kitchen + two additional wet rooms | 0 to 100% | 92 |
| Kitchen + three additional wet rooms | 0 to 100% | 90 |

The very evident link between the loft air temperature and the efficiency of the MVHR system suggests that the thermal losses from the body of the MVHR fan unit are very significant. When the implication of this is assessed in terms of heat loss, the effect on the heating load of the house becomes apparent. Figure 27 presents calculated results for the heat removed from the outgoing air and the heat gained by the incoming air across the MVHR fan unit only, for a three-day period. The temperature of the fresh air coming into the MVHR fan unit is also shown. Overnight there were significant periods when there was a relatively large energy imbalance, ie the heat removed from the outgoing air was significantly greater than that gained by the incoming air.

Once the supply air has left the MVHR fan unit it has, in some cases, a significant distance to travel before passing through the thermal envelope. This brings the system efficiency down to below 60%. The effect of this on the temperature of the supply air to the lounge and bedroom one is shown in Figure 28.

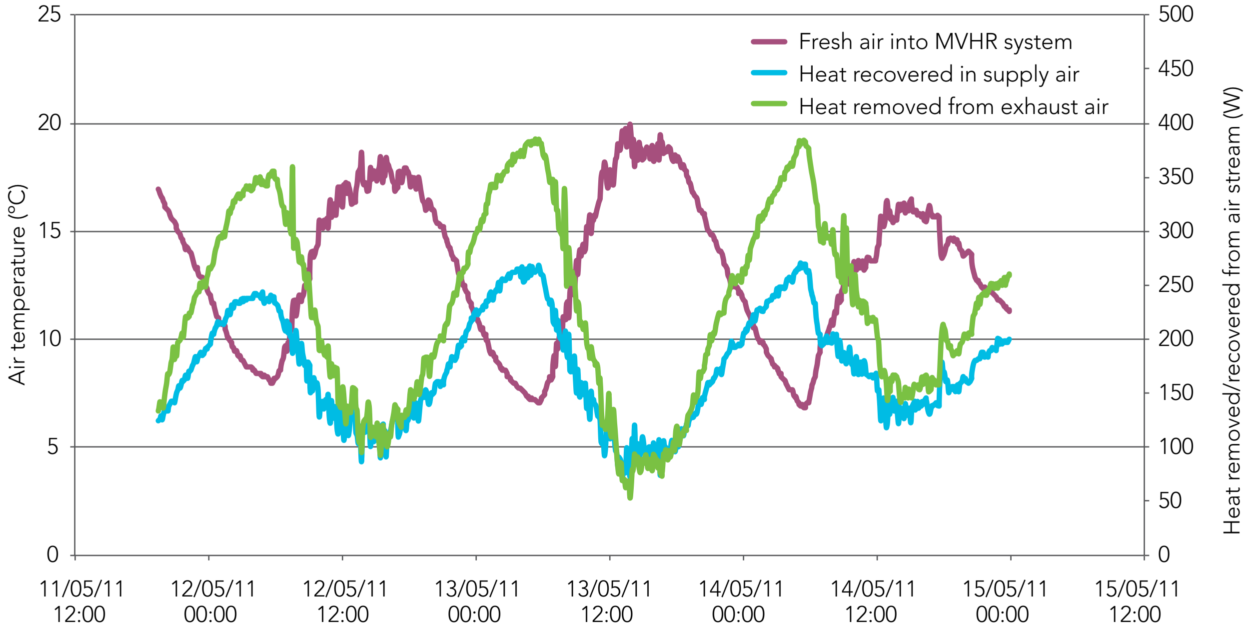


Figure 27 Comparison of heat removed from exhaust air and that recovered in supply air in mid-May

Figure 29 shows the effect of heat losses from extract air as it passes through the duct from the bathroom to the MVHR fan unit. As the temperature of the loft decreases, the drop in temperature of the extract air passing through the duct increases.

This fall in temperature as the ventilation air passes through the ductwork in the unheated loft not only increases the heating load of the house, but also results in the living rooms being supplied with air that is relatively cold. The data presented in Figure 28 and Figure 30 is over a period when the external air temperature fell to below zero. This data shows clearly that in periods of cold weather, when the loft was cold, the supply air to the bedrooms became uncomfortably cold.

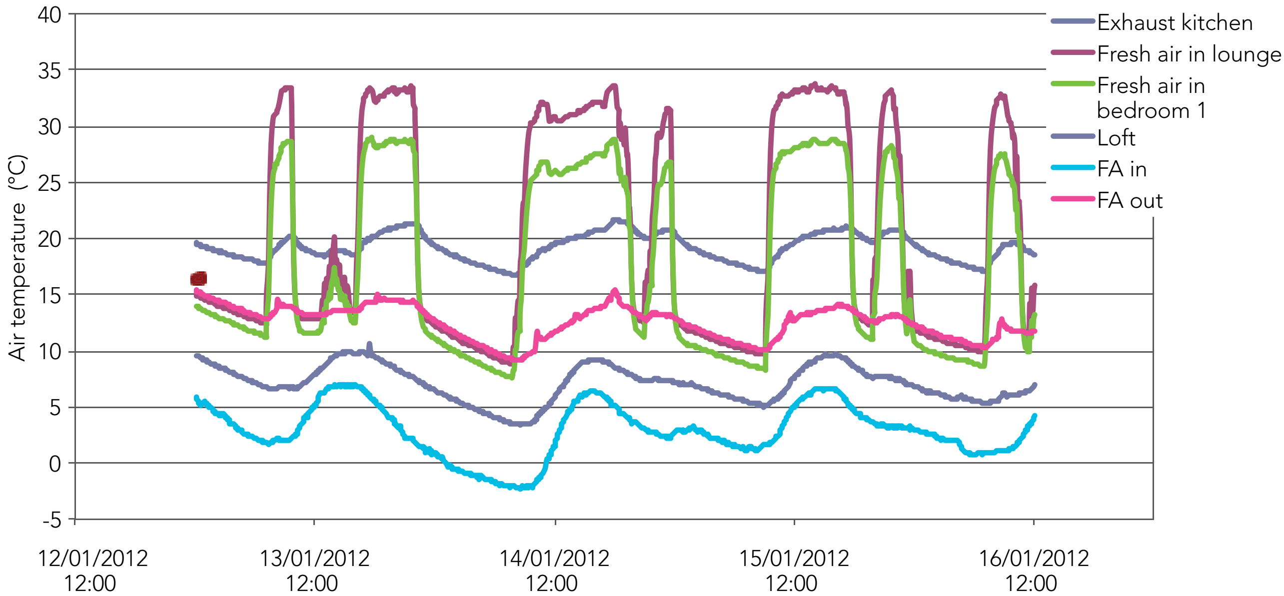


Figure 28 Comparison of supply air temperature (fresh air [FA]) – on leaving MVHR fan unit and on delivery to bedroom one

From Figure 30 it is clear that when the post heater is not running there is a strong correlation between the supply air temperature and the loft air temperature. This reinforces the argument that while the heat exchanger is itself able to recover up to 90% of the heat from the extract air, a very significant percentage of heat from the extract air and the supply air is then lost, both through the MVHR fan unit casing and through the ductwork as it is delivered to the living rooms. The effect of these losses on the system installed in Home 9 is that when the loft air temperature is around 5°C or below, the supply air temperature to the living rooms falls to below 10°C. Air supplied into a warm room at this temperature will tend to dump unless the supply air valve has been very carefully commissioned. If this is not the case then the supply air will be noticed as a cold draught and result in discomfort. In some cases it is possible that such discomfort may lead to an occupant turning the MVHR system off.

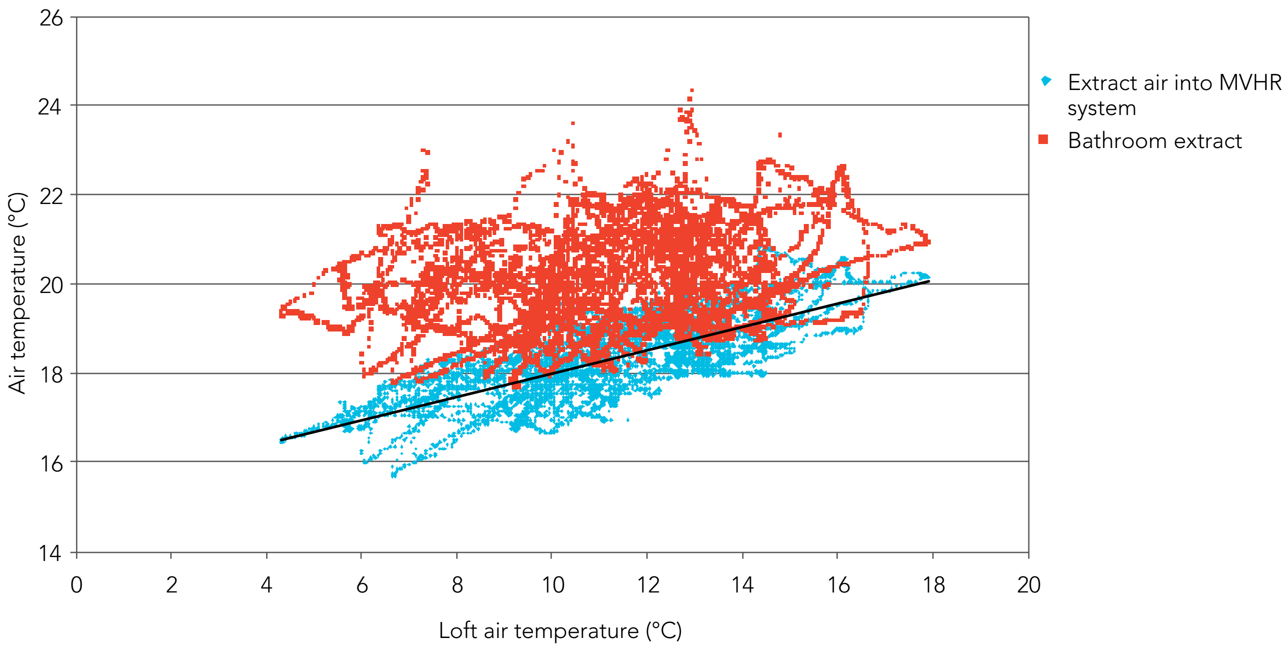


Figure 29 Comparison of bathroom extract air temperature as it leaves the thermal envelope and as it enters the MVHR fan unit, as a function of loft air temperature

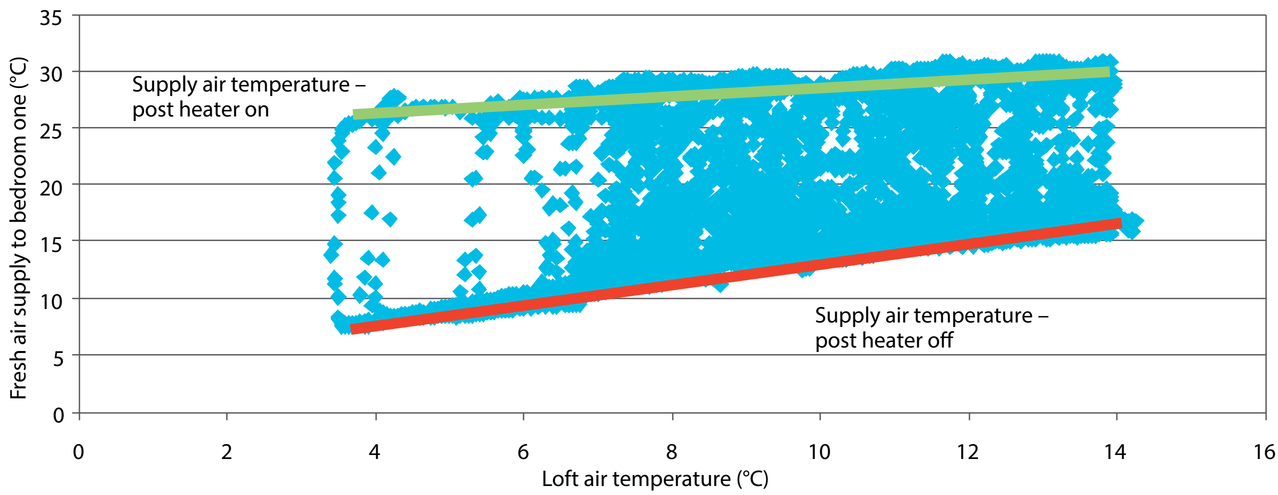


Figure 30 Relationship between supply air delivered to bedroom one and loft air temperature

### 4.5.2 Freezing on the heat exchanger

During February 2012 the outside air temperature dipped to below freezing for periods of up to 24 h. It was noticed from the monitoring that the MVHR system characteristics changed very significantly as the air temperature fell below -2°C. Figure 31 shows one period of cold weather where the outside air temperature fell to around -7°C and remained below zero for 18 h.

From Figure 31 it is clear that as the outside air temperature falls below -2°C the temperature of the fresh air out of the MVHR fan unit starts to fall. When the outside air temperature reaches -5°C the fresh air out of the MVHR fan unit falls very rapidly. This is accompanied with a very sharp fall in thermal efficiency of the MVHR system. These changes in performance are due to the heat exchanger freezing. As this happens the extract air flow rate falls, this reduces the temperature of the supply air, and therefore also the apparent thermal efficiency. As the outside air temperature increases above freezing the system reverts to its original level of operation.

The original MVHR fan units installed in all the homes did not have any means of countering the freezing of the heat exchanger and had the outside air temperature stayed below freezing for a long time, the extract air flow rate would have fallen to almost zero – with the associated IAQ risks.

### 4.5.3 Summary of findings: thermal performance of the MVHR system

- **MVHR fan unit location:** The installation of the MVHR fan unit in the unheated loft demonstrated graphically the heat loss from the casing of the fan unit. The testing of fan units to determine thermal efficiency does not currently require casing losses to be taken into account, however it is suggested that where levels of casing insulation are not high the fan unit should not be mounted outside the insulated envelope.
- **Heat loss from ductwork:** Heat losses from the ductwork in these homes are very significant. This is a function of both the very long lengths of duct mounted in the unheated loft and the level of insulation applied to the duct. Although the insulation thickness meets the present requirements of AD L1A its effectiveness as a means of ensuring heat loss is inadequate.

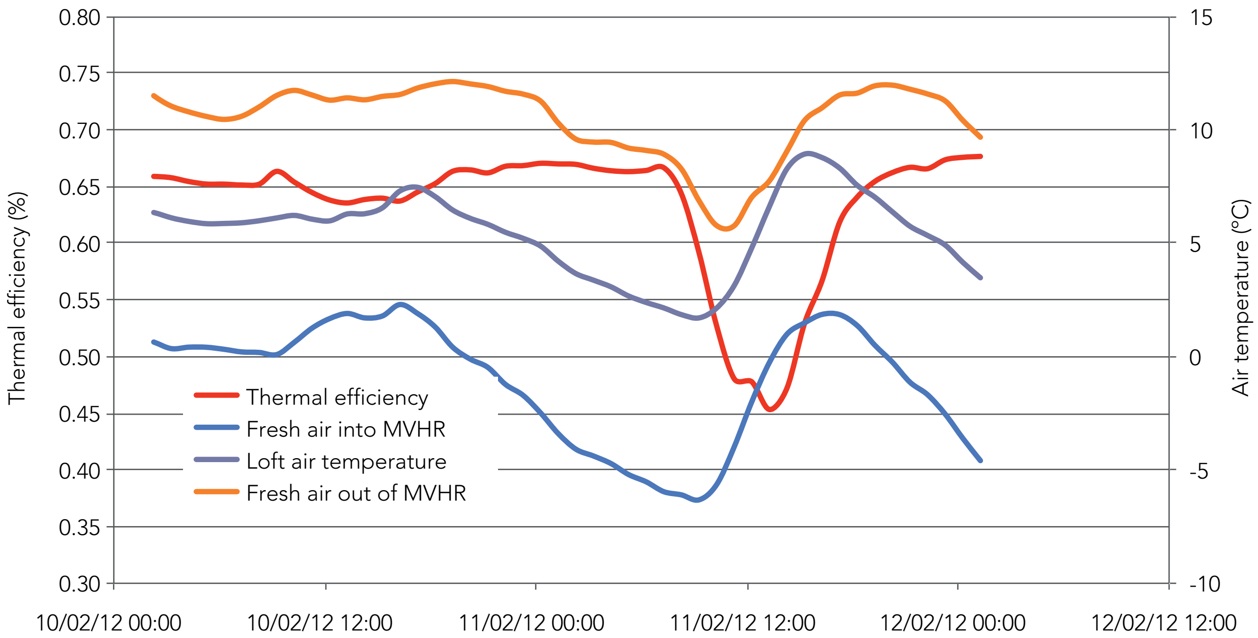


Figure 31 Operation of the MVHR system over a period of freezing weather for Home 9, February 2012

- **Lack of frost protection:** The total lack of any frost protection function on the MVHR fan units installed resulted in the heat exchanger freezing during a cold period. This led to very cold air being delivered into the home. In the UK generally a frost protection measure may not be required often, but failure of the MVHR fan unit to recover any heat at the coldest periods of the year could be very uncomfortable and even dangerous to some members of society. In cold areas of the UK the measure may be required for extended periods (weeks, rather than months as required in parts of continental Europe).

## 4.6 Replacement of the MVHR fan unit

As part of the BRE recommissioning process to increase the performance of the systems, it was agreed that one of the MVHR fan units should be replaced with the aim of addressing the identified deficiencies in thermal performance. It was proposed that in Home 1 the MVHR fan unit would be replaced and the loft ductwork re-insulated to establish whether an MVHR fan unit located in the loft could be made more thermally efficient. The location of the duct penetrations through the loft floor could not be modified. Therefore overall the layout of the ducts within the loft could only be slightly modified. To ensure that the air flow rates could be met for this larger three bedroom home, a larger MVHR fan unit was installed. The product chosen also included a summer bypass (allowing all the supply air to divert around the heat exchanger), frost protection, local RH and $CO_2$ sensors for activating boost, and a remote control to allow occupants to activate boost as required from anywhere within the home.

To minimise the ductwork air flow resistance, with the aim of minimising the fan power required to ventilate the home, it was proposed to replace sections of the loft duct runs with larger 150 mm diameter duct. At the same time it was proposed to upgrade the insulation of the ductwork as far as practicable to minimise the ductwork heat losses. A search of the 'off the shelf' insulation that is available in the UK for application to either 125 or 150 mm diameter ventilation duct revealed that there were very few products, and nothing that increased the insulation level of the ductwork significantly above the 25 mm of foil-backed mineral fibre that was initially installed.

Instead a proprietary product was used which comprised a pre-insulated duct with a wall thickness of 16 mm and a thermal conductivity of 0.041 W/mk. The existing ductwork was wrapped in bubble wrap before being fed through the pre-insulated duct (Figure 32a).

Although this increased the insulation value of the duct by a minimum of 100%, it is not a practical solution for normal installations as it proved to be both time consuming to install and, due to the cost of the insulated duct, an expensive option. Nonetheless other ways of achieving this increase are available.

The loft after the modifications to the ductwork is also shown in Figure 32b.

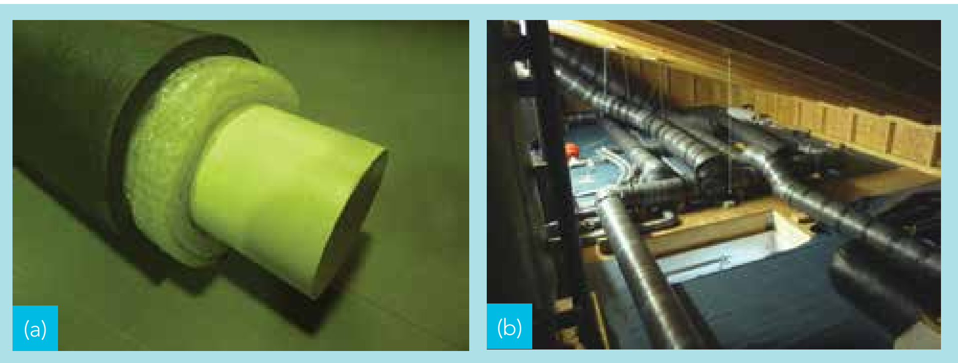


Figure 32 (a) Duct insulation; 125 mm duct wrapped in bubble wrap inside 180 mm pre-insulated duct, (b) loft ductwork layout and insulation after remedial works

## 4.7 Results following remedial works

### 4.7.1 Fan power in Homes 2 to 10

Following the BRE recommissioning of the MVHR fan units in Homes 2 to 10 during October 2011 it was hoped that there would be a marked fall in the energy use by the MVHR fan units. Figure 33 and Figure 34 show the results over eight months across the period of the recommissioning. From Figure 33 it is evident that in Homes 2 to 6 energy use did fall after the recommissioning with all the homes being below 30 kWh per month. However, it is evident that in Home 5 the MVHR fan unit reverted to running at boost speed for a significant percentage of the time.

From Figure 34 it is evident that there was a much smaller reduction in energy use in Homes 1 and Homes 7 to 10. It is clear that none of the fans was running at over 50 kWh per month, equivalent to 70 W, the maximum power that the installed MVHR fan units run at when in boost mode.

Homes 7, 8 and 10 all experienced periods when one or both of the fans in the MVHR fan units failed and required replacement. This makes the monthly figures difficult to interpret, but overall the reduction in fan power is modest since the MVHR fan units are still running at very close to their maximum air flow rates, requiring the fans to run hard.

### 4.7.2 Fan power in Home 1

Following the replacement of the MVHR fan unit in Home 1 with a significantly larger fan unit, it was hoped that the energy use would fall due to the fans being able to handle the relatively high air flow rate without having to run near to their maximum speed. Figure 35 confirms that the new, larger MVHR fan unit's energy use was significantly lower (around 50%) than that of the original fan unit.

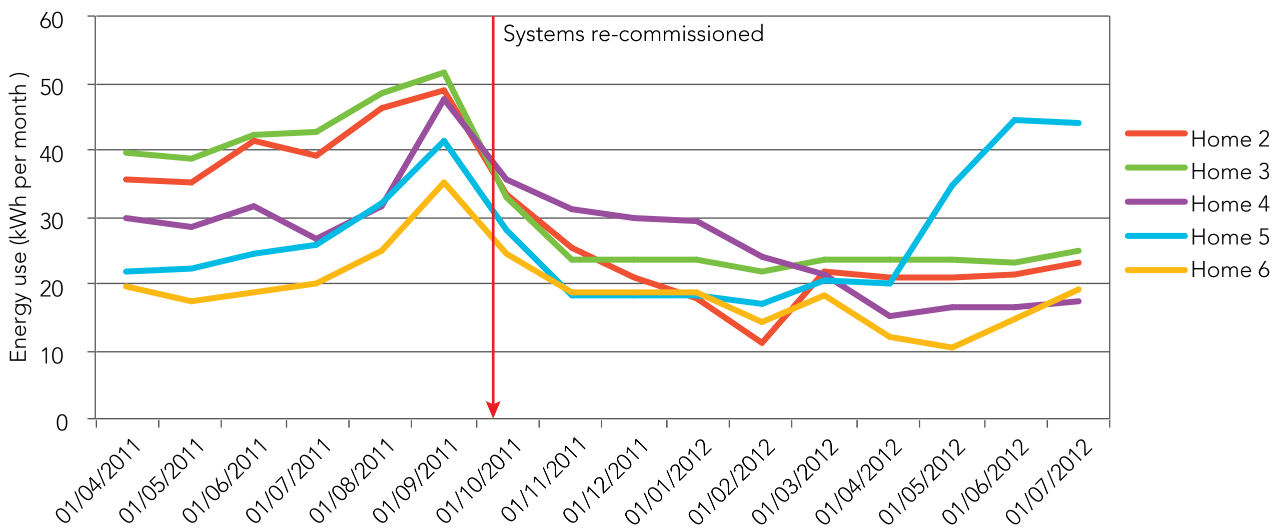


Figure 33 Energy use before, during and after the period of remedial work (October 2011) for Homes 2 to 6

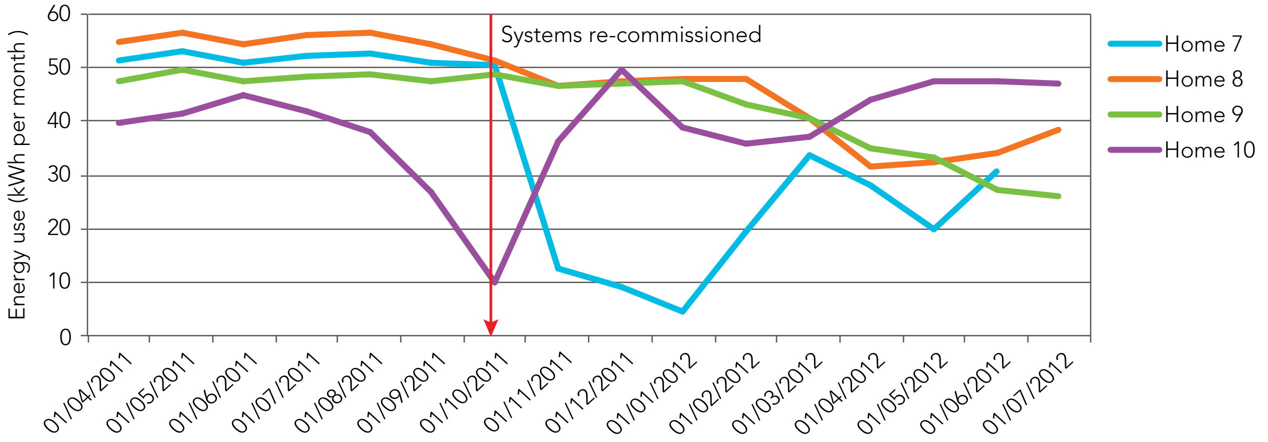


Figure 34 Energy use before, during and after the period of remedial work (October 2011) for Homes 7 to 10

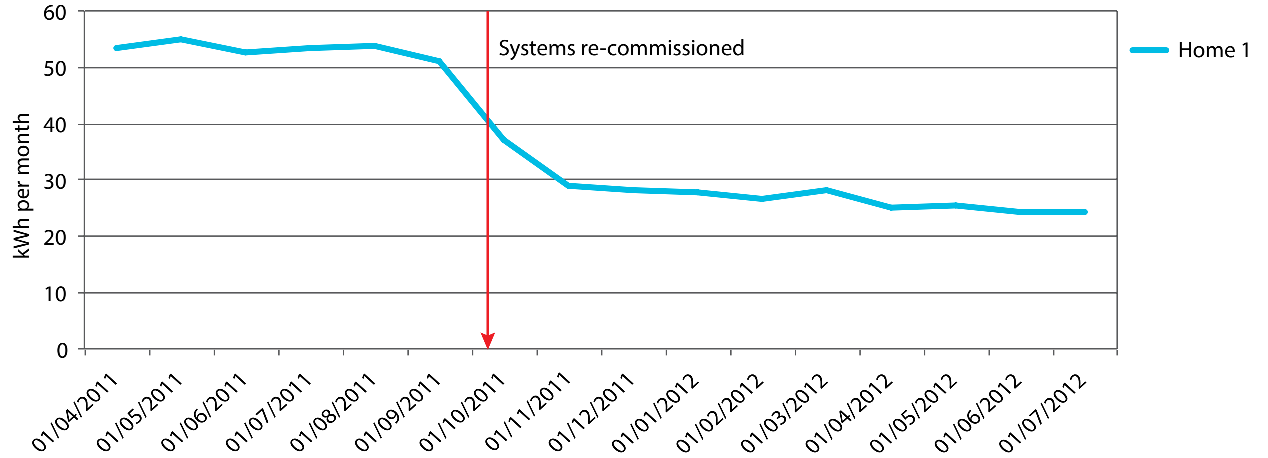


Figure 35 Energy use before, during and after the period of remedial work (October 2011) for Home 1

## 4.8 Comparison of the MVHR fan unit thermal performance in Homes 1 and 9

Detailed monitoring was undertaken in Home 9 over the winter of 2011/12 with the aim of establishing the effectiveness of the MVHR fan unit installed in an unheated loft. Following the replacement of the MVHR fan unit in Home 1, the detailed monitoring instruments were moved from Home 9 to Home 1 to allow this system to be monitored.

Comparison of the calculated thermal efficiency of the MVHR fan units installed in Home 1 and Home 9 can be seen in Figure 36. From this data recorded over the winter and spring period of 2012, it is clear that the new, larger MVHR fan unit installed in Home 1 is significantly more efficient than the original fan unit installed in Home 9. Both of these MVHR fan units have been type-tested in a laboratory and achieved thermal efficiencies of around 90%. What is evident from the results presented in Figure 36 is that this efficiency is achieved only when the outside air temperature and the loft air temperature are at or above 20°C. This suggests that although the thermal performance of the casing of the new MVHR fan unit is significantly better than the original fan unit, it still loses up to 10% when installed in a cold loft.

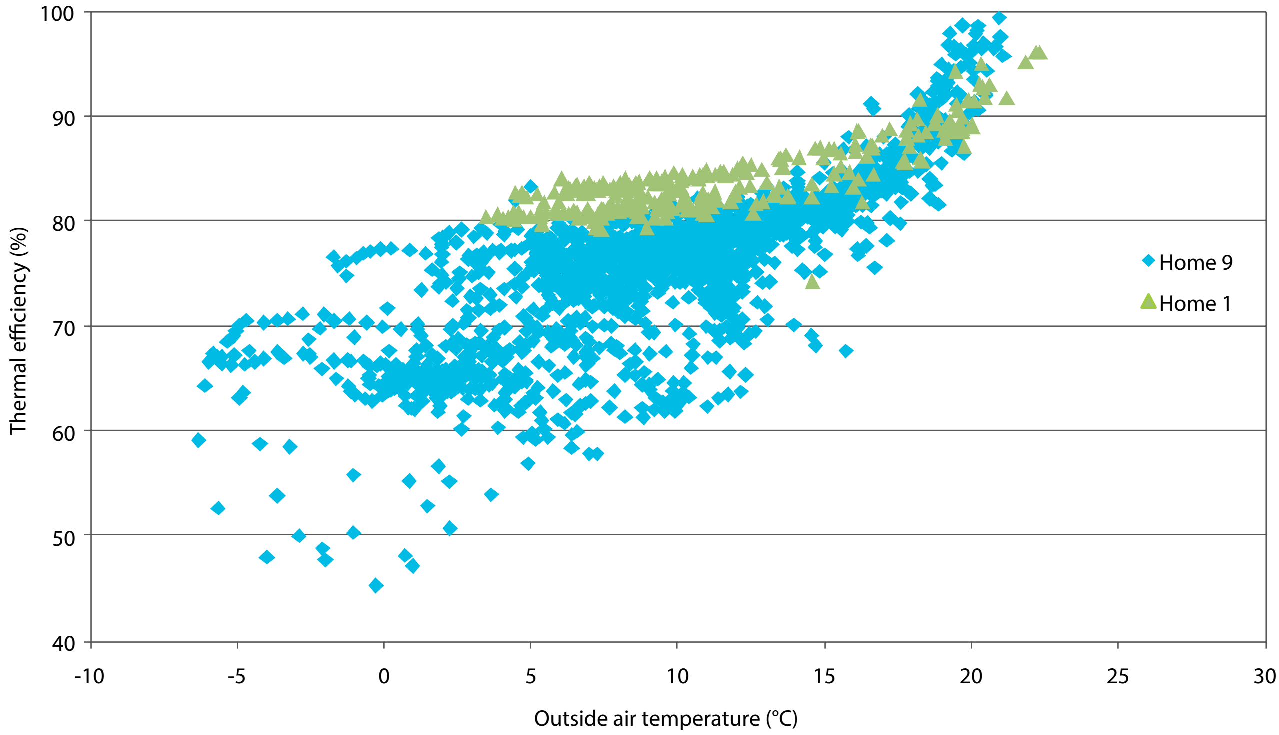


Figure 36 Thermal efficiency of MVHR fan units for Homes 1 and 9

An evaluation of the effect of having significantly increased the insulation of the ductwork installed in the loft of Home 1 revealed that the overall heat recovery rate of this system was not significantly better than that in Home 9, where the ductwork was insulated with the original 25 mm of mineral fibre insulation. The calculated losses from the ductwork and MVHR fan unit in Homes 1 and 9 are shown in Figure 37 and Figure 38. One factor that increased the heat loss from the ductwork in Home 1 was the increase in diameter of the ductwork. This measure was undertaken in order to reduce the fan power, but had the effect of increasing the heat loss area of the duct and therefore the overall heat loss.

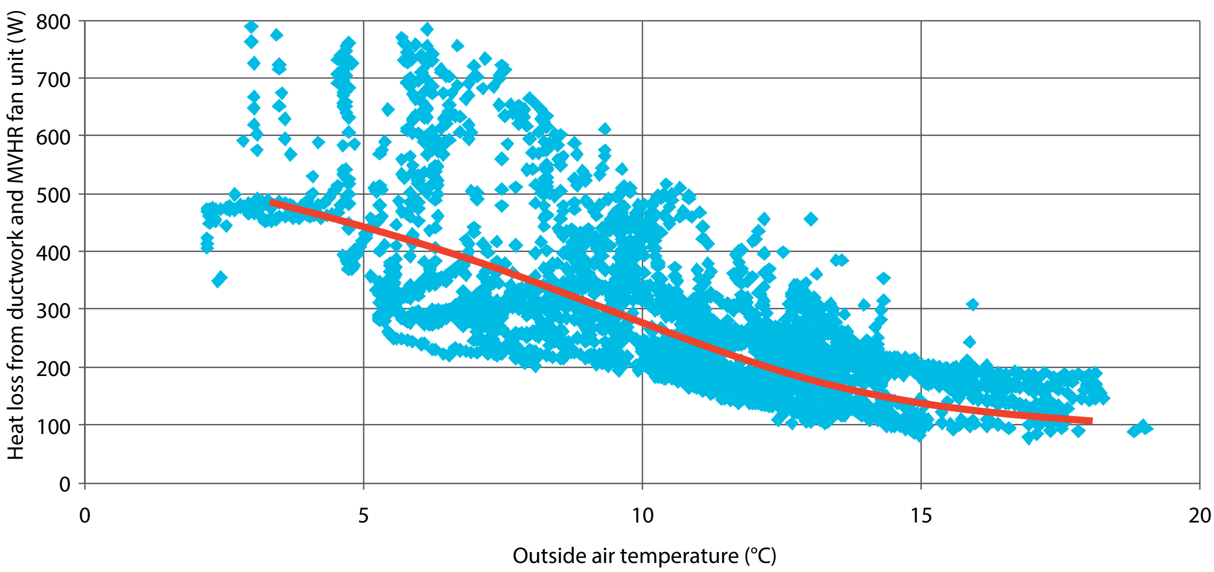


Figure 37 Heat loss from ductwork and MVHR fan unit for Home 9

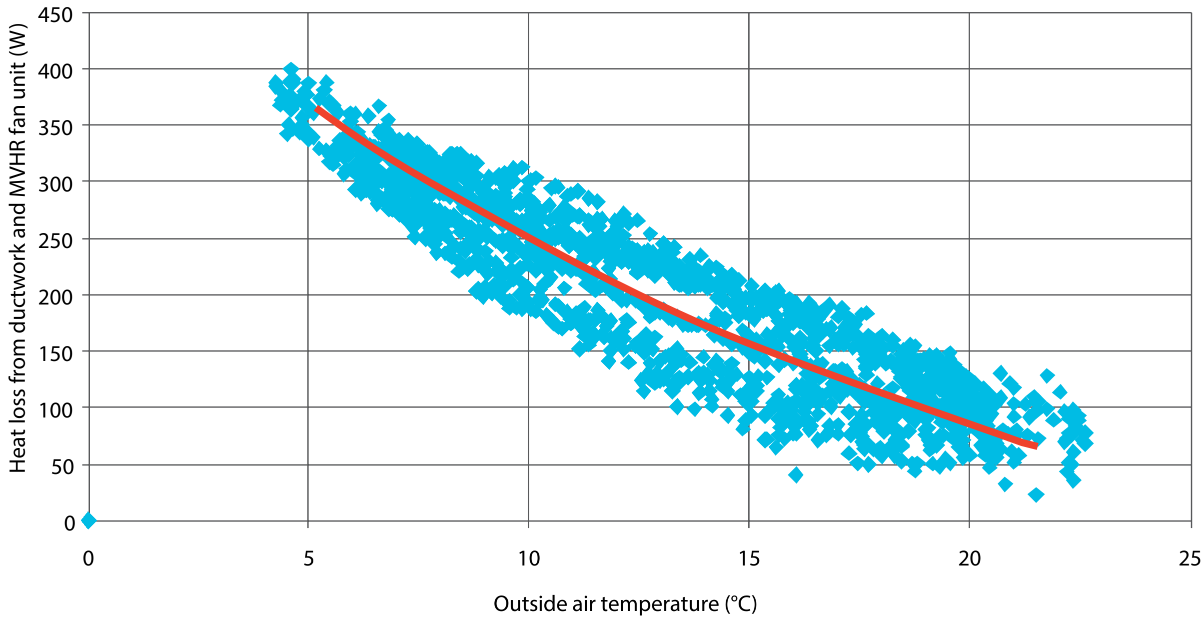


Figure 38 Heat loss from ductwork and MVHR fan unit for Home 1

### 4.8.1 Summary of findings: measures to increase the MVHR fan unit performance

- **Increasing the size of the MVHR fan unit:** The installation of an MVHR fan unit that was able to deliver background ventilation at below 50% fan speed resulted in a very significant drop in fan power. The original MVHR fan unit was not running efficiently at near maximum speed, re-enforcing the idea that MVHR fan units should be sized to meet the required range of flow rates well within their operating envelope, and not need to run at maximum speed in any normal mode of operation (background or boost).
- **Commissioning of air valves:** The importance of commissioning the supply and extract air valves is very clear when the fan power reductions in the flats and two bedroom houses are reviewed. In these homes the MVHR fan unit moves from running at close to maximum speed to the midpoint of its operating range. However, commissioning must consider the thermal comfort of the occupants and air valves must not be opened fully to minimise duct pressures, as that would result in air dumping, causing cold draughts.
- **Insulation of ductwork in unheated spaces:** The relatively small change in overall performance of the system when the insulation of the ductwork was increased very significantly highlights the fact that any ductwork running through an unheated space loses a lot of heat if the temperature difference is great. The only conclusion that can be drawn from this is that all ductwork located in unheated spaces must be insulated well beyond the requirements of the AD L1A minimum, but also that the length of the ducts must be minimised. Placing the MVHR fan unit within the heated envelope would overcome much of the heat loss and associated thermal comfort shortcomings, but would require that the ductwork carrying cold outside and exhaust air to be very carefully insulated to ensure that no condensation occurred on the outside of this ductwork.

## 4.9 Occupant feedback on noise and the ventilation system

### 4.9.1 Noise

As detailed in Section 3.3, occupant surveys were undertaken in February 2011 (following the first winter of occupation), in September 2011 (following the summer non-heating period) and in April 2012 to cover the 2011 to 2012 heating season and parts of autumn 2011 and spring 2012. Noise generated by the MVHR system in homes has been highlighted as being a very important issue[7]. Therefore this became one of the key areas of investigation.

The results of the first survey revealed that the occupants generally thought that the homes were quiet when considering noise transference from outside; however most occupants reported hearing a lot of noise from the home itself. These noises seemed to be mainly coming from the MVHR system and the greywater recycling system associated with the shower. Many reported they could only hear the MVHR system when they were upstairs and that in certain bedrooms it sounded louder than in others. Several occupants, from different homes, reported hearing the MVHR system start up or change sound during the night. Overall this resulted in the MVHR system being listed as one of the 'worst things about the house' in the occupant surveys. The change in noise during the night can be traced back to the boost control being installed and left set at 60% RH. During the day the loft air temperature is high enough to minimise the heat loss from the extract ductwork, but at night the loss increases and the extract air cools, increasing the RH to 60% overnight. In this event the MVHR fan unit would then go into boost speed and not revert to normal operation until the following day as the loft air temperature rose.

During the second survey all occupants rated the noise as much less of an issue. However, most did reveal that they used windows for ventilation, with many being left open overnight during hot periods to assist cooling.

The third survey followed the BRE recommissioning of October 2011, where all of the supply air valves had been changed and the fan speeds adjusted accordingly. The occupants were asked to rate how much noise they could hear from their MVHR system (both prior to and after the recommissioning work) on a five point scale that ranged from 'Nothing' to 'A great deal'. Figure 39 shows the percentages of respondents who marked each point on the scale. As is clear from Figure 39, the perceived noise generated by the MVHR system significantly reduced after the recommissioning and modification work conducted in late 2011.

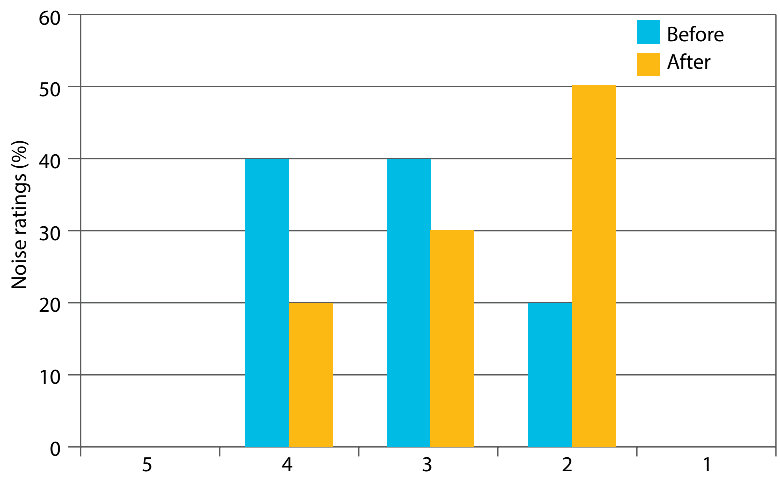


Figure 39 Ratings of noise from the MVHR system before and after recommissioning work from 'Hear a great deal' (5) to 'Hear nothing' (1)

In the focus group in April 2012, the reduction in noise from the MVHR system was listed as one of the best things about their homes since the last survey. The occupants generally reported that the noise was lower and less noticeable. These occupant perceptions are backed up by the results of noise monitoring carried out in the homes before and after the BRE recommissioning and remedial works.

In the CIBSE *Environmental Design, Guide A*[11] the guidance suggests noise rating (NR) limits of 30 for living rooms and 25 for bedrooms. It is noted that the A-weighted equivalent continuous noise level (in dB, as normally measured) approximates to NR + 6. The smallest change in noise level that the human ear can detect is generally considered to be 1 dB.

Analysis of the acoustic data obtained in autumn 2011 prior to the remedial works on the MVHR system showed that 53% (23 of 43) of the rooms measured failed to perform within the limits provided in CIBSE *Environmental Design, Guide A*. This is in contrast to the post-works measurements, in which only 8% of rooms (3 of 38) failed to achieve the CIBSE limits; all of these rooms were in Home 7. Pre-works, those rooms which failed to satisfy the CIBSE criteria failed by 0 to 10 dB, with an average failure of 3.4 dB. Following the works, the range of failure was reduced to between 0 and 3 dB, with an average failure 0.7 dB.

In Home 1 the installation of an acoustic attenuator (duct-mounted silencer) as well as changing the supply air valves and installation of a larger MVHR fan unit were expected to make a very significant difference to the sound levels throughout the home. The results for the acoustic tests before and after the remedial works show that the level of noise reduction was significant and made the system in this home one of the quietest.

### 4.9.2 Ventilation system and thermal comfort

The surveys covered included occupants' overall responses to the temperatures in their homes, their thermal comfort and their overall impressions of the ventilation of the homes.

The results of the first occupant survey revealed that the occupants generally thought that the temperatures within the homes were comfortable, but noted that the bedrooms were cooler than the other rooms. The MVHR systems were criticised heavily for their noise, but also for the lack of any 'feedback' to the occupant. The occupants understood what the systems were meant to be doing, but could not ascertain if they were actually running correctly as there was no control or indication of any form. The draughts caused by the MVHR systems were noted by most occupants as causing discomfort, with the logic of locating the supply air valves directly over the beds being questioned.

During the second survey over the summer period the occupants commented that all the homes were hot. Over the summer period the MVHR systems remained in operation, but most occupants also opened the windows to boost the ventilation rate. Clearly the role of the MVHR system in providing cooling in these homes is limited due to the low flow rates at which they operate.

The third survey, over a winter period again (2011 to 2012), revealed that in the homes the bedrooms were consistently colder than the living room downstairs. The temperature of the air delivered to the bedrooms during the cold period in February was reported as being 'freezing'. Following the BRE recommissioning the reported draughts reduced, but the occupants still commented that the location of the air valves above the beds was inappropriate. The temperature of the supply air across the February 2012 period in one home can be seen in Figure 40, where it is evident that its temperature is very cold for much of the month. The post heater provides sufficient heat to maintain the rooms at a comfortable temperature, but it is operated on an intermittent basis according to the living room thermostat, and so this results in periods when cold air is delivered to the rooms.

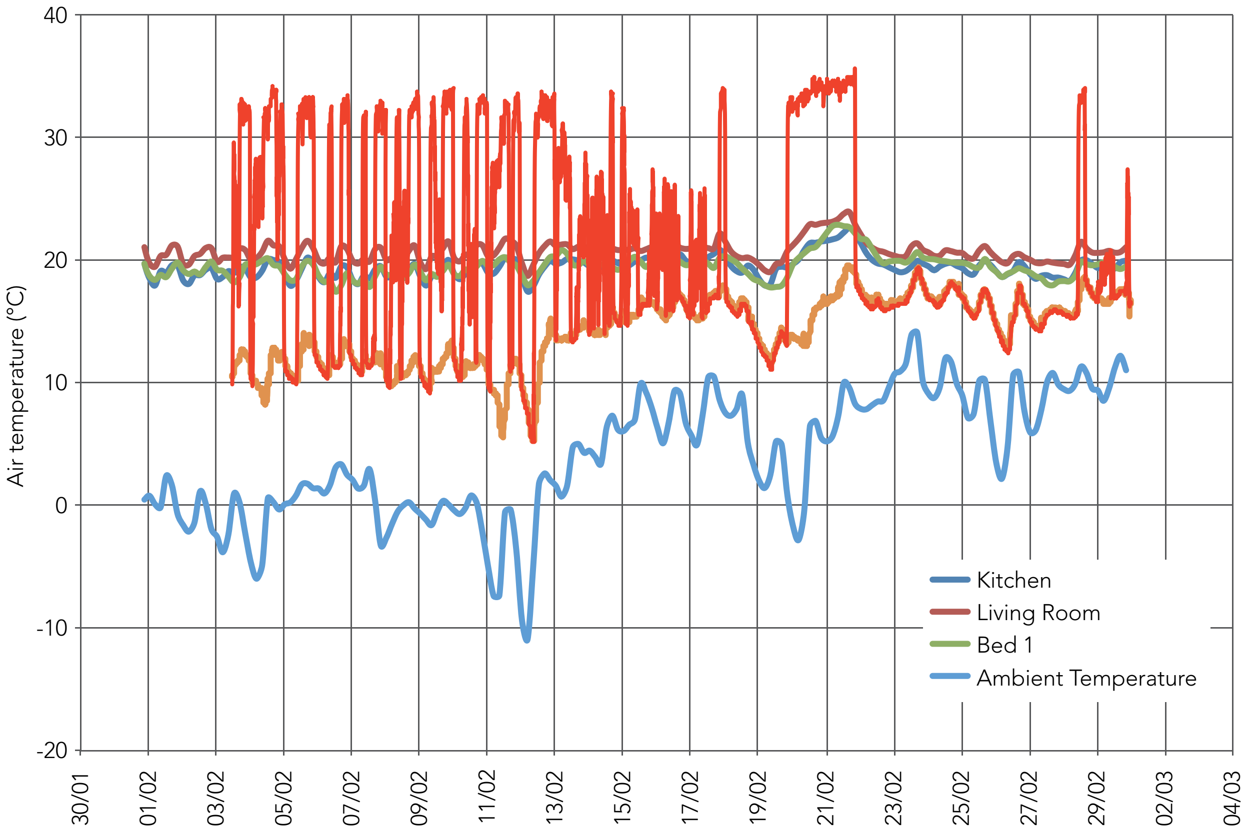


Figure 40 Room air and supply air temperatures across a cold period, February 2012

### 4.9.3 Summary of findings: occupant feedback

- **Initial perceptions of the MVHR system:** The majority of occupants had some understanding of what the MVHR system was meant to do, but did not like having little or no control over it and often not knowing whether or not it was working properly (or indeed at all). Draughts from air dumping in bedrooms were a common cause of complaint.
- **Ventilation and thermal comfort:** Taking all environmental factors into consideration, all of the respondents said they generally found their homes comfortable, and the proportion of respondents who described their homes as 'generally comfortable' increased from 76% to 86% to 100% at successive surveys. This suggests that the occupants had gradually settled into their homes and also that the interventions and improvements made to the MVHR system had made a difference for the better in terms of comfort.
- **Sensitivity of occupants to continuous mechanical noise:** The MVHR fan units initially installed in the homes were running at close to maximum fan speed. This resulted in the systems being very noisy; this was noticed and became annoying to nearly all the occupants. The variation in speed and thus noise was also noted as being an issue. When location of MVHR fan units and acoustic treatment is being considered in very energy efficient homes, one result of such good thermal performance of doors and windows is that they are acoustically very good. This means that in such homes there is often no ingress of noise from outside, making any internal noise more apparent.

- **Reduction in noise levels to within CIBSE guidelines:** The BRE recommissioning allowed the MVHR system to be slowed and the noise levels reduced for most homes to within the CIBSE guidelines. This improvement was noted as being very significant and resulted in the occupants commenting that they could hardly hear the fan units running. This suggests that the CIBSE guideline figures provide a good basis for acoustic design of these products in energy efficient homes.

# 5 Indoor environments

## 5.1 General indoor air quality

As mentioned earlier in this report people in developed countries spend typically over 80% of their time indoors, and certain vulnerable groups of the population spend almost all of their time indoors. Good quality indoor air is therefore vital for the comfort, health and wellbeing of occupants. Indoor air can often be contaminated with pollutants from sources in the indoor environment itself as well as from pollutants that have migrated indoors from outdoor sources, via building infiltration and ventilation processes (see Figure 41).

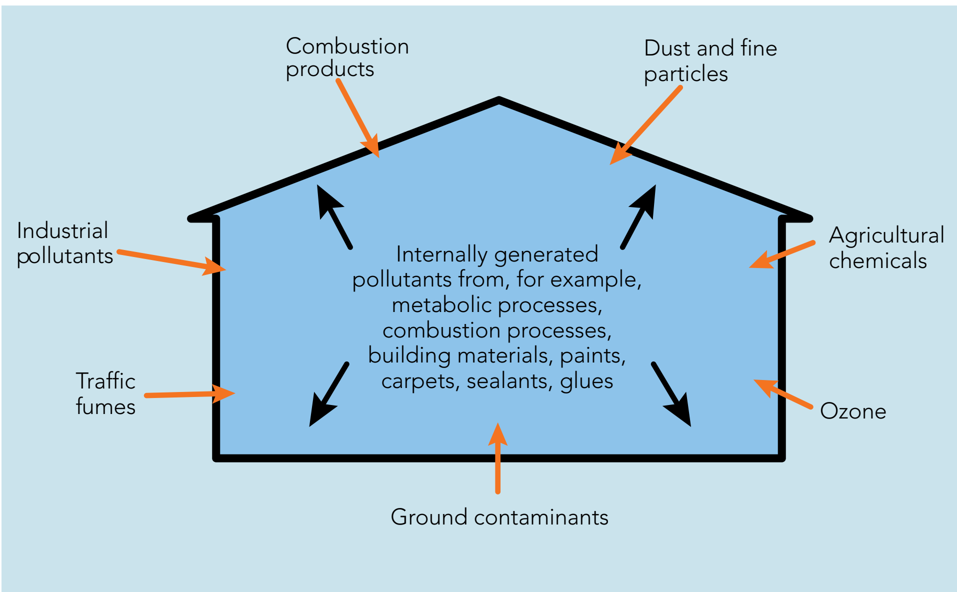


Figure 41 Examples of typical sources of pollutants found inside homes

Many factors have the potential to affect IAQ including the type and use of building, its décor and furnishings, how it is heated and ventilated, and crucially the activity and behaviour of its occupants. The drive to make homes more airtight, and therefore more energy efficient, has the potential to lead to the worsening of IAQ where effective ventilation with fresh air is not achieved. In these circumstances occupants may be exposed to a variety of airborne pollutants, including organic, inorganic and biological substances (in gaseous and particulate forms).

For the purposes of this study the following IAQ parameters were monitored:

- Carbon dioxide ($CO_2$)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs)
- Formaldehyde
- Whole-home ventilation rate.

Spot measurements of each parameter were made in each of the 10 homes in three locations (kitchen, living room, master bedroom) on four occasions: September 2010 (prior to occupation); February 2011, July 2011 and March 2012. The significance of the parameters measured, test methods used and results obtained are summarised below:

**Carbon dioxide** ($CO_2$) is a colourless, odourless gas, and a bio-effluent, whose concentration is a good indicator for the efficacy of ventilation. $CO_2$ was measured using an NDIR (non-dispersive infrared) monitor, and only in two cases was the measured level found to be in excess of 1000 parts per million (ppm), which is the concentration above which some building occupants will begin to find conditions 'stuffy' or uncomfortable due to high occupancy and/or poor ventilation. The highest $CO_2$ concentration found was 1120 ppm in a bedroom in February 2011.

**Carbon monoxide** (CO) is a colourless, odourless gas, produced by the incomplete combustion of most fuels. Incomplete combustion can occur, for example, when inadequate ventilation to an appliance results in depletion of the oxygen content of the air at the point of combustion. CO was measured using an electrochemical monitor and was not found at anything above trace levels in the homes on any occasion.

**Volatile organic compounds** (VOCs) are emitted over periods of weeks or years from construction and furnishing products and have the potential to cause poor IAQ. When concentrations of VOCs are determined in indoor air the total volatile organic compounds (TVOCs) value is defined as the sum of VOCs between n-hexane and n-hexadecane detected by gas chromatography column (quantified as toluene). The relevant IAQ guideline for VOCs is the performance criteria for buildings, including homes, set out in the Building Regulations (Approved Document F: Ventilation 2010)[9], that TVOC should not exceed 300 $\mu g\ m^{-3}$. There are no guidelines for concentrations of specific VOCs in homes or other indoor buildings (except for benzene), but throughout Europe the guidelines for acceptable TVOC concentrations in indoor air range from 200 to 500 $\mu g\ m^{-3}$. In an IAQ survey of 876 UK homes carried out in 1998 to 1999 the geometric mean concentration of TVOC was found to be 210 $\mu g\ m^{-3}$ (in main bedrooms)[12].

Concentrations of VOCs in air were determined by pumped sorbent tube sampling and thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) analysis according to the international standard method BS ISO 16000-6[13]. The results obtained are given in Table 5.

Table 5 Summary of TVOC[a] results

| Home no. | Mean TVOC concentration (μg $m^{-3}$)[b] | | | |
|---|---|---|---|---|
| | September 2010 | February 2011 | July 2011 | March 2012 |
| 1 | 247 | 425 | 265 | 218 |
| 2 | 643 | 275 | 133 | 140 |
| 3 | 555 | 214 | 184 | 302 |
| 4 | 571 | 436 | 354 | 238 |
| 5 | 3810 | 291 | 228 | 210 |
| 6 | 591 | [c] | 373 | 254 |
| 7 | 469 | 234 | 337 | 177 |
| 8 | 495 | 1380 | 120 | 322 |
| 9 | 827 | 400 | 188 | 182 |
| 10 | 1770 | 261 | 420 | 103 |

(a) TVOCs quantified as toluene.
(b) Mean of results obtained from three locations in the home.
(c) No measurement.

The post-construction VOC sampling was carried out at the same time as painting, sealing and other post-second fix finishing was taking place. Therefore the results obtained must be considered in this context, although it is worth noting that the first occupants moved in just over two weeks later. The TVOC levels measured were generally well above the acceptable range for indoor air, but this is certainly in a very large part due to materials and substances used during the very recently completed (or still in progress) building and decoration works. In particular, white spirits could often be smelt at the time of the testing, and the characteristic 'signature' of this mixture of hydrocarbons dominated the VOC samples. In addition, significant quantities of coalescing agents present in emulsion paints were detected.

During the course of the 18-month monitoring period the TVOC levels generally decreased with time in all of the homes, and by March 2012 the samples taken showed that the AD F guideline of 300 μg $m^{-3}$ was being met in eight of the homes, with the other two just above this level. As expected the contribution to the total VOC load from substances associated with building products, furnishings and finishes decreased over time, while concentrations of those compounds associated with occupant behaviour generally increased. Examples of the latter include compounds used in aerosols, cosmetics, and fragrances used in cleaning and personal care products.

**Formaldehyde** is a very volatile organic compound (VVOC) that has been widely studied with regard to indoor air because of its release from a range of building and consumer products. The relevant guideline set for formaldehyde is the WHO recommended IAQ guideline of 100 μg $m^{-3}$ averaged over 30 min[14]. In an IAQ survey of 876 UK homes carried out in 1998 to 1999 the geometric mean concentration of formaldehyde was found to be 22.2 μg $m^{-3}$ (in main bedrooms)[12].

Concentrations of formaldehyde in air were determined by pumped cartridge sampling and high performance liquid chromatography analysis according to the international standard method BS ISO 16000-3[15]. The results obtained are given in Table 6. In only two individual cases was the WHO guideline exceeded, these being in individual rooms in Homes 5 and 10 during the sampling undertaken immediately post construction, and probably due to emissions from new materials used in the homes. In all homes except Home 1 the levels of formaldehyde have been seen to diminish over the course of the monitoring period as expected with time. By March 2012 all formaldehyde levels found were in the range expected for UK homes.

Table 6 Summary of formaldehyde results

| Home no. | Mean formaldehyde concentration ($\mu g\ m^{-3}$)[(a)] | | | |
|---|---|---|---|---|
| | September 2010 | February 2011 | July 2011 | March 2012 |
| 1 | 19 | 38 | 52 | 30 |
| 2 | 52 | 23 | 27 | 22 |
| 3 | 40 | 28 | 34 | 26 |
| 4 | 37 | 51 | 55 | 25 |
| 5 | 91 | 31 | 30 | 22 |
| 6 | 24 | (b) | 48 | 23 |
| 7 | 48 | 36 | 76 | 32 |
| 8 | 37 | 33 | 27 | 23 |
| 9 | 55 | 33 | 37 | 17 |
| 10 | 71 | 25 | 61 | 21 |

(a) Mean of results obtained from three locations in the home.
(b) No measurement.

**Whole-home ventilation rate:** Building Regulations AD F[9] provides guidance on satisfying the requirements of the Building Regulations by the provision of background, rapid and extract ventilation. A whole house ventilation rate of between 0.5 and 1.0 air changes per hour (ach) is considered to be normally sufficient to control the build-up of moisture[16]. Spot measurements of whole-home ventilation rate were undertaken on at least two occasions for each home construction using a tracer gas (butane) decay technique. The results are shown in Table 7. Although these measurements are very much 'snapshot' in nature, the whole-home ventilation rates found are mostly within the range considered to be sufficient to control the build-up of moisture and provide adequate fresh air.

Table 7 Summary of whole-home ventilation rates

| Home no. | Whole-home ventilation rate (ach) | | | |
|---|---|---|---|---|
| | September 2010[(a)] | February 2011 | July 2011 | March 2012 |
| 1 | 0.41 | 1.2 | – | 0.79 |
| 2 | 3.9 | – | 0.82 | – |
| 3 | 0.26 | 0.89 | – | 0.94 |
| 4 | 1.0 | – | 0.56 | – |
| 5 | 0.56 | 1.1 | – | 0.98 |
| 6 | 1.4 | – | 0.74 | – |
| 7 | 1.3 | 1.1 | – | 0.71 |
| 8 | 0.70 | – | 1.1 | – |
| 9 | 3.2 | 1.0 | – | 0.69 |
| 10 | 1.7 | – | 0.56 | – |

(a) Testing carried out during snagging phase; in some cases doors opened by site workers will have affected the quality of results.

## 5.2 Temperature and humidity

Battery operated loggers with the capability to measure air temperature and RH every six minutes were deployed in four locations per home. The data recorded was used for comparison with occupant feedback on environmental conditions (see Section 5.4) and in the study of the efficacy of the MVHR systems (Section 4).

## 5.3 Cooking studies

As seen in Section 5.1, the indoor environment, as well as being affected by the ingress of external air pollution, also contains a range of airborne contaminants produced from building materials, furniture and human activities. One occupant activity of particular concern is cooking, especially when using gas as the fuel. In many previous studies, the use of gas appliances for cooking, especially in poorly ventilated kitchens, has been shown to produce high concentrations of particles, nitrogen dioxide, nitric oxide and other pollutants which are potentially deleterious to human health.

The show home at Greenwatt Way (Home 9) is a fully furnished three bedroom end of terrace house of masonry construction, in which visiting SSE staff and others spend short stays of occupation. A set of experiments to investigate the effects of cooking on IAQ was carried out in this home during the course of a week in July 2012.

The home's kitchen (part of an open plan ground floor) was fitted with an electric induction hob. The first set of tests was carried out using this appliance. The second set of tests was carried out after replacement of the electric hob with a gas hob. With both types of cooker hob, the same predetermined set of cooking activities was carried out. Sets of tests were carried out with the home's MVHR system operated at three settings as follows: normal mode; permanent boost mode and turned off. The three predetermined and repeatable cooking activities carried out by the same researcher were: boiling potatoes, frying breakfast and frying steak.

For each of the nine main tests the following air quality monitoring and testing were carried out at two locations – near to the cooker (at close to breathing height when standing to cook) and in the lounge area of the ground floor open-plan (at sitting height):

- Continuous monitoring of particulate matter ($PM_{10}$; $PM_{2.5}$; $PM_1$; ultrafine, ie 20 nm – 1 μm).
- Continuous monitoring of nitrogen dioxide ($NO_2$) and nitric oxide (NO) – collectively known as NOx.
- Continuous monitoring of carbon dioxide ($CO_2$) and carbon monoxide (CO).
- Continuous monitoring of temperature and relative humidity (RH).
- Spot measurements of volatile organic compounds (VOCs) by pumped tube sampling and thermal desorption gas chromatography-mass spectrometry.
- Spot measurements of formaldehyde by pumped cartridge sampling and high performance liquid chromatography.
- Measurements of whole-home ventilation rate using a butane tracer.
- Measurement of the air flows at all of the supply and extract vents in the home using a low-airflow-resistance balometer at each of the ventilation system settings used.

Figure 42 shows the BRE monitoring equipment deployed in the show home.

A summary of the IAQ data obtained for selected tests is given in Table 8. Since the levels of most contaminants were found broadly to be similar in the kitchen and lounge area, only results from the kitchen are presented in Table 8. Also, since the levels obtained when using gas were generally higher than when using electric, only one set of results is shown for electric cooking. Similarly, due to the similarity of air flow rates when the MVHR system is set to normal or boost, only data from one test is presented for the latter MVHR setting.


Figure 42 Overall layout of monitoring equipment in the show home

Table 8 Air quality measurement results in the kitchen from selected tests during the cooking period

| Cooking fuel | Cooking type | Ventilation mode | Maximum NO concentration (ppb) | Maximum $NO_2$ concentration (ppb) | Maximum $PM_{10}$ concentration ($\mu g\ m^{-3}$) | Maximum ultra fine particle concentration (per $cm^3$ air) | 30-minute mean TVOC concentration ($\mu g\ m^{-3}$) | 30-minute mean formaldehyde concentration ($\mu g\ m^{-3}$) |
|---|---|---|---|---|---|---|---|---|
| Electricity | Boiling | Normal | 10 | 15 | 20 | 2600 | 173 | 60 |
| Electricity | Frying breakfast | Normal | 5 | 10 | 27 | 38,000 | 151 | 50 |
| Electricity | Frying steak | Normal | 2 | 10 | 62 | 64,000 | 107 | 40 |
| Gas | Boiling | Normal | 101 | 161 | 55 | 56,500 | 86 | 39 |
| Gas | Frying breakfast | Normal | 75 | 35 | 610 | 340,000 | 121 | 43 |
| Gas | Frying steak | Normal | 64 | 32 | 189 | 360,000 | 81 | 40 |
| Gas | Boiling | Off | 89 | 59 | 44 | 34,600 | 366 | 45 |
| Gas | Frying breakfast | Off | 58 | 111 | 228 | 250,000 | 233 | 51 |
| Gas | Frying steak | Off | 72 | 37 | 63 | 258,000 | 101 | 35 |
| Gas | Frying steak | Boost | 43 | 31 | 59 | 225,000 | 63 | 31 |

From the data gathered, the conclusions drawn from the cooking experiments at Greenwatt Way are as follows:

- Concentrations of pollutants were, in general, found to be higher from frying than from boiling.
- Gas cooking produced more fine particles and $NO_x$ than electric cooking.
- Intentional burning of toast in an electric toaster gave rise to significant levels of fine and ultra fine particles, which as expected were higher when the MVHR system was turned off.
- Some variation in volatile organic compound (VOC) concentration measurements was found between the different tests.
- Formaldehyde was present at concentrations expected in a home, and in line with levels found in the home during previous monitoring.
- Mechanical ventilation on at both 'normal' and 'boost' mode gave similar results in terms of supply/extract vent flow rates and whole house ventilation, even although the system was working harder and using more power. The very limited boost ventilation capability was due to the MVHR fan unit running at a relatively high fan speed to achieve the background ventilation rate. This left little or no additional fan capacity to achieve a meaningful boost ventilation rate. As expected, when the ventilation was on 'off' mode, pollutants generally remained in the home for longer periods of time. For example airborne concentrations of NO, which is an unreactive gas, remained high unless ventilated away; $NO_2$ levels generally decreased as a result of reactions; and particle concentrations also decreased as a result of losses to furniture, wall and ceiling surfaces (through gravitational and electrostatic mechanisms).
- Were more sources (rings) to be used and/or longer cooking times used, the concentrations of airborne pollutants indoors would be expected to be higher. Concentrations are likely to be exacerbated at lower ventilation rates; for example if the ventilation system fails, is turned off or has greatly reduced flows as a result of filters in the system becoming clogged.
- The comprehensive dataset produced during these measurements provides a valuable resource for comparing indoor concentrations (both measured and potential) with health-related air quality standards and guidelines. It is also extremely useful for the development and validation of IAQ models for predicting the potential exposure of building occupants to air pollutants in indoor environments.

In summary, the air quality tests carried out did not demonstrate any dangerous levels of airborne pollutants over the limited cooking periods studied. On occasions UK Air Quality Strategy and/or WHO guideline values were exceeded for NOx and particles (mainly when frying), but it is important to note that these guidelines are intended for ambient air. The Building Regulations (AD F[9]) guideline value for $NO_2$ was slightly exceeded in some frying tests. Increased levels of certain parameters were found due to frying, cooking with gas and burning toast, and when the MVHR system was turned off.

## 5.4 Occupant feedback

In each of the sets of occupant studies carried out in February 2011, September 2011 and April 2012 the Greenwatt Way residents were asked about thermal comfort, IAQ, noise and the levels/quality of light experienced in their home during the preceding period.

### February 2011

Over 70% of respondents described the temperature in their home as comfortable during the initial autumn/winter period September to February. However, two-thirds reported the temperature as 'variable', and many said they found it hard to heat their home to comfortable level throughout. In the houses a common comment was that if the first floor was at a comfortable temperature then the ground floor was not, and if the ground floor was at a comfortable temperature then the first floor was too cold. The majority of occupants described the bedrooms as cold (although this may have been due to sizing, installation and commissioning issues with the MVHR systems, as described in Section 4). A study of the temperature averages from all rooms in each home suggests that there was not a great difference between downstairs and upstairs; typically bedrooms were up to 3°C cooler than downstairs, but there were instances when bedrooms were warmer by about 1°C. Just over half of respondents reported that the only radiator in the homes (located in the living room) at best 'sometimes' provided enough heat to warm the entire home, and over 80% often or always used the heated towel rail in the bathroom to heat the bathroom, and in some cases to attempt to heat the whole home (see Figure 43).

Internal air quality was generally described as 'being on the dry side of average', 'more fresh than stale', 'reasonably odourless' and 'quite still'. All respondents reported doing their laundry at home and the majority dried clothes on the airer or on the heated towel rail. Despite this none of the respondents reported that the internal air was particularly humid, which is borne out by the recorded humidity data. However, 25% reported condensation on the windows and two reported damp patches or signs of mould near to MVHR system air valves.

Occupants were generally happy with the natural and electric lighting in their homes, although all thought that the outdoor lights were too bright and often shone through their blinds and curtains. The lack of noise transference from outside the properties was listed as one of the best things about the homes, and occupants were surprised at how little they could hear from outside. This is significant since Greenwatt Way is less than half a mile from the M4 motorway and close to the Heathrow flight path. However, as detailed in Section 4 the occupants reported hearing a lot of noise from the building itself.

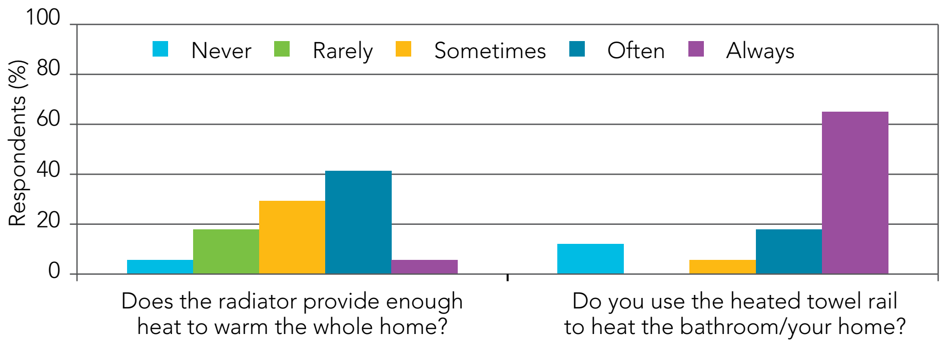


Figure 43 Heat sources in the home

### September 2011

During the spring/summer period of 2011 the high internal temperatures over the summer season were generally reported as being the worst thing about living in the homes since the previous occupant survey. Occupants of the timber-framed houses described temperatures as often being ‘uncomfortably hot’, and all used electric fans at some point during the summer. Those living in the masonry houses did not describe internal temperatures as ‘uncomfortably hot’; a suggested contributory factor was that the timber-framed homes are on the main road, with several occupants reporting having not opened their windows very often due to security concerns. The occupants reported internal temperatures having been up to 26°C, in a summer when external temperatures were rarely high, and study of the temperature data shows that temperatures in all of the homes reached this level at times, with June being the hottest month.

All respondents reported temperatures as being hotter upstairs than downstairs, which is supported by the measured data (temperature differences in the range 1 to 2°C). This is the opposite of what was reported for the majority of the preceding winter season. All occupants said that they used any or all of their patio doors, windows and roof light to provide ventilation and cooling in the summer months, and overall the measured temperature data does suggest that comfortable temperatures could be achieved for the majority of the time. One of the limiting factors for achieving good ventilation, especially at night, was that in the lounge the only opening ‘window’, was the patio door. This could not be left open therefore limiting the potential of overnight ventilation to minimise overheating the following day.

In line with the responses in the previous survey, the internal air was described as being ‘fairly dry’, ‘more fresh than stale’, ‘reasonably odourless’ and ‘quite still’. Many occupants complained that conditions were often ‘stuffy’ during the summer months. The vast majority dried washing on the airer in the home or outside during the summer, and some occasionally used the heated towel rail in the bathroom. Apart from one resident who had found mould growth around a ventilation extract in the kitchen, there were no reports of condensation, mould or damp patches. Most occupants remained content with the level of natural light and provision of electric lighting, although there were some issues with glare on TV screens during the day. The majority of focus group participants reported that the levels of outside noise perceived while indoors remained very low and that they were getting used to the noises made by the building itself.

### April 2012

Three-quarters of residents described the temperatures in their homes during the autumn/winter/spring period of 2011 to 2012 as being either comfortable or comfortably warm, and the majority also described the temperature as reasonably stable. As seen in the preceding heating season, the occupants generally reported that the bedrooms were cooler than other rooms in the home. Most occupants indicated that they had become better versed in controlling the heating and making themselves comfortable, which suggests that they were now settling in to their homes, and that the interventions and improvements made to the MVHR system in November 2011 were making a difference.

Compared with the responses of the previous two surveys, the air quality was now perceived to be slightly more humid, slightly more odorous and with more air movement, but none of the respondents stated that they were unhappy with the air quality in their home. Over 80% said that they dried their clothes on the airer inside the home during winter and spring, although some dried clothes outside when the weather allowed. None of the respondents had noticed any condensation, mould or damp patches since the last occupant survey in September 2011.

Although all remained happy with most aspects of lighting and with the levels of outdoor noise perceived when in their home, over two-thirds now reported hearing a lot of noise transference from other rooms in the home itself (mainly relating to the stairs and first floor in the houses). However, more than one occupant commented that this probably had a lot to do with the low level of noise coming from outside their home.

**Summary of findings: indoor environments**

- **Overall perception of the home**: The majority of occupants found their homes comfortable when considering all environmental factors; the level of satisfaction increased over time.
- **Indoor air quality (measured):** IAQ in the homes, as measured by spot measurements on four occasions, was found to be generally acceptable. Elevated levels of VOCs and formaldehyde were present in the period after construction and handover, and persisted at appreciable levels for over six months. Different VOCs were found as the occupancy phase progressed, but overall TVOC levels followed a downward trend with time.
- **Indoor air quality (perceived):** Generally the occupants found the air quality, including humidity levels, acceptable in their homes. Complaints of stuffiness would appear to have arisen from issues concerning the MVHR system at certain times of the year.
- **Cooking tests:** The experiments conducted showed that the levels of airborne contaminants generated using either gas or electric cooking were not dangerous. However, the tests were carried out over short periods using only one ring, and levels of certain contaminants were higher when cooking with gas, when frying, and when the MVHR system was not operating. This illustrates that source control and effective ventilation are vital to ensure good IAQ and health and wellbeing.
- **Noise:** As seen in Section 4, the nature of these low energy homes in terms of airtightness and acoustics dictated that few issues arose concerning outside noise, but that noise from the building itself (eg from the MVHR system) was far more of an issue with occupants, especially at first.
- **Lighting:** Although no measurements were made in this project, occupants were generally content with the levels of daylight available and with the quality of electric lighting provided.

# 6 Conclusions and recommendations

## 6.1 Construction

Although the project focused on MVHR systems and the quality of the indoor environments, airtightness tests, air leak audits and infrared thermography were used to assess the fabric of the homes at Greenwatt Way. The homes were built to a good level of airtightness and there was a general trend for levels of airtightness to increase over time for both the timber and masonry construction types. Where air leakage paths were identified they tended to be common across all of the homes (around doors, through electrical wall sockets, around service pipe penetrations and light fittings). Infrared thermography carried out both externally and internally demonstrated a limited amount of heat loss or thermal bridging respectively. There were no obvious signs of heat loss across the external façades of the homes. Common areas of heat loss were those seen around front entrance doors, rear patio windows and roof lights, and in the flats there was also evidence of significant heat loss from the roof areas at eaves level.

## 6.2 Indoor environments and occupant feedback

During the period of the monitoring project the Greenwatt Way residents found life within their homes comfortable overall, with their level of satisfaction generally increasing with time as they grew used to living in their homes. There was evidence that most occupants 'coped' with the technologies in their homes rather than being able to understand them fully.

Measurements made across the post-occupancy period showed the air quality in the homes to be generally acceptable. This was borne out in the occupant feedback, which indicated good air quality and highlighted only sporadic cases of perceived 'stuffiness', which appeared to be due to issues associated with the MVHR system at certain times of year. Elevated levels of VOCs and formaldehyde persisted for up to six months after completion of construction but generally decreased with time. As expected, as the occupancy phase proceeded the main VOCs found in the air were those associated with occupant activities and use of consumer products. Cooking tests suggested that source control and ability to achieve purge ventilation, particularly in cases where the MVHR system is not in operation or fails, are important in order to maintain good IAQ.

There was limited occupant perception of high humidity despite a lot of clothes drying within the homes and this was borne out by the measured RH data and only isolated and localised reports of damp or mould. Occupant perceptions of thermal comfort and quality of ventilation in the homes were found to be different across the different seasons. Differences in temperature between upstairs and downstairs were flagged by most residents in the houses, as were draughts from the MVHR system supply air valves in bedrooms before this issue was resolved. Lack of control of heating and ventilation were also highlighted as significant issues, although as alluded to above these factors reduced as occupants settled into their homes, and more so following the remedial work to the MVHR systems.

Despite the location of Greenwatt Way close to the Heathrow flight path and the M4 motorway, perception of outside noise was low, mainly due to the airtight nature of the buildings. Noise from within the home was reported as more of an issue, which is to be expected in airtight homes featuring mechanical ventilation systems, although this became less of an issue with time and following changes to the MVHR system. Occupants were generally satisfied with the availability of daylight and quality of electric lighting, except for some problems with glare from sunlight on television screens and with the strength of external lighting at night.

## 6.3 MVHR systems

The main findings from the extensive studies of all aspects of the MVHR systems at Greenwatt Way, along with recommendations for better practice where appropriate, may be summarised as follows:

- It is critical that the overall ventilation strategy is taken into consideration during the design stage when intending to use a MVHR system in homes. The original design intent for MVHR systems in the Greenwatt Way homes was not developed into a detailed design. Critical details regarding system control sensors, wiring instructions and air flow rates for each supply and extract location were missing and, due to the installation not being undertaken by experienced ventilation system installers, these omissions were not questioned. With the MVHR fan units and a substantial part of the ductwork located outside the insulated envelope of the homes, insufficient attention was paid to insulation of the MVHR fan unit and ductwork.
- During the procurement process it is important to seek technical input from the MVHR system supplier and installer. At Greenwatt Way the MVHR fan units were procured from the supplier on a 'supply-only' basis without recourse to the design service available as part of the supplier's sales package. As a result 10 of the same small 'off the shelf' MVHR fan units were supplied and installed in all homes from the one bedroom flats to the three-bedroom houses, leading to under-sizing issues in the larger houses. In addition, the original ductwork procured proved to be of the wrong cross section making it impossible to feed it through the floor joists, and all of the air valves procured were extract type only, with no supply type air valves.
- MVHR systems should be installed by trained and experienced ventilation system installers. Installation of the MVHR ductwork and fan units at Greenwatt Way was carried out by pipe fitters and electricians respectively. This led to: well laid out ducts, but little appreciation of the effects of supply valve location on occupant comfort; wiring of MVHR fan units to permanent boost; failure

to install system control sensors; and failure to provide sufficient insulation around the MVHR fan units and ductwork in the unheated loft space. Where installation is carried out by trained operatives, deficiencies in system design and inappropriate equipment procurement may be identified and addressed during the construction phase.

- Commissioning of MVHR systems must be fit for purpose. At Greenwatt Way the first round of third party commissioning was carried out using the same set of air flow rates across all sizes of home, which demonstrated a total lack of understanding of the requirements of the Building Regulations. In the second round, air flow rates used were correct and values achieved met the Building Regulations, but to minimise cold draughts the air valves were left near shut, significantly impacting fan power. In neither round of commissioning was the inappropriateness of the type of air valves used for air supply identified.
- Factors likely to adversely affect the power consumption by MVHR fan units during operation must be considered. The fact that air valves were commissioned near shut required the fans to be set at a high speed to achieve the required air flow rates, resulting in high power consumption. Heavily soiled air filters at the time of handover, clogged fly screens and a lack of maintenance schedule all contributed to fans overworking and power use increasing. Installation of RH control sensors in the MVHR fan units themselves rather than in wet rooms is questionable, and the original setting of the RH value for boost as low as 60% resulted in MVHR systems spending a lot of time in boost mode, again increasing power consumption.
- Factors likely to adversely affect the thermal performance of the MVHR system in operation must be considered. Due to the siting of all the MVHR system in the unheated lofts at Greenwatt Way, evidence of significant heat loss from the casing of the fan units was gathered. Levels of heat loss from the ductwork in the loft spaces were also significant, arising from both the sheer length of ductwork used and the fact that levels of insulation (although they met Building Regulations) were not sufficient. During a cold period a case of a heat exchanger freezing highlighted the significant risks associated with the lack of any frost protection function on the MVHR fan units installed.
- Successful measures may be taken to increase MVHR performance. The remedial works undertaken on the MVHR systems at Greenwatt Way part way through the monitoring period were shown to have positive effects on the performance of MVHR system within the homes. Total replacement of one MVHR fan unit with a correctly sized alternative in one of the three bedroom houses demonstrated that, although thermal losses from the MVHR fan unit could be reduced, they still remained significant, and that losses from the ductwork remained very significant despite increasing insulation thickness to an appreciable extent. Replacement of inappropriate air valves, and recommissioning carried out with valves opened to an appropriate extent, led to improved MVHR performance and eradicated dumping of cool air.
- Initial occupant feedback connected with the MVHR systems installed at Greenwatt Way centred around:
  - Perceived lack of control
  - Issues regarding temperature differences upstairs and downstairs (for instance due to cold air being supplied in winter, with no heating upstairs)
  - Experience of draughts from cool air dumping in bedrooms
  - Dissatisfaction with levels of mechanical noise, especially at night time.

When all environmental factors were taken into consideration the occupants' rating of comfort within their homes increased with time, indicating that they were growing used to their homes and the MVHR systems within them. Moreover, interventions and improvements to the MVHR systems undertaken in November 2011 appeared to contribute significantly to increased occupant satisfaction, with draughts from supply air valves being eradicated, temperature profiles being smoothed, and levels of mechanical noise being reduced.

## 6.4 Recommendations for further research

From the findings of this investigation into the design, installation, commissioning and operation of the MVHR systems in the homes at Greenwatt Way it is evident that the following issues are particularly worthy of further research in the UK:

- Comparison of performance of the MVHR systems when the MVHR fan unit is situated outside and inside the heated envelope.
- Effects of different types and amounts of insulation on MVHR fan units and associated ductwork when located outside the heated envelope.
- The effectiveness of different types of occupant control.
- Efficacy and practicality of filters currently installed in the MVHR systems and requirements for and ease of maintenance.
- The effect trained designers, installers and commissioning operatives can have on the overall effectiveness of an MVHR system.

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# NHBC Foundation recent publications

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As a follow-up to the 2011 publication *Fire performance of new residential buildings*, this report focuses specifically on fire spread within external walls where the cavity between the external façade and the structural frame is incorporated either as a lining material or as a form of insulation (or both).

In support of the project, a programme of 21 fire experiments on walls containing various options for sheathing and cavity barriers was undertaken. ***NF 51*** April 2013

## Designing homes for the 21st Century


The aim of the guide is to promote a better understanding of the 'whole' without getting drawn into the detail of specific technological solutions or regulations, proposing a model for planning new homes that splits into four stages: evaluation, best practice, integration and optimisation. It advocates a 'fabric first' approach making sure that insulation, airtightness and ventilation are designed to give the best practical performance before low carbon technologies are applied. ***NF 50*** May 2013

## Building Information Modelling


This report explains what BIM is, and outlines the Government's requirements. It assesses the house-building industry's current engagement of BIM, and looks at ways in which it might make the most of the opportunities BIM presents. Once the house-building industry understands the concepts of the BIM process its participants can make an informed decision on how it can be adopted to best suit their working practices. ***NF 49*** February 2013

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- The use of lime and cement stabilised soils on residential housing developments
- Socio-technical analysis of microgeneration technologies in UK and France

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# Assessment of MVHR systems and air quality in zero carbon homes

NHBC Foundation has been concerned for some years at the risks, which a move towards higher standards of airtightness, could present to indoor air quality. Alongside the increased risk of overheating, it is one of our main concerns in relation to the zero carbon homes agenda.

This report is based on the experience of MVHR systems in 10 homes built by Scottish and Southern Energy (SSE) at Greenwatt Way, Chalvey. Achieving Code for Sustainable Homes Level 6, these homes provided a perfect test bed for the detailed evaluation of MVHR systems in practice. As well as looking at design, specification, installation, and commissioning issues, the research has very importantly gauged the use of these systems by some typical home occupants.

NHBC Foundation has been established to facilitate research and development, technology and knowledge sharing, and the capture of industry best practice. NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the UK's wider housing needs. NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

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