Performance Evaluation of a Mechanically Ventilated Heat Recovery (MVHR) System as Part of a Series of UK Residential Energy Retrofit Measures

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ABSTRACT

This study involves a detailed analysis of a mechanically ventilated heat recovery (MVHR) system installed as a case study retrofit project in a UK test dwelling. Comparisons of predicted and in-situ performance are made through the calculation of a theoretical and practical heat loss coefficient value (HLC).

Analysis revealed underperformance in the installed MVHR system, as compared to predicted data. Issues were identified in the installation and function of the control unit and ductwork. Improvement work enabled the system to function more closely to optimum performance levels. However, discrepancies still existed between the predicted and actual HLC values, which were largely accounted for through theoretical heat loss calculations attributable to slight imbalances within the system supply and extract rates. When normalized, the data still showed an unaccounted heat loss of approximately 6 W/K in both MVHR tests.

The study reinforces the need for high quality MVHR installation and commissioning work, which is critical to ensure that a system can perform to the optimum levels specified in manufacturer literature. Education and training throughout the supply chain is essential in achieving this, as system inefficiencies can lead to unnecessary heat losses resulting from increased levels of air infiltration or leakage.

KEYWORDS: Standard Assessment Procedure (SAP), Coheating Test, MVHR system performance

INTRODUCTION

The UK has set stringent targets to reduce greenhouse gas emissions by 80% by 2050 (against 1990 baseline conditions). Up to 30% of total emissions can be attributed to domestic buildings, and so improving the energy performance of housing is key to achieving this objective. Building Regulations are becoming more stringent in order to ensure that buildings have high thermal performance properties. This includes focus on air tightness levels, thus reducing natural infiltration rates and heat losses through the building fabric. However, in doing this, the natural supply of fresh air and removal of stale air is impaired, leading to the potential for poor internal air quality and issues such as high humidity, damp and mould.

At a certain point, it becomes necessary to introduce an additional form of ventilation, and mechanical ventilation with heat recovery (MVHR) could provide a viable option. This type of system works well in an air tight property, as it reduces heat losses from stale air leaving the property as this is used to pre-heat supply air. In doing so, it not only maintains a constant supply of fresh filtered air and the removal of stale air, but also reduces space heating energy requirements. However, if the property is not sufficiently air-tight, or if the MVHR system is not correctly installed or commissioned, heating and auxiliary energy demand can be increased.

Whilst the use of mechanically ventilated heat recovery systems (MVHR) is generally standard practice in parts of the USA and Europe (Balvers 2012), it is only in more recent years that they have been utilized in housing in the UK. With UK Government targets to reduce carbon emission levels to 80% below 1990 levels by 2050 still in place (DECC 2008), there is a renewed drive towards lower energy use in buildings. The building stock in the UK currently accounts for approximately 40% of total carbon emissions (MacKenzie 2010), with up to 30% attributable to domestic housing stock (Utley 2008). Progress has been made in many sectors (for example industry and transport) in order to reduce the overall national carbon burden yet, conversely, emissions from the domestic sector appear to have increased by 11% since 1990 (DECC 2010). This trend can be seen in Figure 1, where carbon emissions are measured against baseline 1980 levels through use of a comparative index.

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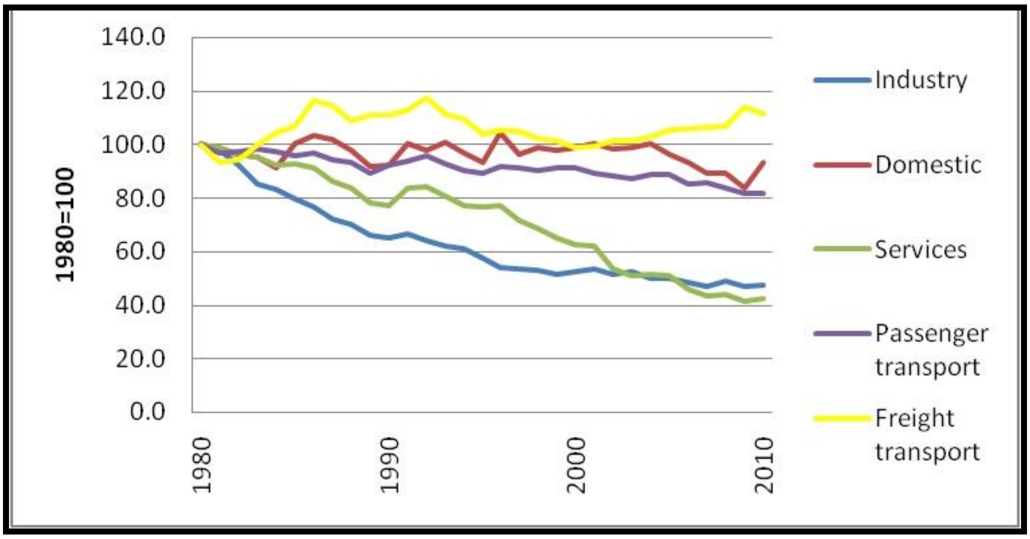

Figure 1 – Carbon Emissions from Sectors (Data from (DECC 2011))

In order to reduce the space heating and total energy requirements of housing, much focus has been placed on achieving an ‘airtight’ (i.e. minimal air ‘leakiness’) building envelope. The building fabric is the primary heat loss pathway in buildings, due to fabric heat conduction and infiltration/air leakage. However, whilst creating an air-tight environment may have a beneficial effect by lowering energy demands, the lack of background infiltration can lead to higher moisture and humidity levels. This can result in poor indoor air quality, potentially affecting the health of the occupants (World Health Organisation 2010).

It is important, in any building, that the ventilation strategy is designed and installed to allow the correct throughput of fresh air and removal of stale air. This can be achieved through natural means, via vents and window openings. However, in highly airtight properties, it is necessary to create a sufficient air change rate by means of an artificial system, such as MVHR, and this can theoretically reduce space heating energy demand through recovery of heat from the extracted air. MVHR systems are efficient in recovering heat from air and resupplying it to the property. However, if the property is not sufficiently air-tight, or if the MVHR system is not correctly installed or commissioned, heating and auxiliary energy demand can be increased.

This study investigates the installation, commissioning and performance of a commercial MVHR system fitted in a 1930’s style semi-detached property, which has been retrofitted with fabric insulation. The as-built thermal performance of the house has been tested by means of a methodology known as the co-heating test, which is designed to assess the heat loss of a building by means of monitoring the energy required to maintain a constant internal temperature over a number of days. Theoretical heat loss assessments have been produced for comparison to the experimental data by utilising a methodology set out in the UK’s Standard Assessment Procedure (SAP). It has been possible to assess the system as originally installed and also after improvements to the installation, in order to evaluate the impact of this on the operation of the system and, ultimately, the energy demand of the dwelling.

AIRTIGHTNESS AND VENTILATION STRATEGIES

Many existing homes in the UK rely on infiltration through the building fabric and unregulated natural ventilation in order to maintain a constant supply of fresh air and good internal air quality. Low airtightness levels allow sufficient air changes to occur, but can also lead to poor thermal performance as heat is lost due to the high permeability of the construction.

As a result of the air leakage that often occurs in older houses, the free flow of air can lead to excessive heat losses and high energy demands. To achieve higher levels of airtightness, and thus reduce the need for space heating, improvements are being made to dwellings to raise building fabric and thermal performances, frequently through retrofit project initiatives. The UK Building Regulations Part L (Communities and Local Government (CLG) 2010b; Communities and Local Government (CLG) 2010c) specify a minimum air tightness level of 10 $m^3/m^2/h$ for new build domestic dwellings. However, best practice standards seek to achieve a value as low as 3 $m^3/m^2/h$ (Energy Saving Trust 2007) and, as airtightness levels increase and natural ventilation rates reduce, it becomes necessary to install an alternative means of ventilation.

A Mechanically Ventilated Heat Recovery (MVHR) system is one solution, and can help to maintain a good standard of air quality. It has been suggested that two key measures are required to reduce dwelling space heating demand, namely increased airtightness and installation of an MVHR system (Banfill 2011a). Energy savings are achieved due to a decrease in infiltration levels, in conjunction with an elevated base air temperature obtained via the preheating of supply air using recovered heat from the extracted air. However, this is balanced against the energy costs associated with the running of the MVHR system.

The effectiveness of an MVHR system is directly dependent upon the correct balance between the efficiency of system fans, efficiency of the heat recovery unit, air flow rate, and building airtightness (Banfill 2011b). Correct installation and commissioning of an MVHR system is essential to ensure that it works efficiently, and provides the correct levels of supply and extract air to maintain a healthy living environment. The extract flow rate for a continuous ventilation system must comply with UK Building Regulations Part F requirements (Communities and Local Government (CLG) 2010a), as detailed in Table 1.

	Kitchen	**Utility Room**	**Bathroom**	**Toilets etc**	
Minimum Extract High Rate (l/s)	**13**	**8**	**8**	**6**	
Minimum Extract Low Rate (l/s)	Total extract rate should be at least equal to the relevant whole dwelling ventilation rate below				
WHOLE DWELLING VENTILATION RATE (l/s) (based on no. of bedrooms)	**1 BEDROOM**	**2 BEDROOM**	**3 BEDROOM**	**4 BEDROOM**	**5 BEDROOM**
	13	**17**	**21**	**25**	**29**

Table 1 – Building Regulation Part F Extract Ventilation Rates (Communities and Local Government (CLG) 2010a)

The supply rate should be as close to the extract rate as possible, to ensure that the system is providing a balanced state within the house, thus avoiding pressurization or depressurization. If either excessive or inadequate levels of air are supplied and replaced, it could result in inefficient working of the system due to increased infiltration and air movement through the building fabric, and lower levels of pre-warmed air being available to the heat recovery system.

Whilst the installation of an MVHR system is becoming more of a necessity in UK new build homes due to higher levels of airtightness, there is also a need to ensure that existing dwellings maintain a high level of air quality as retro-fit improvements are made to the building fabric. Several investigations into the performance of MVHR systems have been undertaken, which highlight the general problems that are commonly encountered during ventilation system design, installation and commissioning ((Dorer and Breer 1998; Zero Carbon Hub & NHBC Foundation 2013). Factors, prior to occupant intervention, that can ultimately lead to system underperformance include flawed system design (siting of vents in rooms, placement of control unit in unheated space), poor installation (inadequate insulation levels), faulty commissioning processes (incorrect extract/supply rates), and debris blocking ducts and vents (building dust, etc).

There is limited published research relating to MVHR function in new build and existing homes. This paper describes a unique opportunity to investigate the installation of a commercial MVHR system installed as a case study retrofit project in a 1930's replica dwelling (the E.On Retrofit Research House), and report findings from a range of tests.

CASE STUDY – THE E.On RETROFIT RESEARCH HOUSE

The E.On Retrofit Research House, completed in 2008 on the Nottingham University Park campus, comprises of a newly constructed property, built to 1930's building standards in the style of a traditional semi-detached UK dwelling. It forms the basis for staged retrofit programmes, with fabric and systems upgrades undertaken utilising materials, technology and methods that would be available to an average homeowner. Each intervention can be evaluated and the impact of the work on various parameters, such as thermal performance and energy efficiency, can be assessed and attributed to individual stages of the programme. No renewable energy technologies were installed in the E.On Retrofit Research House, as the main aim of the project was to investigate a 'fabric first' approach to retrofitting of existing housing stock.

As part of the overall investigation, several fabric upgrades were undertaken during the project, with air tightness levels measured through the use of standard pressure test/blower door methodology (ATTMA 2010). Table 2 contains information relating to the work undertaken and pressure test value obtained at each stage.

Improvements to House	Test Date	Result from Pressure Test
		(m^3/hm^2)
Baseline position. Single glazed windows. Uninsulated cavity wall, floor and roof space, No Draught Proofing	18/03/2009	15.57
Double Glazing, Cavity filled, Loft insulation, Draught proofing applied to windows and doors	09/09/2010	14.31
Undercroft trap-door/Kitchen/Bathroom/WC windows now draught proofed. Draught proofing throughout house re-done as inadequate installation. Block up window trickle vents.	01/10/2010	9.84
Service risers sealed. Covers fitted to door locks, pipework envelope penetrations sealed (radiators, water pipes etc), Kitchen fan removed and bricked-up. Sealing around boiler flue.	19/11/2010	8.60
Floor membrane and over-cladding to skirting installed. Carpets laid to upper floor.	20/12/2010	5.00
Coving to wall/ceiling joint. Insulation to service voids in chimney breast. Minor snagging works to pipe lagging and door/window joints.	14/02/2011	4.74

Table 2 – Air Tightness Levels

For the MVHR case study reported in this paper, the relevant air tightness level present at the time is 4.74 $m^3/m^2/h$, as the detailed assessment of the MVHR system was undertaken after completion of the final fabric improvements to the house. The MVHR system was fitted as a retrofit installation in September 2010. A summary of the main construction details of the house at the time of the MVHR tests is shown in Table 3.

	EOn Research House	
Parameter	**Specification**	**U Value (W/m^2K)**
External Walls	Brick and 100mm Tarmac Hermalite Block with 50mm cavity injected with loose glass mineral fibre insulation	**0.554**
Party Wall	Blockwork with filled cavity	**n/a**
Internal Walls	Solid blockwork	**n/a**
Internal Wall Finish	Plaster	**n/a**
Ground Floor	Suspended timber floors with softwood boards and joists	**0.12**
Upper Floor	Suspended timber floors with softwood boards and joists	**0.81**
Roof	Timber rafter and purlin pitched roof, clay tiles, breathable membrane, 300mm deep rolled glass mineral wool insulation	**0.164**
Windows/Doors	24mm argon filled double glazed units - Saint Gobain Planitherm (clear pane) and Pilkington Stipolyte (obscure)	**1.2 and 1.7 respectively**
MVHR System	Titon HRV2 Q Plus	**n/a**

Table 3 – Structural Specification of E.On Research House (Following Retrofit Work)

BASELINE DESIGN STAGE ASSESSMENT

It is possible to assess the design stage fabric performance of the E.On house using the methodology outlined in the UK Standard Assessment Procedure (SAP). This is an approved energy performance assessment methodology, which is based upon the Building Research Establishment Domestic Energy Model Version 12 (BREDEM 12) (Anderson 2001). The model forms part of the UK Government-endorsed assessment procedure that is used to evaluate compliance with energy performance and carbon emissions requirements stipulated by the UK Building Regulations Part L (Communities and Local Government (CLG) 2010b; Communities and Local Government (CLG) 2010c).

The SAP methodology includes a calculation process that enables determination of heat losses attributable to background infiltration (ACH), fabric heat losses including thermal bridges (W/K), and ventilation heat losses (W/K). Environmental influences such as sheltering/exposure and wind speed are also taken into account. In this study, wind speed data obtained from a local weather station for the relevant testing period has been applied to each of the SAP theoretical worksheets created for each day, in order to achieve a more representative analysis than that provided when using seasonal monthly average data embedded in the standardised SAP methodology.

There are a number of key items within the SAP 2009 methodology that contribute to the calculation of a HLC output value, as shown in Figure 2 12. This provides a measure of the whole house heat losses in terms of W/K, that is, the required energy (W) required to heat the building per degree of difference between the internal and external temperatures (K). The calculation is derived from BS EN ISO 12831 (Building Standards Institute (BSI), 2003), where Total Design Heat Loss is equal to the sum of the design transmission heat loss for heated space (W) and design ventilation heat loss for heated space (W). Element u-value multiplied by element surface area data provides a value of fabric heat loss for each aspect of the building (floors, walls, roof, windows and doors). The contribution of thermal bridging losses, background infiltration and additional ventilation losses are summed, together with fabric heat loss, to calculate the HLC (W/K) under steady state conditions. This provides a measure of the required energy (W) required to heat the building per degree of difference between the internal and external temperatures (K), enabling comparison of a base case model with those where different scenarios are applied.

Initially, a comparison was made between the naturally-ventilated and mechanically-ventilated case results. This showed theoretically that an energy saving could be realised in the test house when the MVHR system was in operation. This could be plausible, as work undertaken by (Banfill 2011a) relating to the E.On House suggests that a building airtightness level of 7 $m^3/m^2.h$ at 50Pa is required in this property to realise a reduction in overall heat loss when MVHR is in use. The relevant value at the time of testing was 4.74 $m^3/m^2.h$ at 50Pa, which could potentially result in a lower HLC.

However, previous work has demonstrated that the use of the 'natural ventilation' option within the SAP model is not appropriate for the work being undertaken, as this was not the ventilation strategy in operation during the post-construction co-heating experiments (White 2013). Within the SAP methodology, a 'natural ventilated' case includes a factor for additional ventilation being introduced by vents and resident intervention. This could possibly include the opening of windows, doors and trickle vents, which are all sealed in an unoccupied dwelling during a co-heating test. Therefore, any loss of heat through air changes is solely due to the natural infiltration through the fabric, and so it is concluded that the design stage benchmark data derived from SAP to be used in this work should relate to each house in a state with no ventilation (solely natural infiltration), and secondly in a state with the relevant MVHR system in operation.

The scenarios applied to the data were constructed to represent the building in either of the following states: background infiltration rate only, and mechanically ventilated. The calculation for ventilation rate was set to include 90% system efficiency, in line with SAP default data and manufacturer performance data. It is also important to note that when MVHR is included in the SAP calculations, the air change heat loss component includes an air change rate of 0.5 ACH in addition to the infiltration-only heat loss value. The resultant heat loss data is shown in Table 4.

EOn House - Infiltration Only - No Ventilation Included	132.8	34.4	167.2	5.9	173.1
EOn House - MVHR in Operation (90% Efficiency Assumed)	132.8	34.4	167.2	16.8	184.0

Table 4 - Calculated SAP Heat Loss Values
*(N.B Air Change Heat loss is the heat loss due to the components of ventilation and infiltration)

It can be seen that the predicted ventilation heat loss is higher when the MVHR system is in operation, which results in the HLC values also being increased when mechanical ventilation is introduced into the model. This is not surprising, given the additional energy load of the system.

BASELINE POST CONSTRUCTION STAGE ASSESSMENT

The co-heating testing procedure, as set out by Wingfield et al (Wingfield 2010), was used in order to assess post-construction performance of the E.On House. This procedure measures the heat losses arising from fabric heat transfer, fabric infiltration and background infiltration.

The general concept of the test is based on the principle that by heating a dwelling to a constant temperature (approximately 25°C) with electrical heaters, and then measuring the power required to maintain that temperature, the daily heat input into the house can be measured (W). When this value is plotted against the daily difference between internal and external temperatures (ΔT), a heat loss coefficient is calculated (HLC) (W/K).

As indicated by Everett et al (1985), the calculation of the HLC can be undertaken using a rearranged form of the standard heat balance equation (Eq 1).

$$Q/\Delta T = (\Sigma U.A + 1/3nV) - R.S/\Delta T \qquad (1)$$

Where:

Q = Total measured power (W)
R = Solar aperture (m^2)
S = Total south facing solar radiation (W/m^2)
$\Sigma U.A$ = Total fabric heat loss (W/m^2)
n = Background ventilation rate (h^{-1})
V = Internal volume of the dwelling (m^3)
ΔT = Temperature difference between the inside and the outside of the dwelling (K)

The raw data from the co-heating test provides a measurement of the total heat input from the heaters required to maintain a uniform internal temperature. However, the effect of solar gains needs to be accounted for, as less power may be required to heat the dwelling on days with high levels of solar radiation.

Solar radiation data from a local weather station was obtained, and then the relationship between power, ΔT and radiation values was assessed through multiple regression analysis in order to obtain a value for solar aperture (R). The calculated R value was then applied to the solar radiation data in order to obtain a value in watts for solar gains to the property. Finally, the original value of measured power (Q) was adjusted to reflect the true amount of electrical power required to heat the property, through addition of the solar gains value.

A co-heating test was undertaken in the E.On House in Spring 2011, with no MVHR operating and with the MVHR in operation. The results from the co-heating tests, with and without adjustment for solar radiation, are shown in Table 5.

	Uncorrected Data Heat Loss Coefficient (HLC) W/K	**Regression Analysis-corrected Heat Loss Coefficient (HLC) W/K**
EOn House - Infiltration Only - No Ventilation Included	162.9	172.3
EOn House - MVHR in Operation	160.3	213.7

Table 5 - Results from Co-heating Tests

The uncorrected HLC values show an improvement in the HLC coefficient when the MVHR system is in operation. This is misleading, and highlights the importance of correction of data in order to account for solar gains. The practical tests were undertaken during the Spring, when levels of solar irradiance generally start to increase in the UK. After multiple regression analysis has been completed and adjustments made to the data, it can be seen that there is a considerable increase in the HLC values, particularly in the case of the co-heating test relating to the MVHR system in operation. This indicates a large solar effect during this test period, resulting in lower power requirements in the house to maintain a steady temperature of 25°C. The corrected data shows a large increase in HLC value when the MVHR system is in operation.

COMPARISON OF DESIGN STAGE AND POST CONSTRUCTION DATA

The Heat Loss Coefficient (HLC) and Heat Loss Parameter (HLP) data obtained from the SAP model and from the co-heating tests can be used to compare actual performance with that predicted at the design stage, as shown in Table 6. The HLP is a parameter that uses the HLC value divided by dwelling floor area in order to calculate a normalised effective whole house u-value measured in W/m^{2}K (Sutton *et al.*, 2012).

<table>
<tr><td>EOn House - Infiltration Only - No Ventilation Included</td><td>173.1</td><td rowspan="2">+10.9 W/K</td><td>172.3</td><td rowspan="2">+41.4 W/K</td></tr>
<tr><td>EOn House - With MVHR in operation</td><td>184.0</td><td>213.7</td></tr>
</table>

Table 6 – Design Stage and Post Completion Test Data

When the data relating to the E.On house without the MVHR system in operation is considered, it can be seen that the SAP values and co-heating values are virtually identical. This demonstrates that, following detailed adjustment of the SAP inputs, the SAP predictions (at the design stage assessment) are in agreement with the measured as-built fabric performance of the property.

After activation of the MVHR system, both the design stage and co-heat test HLC values increase. However, the additional W/K calculated in the post-construction analysis is considerably greater than that indicated by the SAP assessment. The magnitude of the divergence in values, at four times the predicted level, appears to be significant.

As previously indicated, the increase in HLC associated with the use of the MVHR system calculated through the SAP methodology is not unreasonable. This then led to the reasonable conclusion that there may be an issue with the actual functioning of the MVHR system as installed, as the large difference in HLC value is only apparent in the post-construction performance testing, where ventilation heat losses have a more pronounced impact on the HLC.

ASSESSMENT OF MVHR SYSTEM OPERATION

In a previous study of the MVHR system in the E.On House, detailed investigation into the functioning of the unit indicated that it was not performing to manufacturer's guidelines or to the level of operational efficiency assumed in the default SAP model parameters (White 2013). Therefore, work was undertaken to assess the performance of the system at the time of the current testing schedule (Spring 2011).

System flow rates and temperatures were measured at each supply and extract duct using a Testo 417 vane anemometer with an inbuilt thermometer. Temperature probes were placed in the supply and extract air ductwork close to the unit. A power meter was installed on the MVHR unit to collect data relating to system energy consumption, as shown in Figure 2.

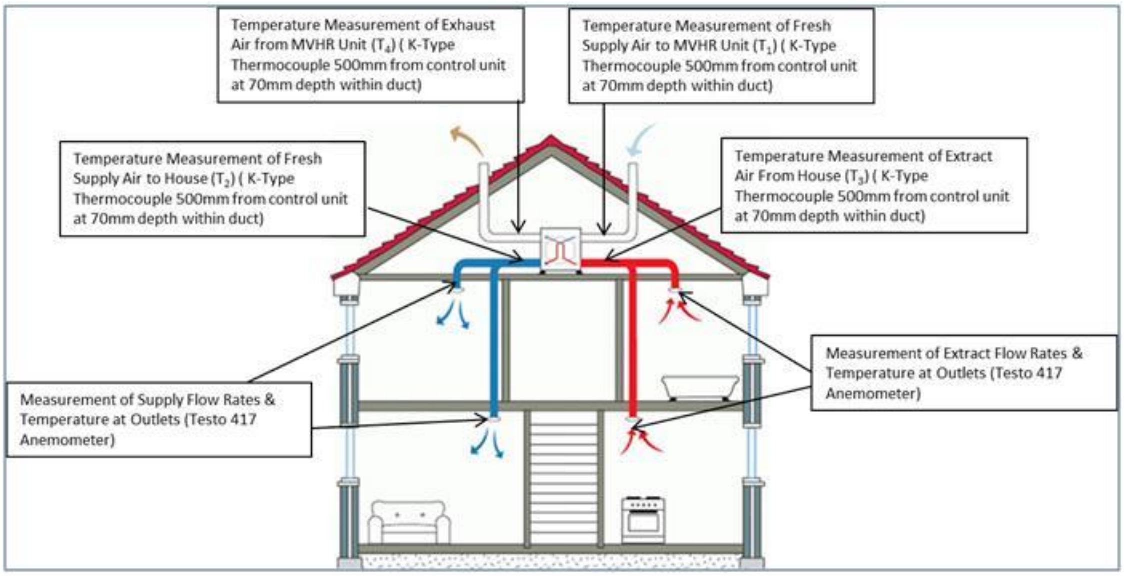

Figure 2 – MVHR System Measurement Locations
(Based upon Source Data from Efficiency Meets Sustainability (2011))

Using the data gathered, was possible to assess the overall temperature efficiency of the system, using Equation 2:

$$\boldsymbol{\eta_t = T_2 - T_1 / T_3 - T_1} \quad (2)$$

Where:
η_t = Temperature Efficiency of the MVHR System (efficiency of heat exchanger)
T_1 = Temperature of Intake Air, K
T_2 = Temperature of Supply Air, K
T_3 = Temperature of Extract Air, K

The measured efficiency of the system was found to be 76%, which is significantly lower than the 90% value previously used in the design stage analysis and suggested in manufacturer literature.

With regard to MVHR flow rates, the SAP methodology assumes that the system is balanced, so that both supply and extract flow rates are fixed at 0.5 air changes per hour (ACH). In practice, this may not always be the case and this will impact upon the performance of the heat recovery potential of the ventilation system. When the supply and extract rates are not equal, the dwelling may be placed in a pressurised or depressurised state, which could result in the absolute loss of warm air that cannot be heat recovered. It may also influence natural infiltration levels within the property. The measured system flow rates were found to be unbalanced, as shown in Table 7.

	Supply Flow Rate (l/s)	**Supply Flow Rate (ACH)**	**Extract Flow Rate (l/s)**	**Extract Flow rate (ACH)**	**Supply-Extract Imbalance (ACH)**
MVHR - EO.n House (76% Efficiency)	51.2	0.9	37.4	0.6	+0.2

Table 7 - MVHR System Air Throughput Values

In terms of actual air throughput in l/s, a comparison can be made with the optimum levels specified in literature provided by the manufacturer. This indicates that the commercial system has a specified flow rate of 33 l/s, which is lower than that measured on site. The extract flow rate is also greater than 21 l/s, indicated as the minimum extract flow rate for a 3 bed house as per UK Building Regulations Part F (CLG 2010).

In summary, the investigation at this stage showed that the MVHR system as installed in the E.On house was underperforming, with an efficiency of 76%, an imbalance in extract/supply air rates of 0.23ACH (excess), and a high overall air throughput rate. This combination of problems would all have a detrimental effect on the function of the system and therefore, potentially, the in-use HLC calculated using the measured co-heating test data.

In order to assess the impact of the low efficiency on the dataset, the SAP methodology was used to calculate a predicted HLC based on an efficiency of 76%, as shown in Table 8.

	Fabric Heat Loss W/K	**Thermal Bridges W/K**	**Total Fabric Heat Loss W/K**	**Air Change Heat Loss W/K**	**Heat Loss Coefficient (HLC) W/K**
EOn House - Infiltration Only - No Ventilation Included	132.8	34.4	167.2	5.9	173.1
EOn House - MVHR in Operation (76% Efficiency Calculated)	132.8	34.4	167.2	20.1	187.2
EOn House - MVHR in Operation (90% Efficiency Assumed)	132.8	34.4	167.2	16.8	184.0

Table 8 – Extended Calculated SAP Heat Loss Values

(N.B Air Change Heat loss is the heat loss due to the components of ventilation and infiltration)

This shows that, whilst the SAP HLC value does increase slightly when the MVHR efficiency levels within the SAP model are adjusted to 76%, this does not account for the considerable discrepancy between the predicted and measured data.

MVHR SYSTEM IMPROVEMENTS

In order to gain a more detailed understanding of the issues surrounding the performance of the MVHR system, a FLIR T400 thermal imaging camera was used to investigate areas of potential heat loss from both the system control unit and heat exchanger, and from the ducting work in the loft space. The images, as shown in Figure 3 and 4, revealed that there was scope for improvement in both areas. It was concluded that increased insulation of all system elements could enable higher system efficiencies to be achieved.

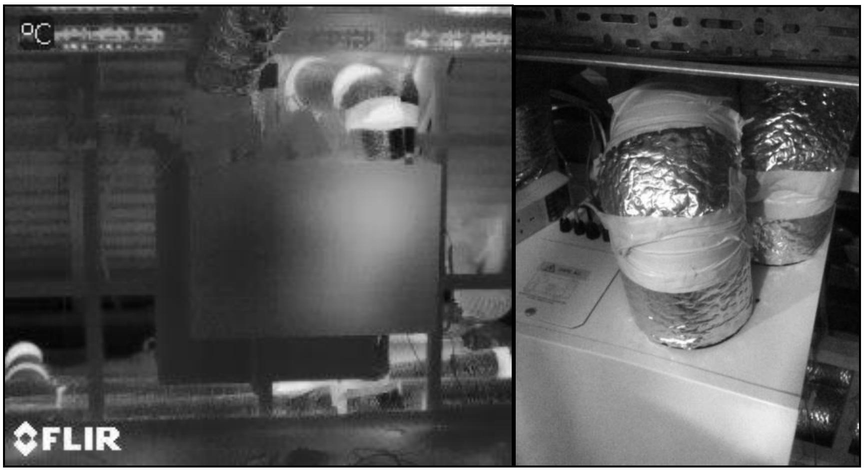

Figure 3 - Poor insulation of MVHR control unit

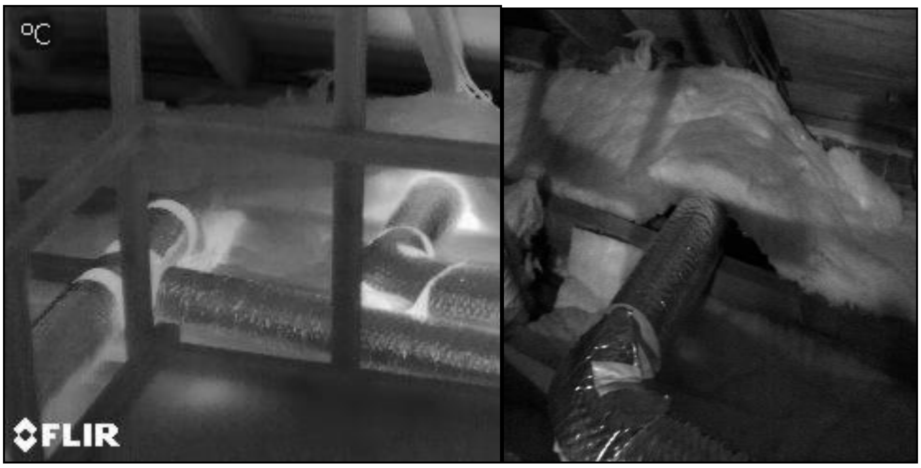

Figure 4 - Inadequate insulation of duct work

The system manufacturer was contacted in order to discuss the performance of the system and potential ways in which the issues of poor performance (both balancing and efficiency) could be addressed. Representatives from the company then worked to investigate possible solutions.

A new control panel was fitted to the system, which allowed more refined regulation of air flow rates, due to the ability to adjust the supply and extract fan speeds independently. Members of the manufacturer's team installed the control panel and recommissioned the system, following individual adjustment of the supply and extract rates to achieve the design flow rate of 33 l/s.

Additional insulation was applied to the MVHR control box unit, in order to reduce heat losses from the heat exchanger at source. Further work was undertaken to improve the seal at junctions between insulation lengths around the ducting in the loft space. Figure 5 shows the main MVHR unit following the improvement works.

Figure 5 - MVHR Control Box Following modifications by manufacturer

The images show some improvement within the system, and that heat losses in the area close to the heat exchanger are not as distinct as those prior to the fitting of the insulation jacket.

POST-IMPROVEMENT ANALYSIS

Following the completion of the improvement works by the MVHR manufacturer, further investigation of the MVHR system performance was undertaken to evaluate the effect of the new controller and enhanced insulation. This involved a co-heating test, and re-measurement of system efficiencies and flow rates.

The flow rates and system temperature efficiency measured before and after the recommissioning process are included in Table 9.

	Supply Flow Rate (l/s)	Supply Flow Rate (ACH)	Extract Flow Rate (l/s)	Extract Flow rate (ACH)	Balance	Temperature Efficiency
MVHR - EO.n House (76% Efficiency - Before Work)	51.2	0.9	37.4	0.6	+0.2ACH	76%
MVHR - EO.n House (90% Efficiency - After Work)	33.7	0.6	28.9	0.5	+0.1ACH	90%

Table 9 – MVHR System Function

The measured flow rates following the installation of the new controller are significantly lower than those present prior to the works, and are more comparable to the optimum air throughput values suggested by the manufacturer (33l/s) but still in excess of minimum required extract flow rates. The MVHR system is still placing the house in a pressurized state, although the level of air over-supply has reduced considerably. The calculated system efficiency is now 90%, indicating that the heat recovery performance has improved due to the insulation of the control unit and ductwork in order to achieve optimum operational conditions.

Further comparative analysis of the predicted and measured heat loss coefficients was undertaken, in order to assess the effect of the improvement works to the overall energy demand of the E.On House. The initial analysis (Table 6) was based on a comparison between the SAP and coheat data, which has now been shown to be inappropriate as the predicted and measured heat loss values were not based on analogous operating conditions due to inefficiencies later measured within the MVHR system. The HLC calculated using SAP assumed a system efficiency of 90%, whilst at the time of the coheat testing, the MVHR system was found to be operating at 76% efficiency. The original HLC data did, however, highlight the inefficient working of the system, resulting in further research and system improvements.

Table 10 shows the relationship between predicted and measured HLC calculated for each ventilation scenario.

	SAP Heat Loss Coefficient (HLC) W/K	Increase (W/K)	Regression Analysis Heat Loss Coefficient (HLC) W/K	Increase (W/K)
EOn House - Infiltration Only - No Ventilation Included	173.1	+14.2 W/K	172.3	+41.4 W/K
EOn House - With MVHR operating (76%)	187.2		213.7	
EOn House - Infiltration Only - No Ventilation Included	173.1	+10.9 W/K	172.3	+20.3 W/K
EOn House - With MVHR operating (90%)	184.0		192.6	

Table 10 – HLC Data for Ventilation Scenarios

It can be seen that the difference between the predicted and calculated heat loss for the system has been halved due to the evaluation being based on comparable conditions. However, there is still some discrepancy in the datasets, which is so far unaccounted for. This can be seen more clearly in Table 11.

	SAP Heat Loss Coefficient (HLC) W/K	Regression Analysis Heat Loss Coefficient (HLC) W/K	Difference (W/K)
EOn House - Infiltration Only - No Ventilation Included	173.1	172.3	-0.8
EOn House - With MVHR operating - 90%	184.0	196.6	+12.6
EOn House - With MVHR operating - 76%	187.2	213.7	+26.5

Table 11 – Comparison of Predicted and Measured HLC Data

The difference between the measured and predicted HLC for the infiltration only baseline case is minimal, which suggests that the fabric of the E.On House is functioning to design levels of thermal performance. However, even when the MVHR system is functioning at 90% optimum efficiency, there is a discrepancy between the two HLC values of 12.6 W/K. This is greater when the system is functioning at 76% efficiency (26.5 W/K).

There is an apparent imbalance of +0.1 ACH (Table 9) in the supply and extract flow rates following modifications and re-commissioning of the system. Calculations show that an air leakage rate equivalent to this amount would account for an increase in the theoretical heat loss of approximately 7 W/K. The imbalance is larger prior to the improvement works, where the MVHR system is pressurizing the house with an over-supply of air of 0.2 W/K, which is the equivalent to heat loss of approximately 20 W/K. The impact of the system imbalance is shown in Table 12.

	SAP Heat Loss Coefficient (HLC) W/K	Regression Analysis Heat Loss Coefficient (HLC) W/K	Difference (W/K)	Heat Loss Due to Imbalance (W/K)	Unaccounted Heat Loss (W/K)
EOn House - Infiltration Only - No Ventilation Included	173.1	172.3	-0.8	n/a	n/a
EOn House - With MVHR operating - 90%	184.0	196.6	+12.6	7.0	5.6
EOn House - With MVHR operating - 76%	187.2	213.7	+26.5	20.1	6.4

Table 12 – Heat Loss Calculations

Whilst the heat losses associated with the MVHR system imbalances are quite different for 76% and 90% efficiency levels, when they are evaluated in the context of the difference between the SAP and coheating test values, it can be seen that the data relating to unaccounted head losses is similar, being approximately 6 W/K in both cases. This is not due to incorrect efficiency levels being used in the initial design stage calculations, or related to the air throughput rates, as both of these parameters are taken into account in the data analysis.

The study shows that both SAP and co-heating methodologies appear fit for purpose, in that it does provide a coherent basis for the comparison of predicted and design stage data. However, the consistent unaccounted heat loss value of 6 W/K could be attributable to uncertainties within the test analysis methodologies. This could include solar gains corrections within the co-heating data, as there were high levels of radiation at the time of the tests which significantly affected the calculated HLC when accounted for against the raw power data.

Embedded calculations and assumptions within the SAP methodology could also contribute to a difference in HLC outputs. For example, the formula used to estimate background infiltration rates is based upon a standardized rule of thumb, where the Q50 air pressurization test result is divided by a factor of 20. The methodology applied has been simplified in the SAP model, as originally a series of additional factors were developed to adjust for dwelling height, shelter/exposure, type and size of air leakage pathways, and environmental concerns, which led to subsequent modification of the default division factor (Sherman 1987; Berge 2011). The ability of the simplified equation to accurately reflect background infiltration rates in energy models has been questioned, although research in this area is currently limited (Jones 2012). In the context of the work presented here, a basic evaluation of the data showed that when the Q50 value was divided by a range of values from 10% to 30%, a variance of up to 9 W/K was observed in the calculated HLC. Therefore, further investigation could be useful in assessing whether lack of refinement of the divide by 20 value is impacting upon the SAP 2009 predicted HLC.

CONCLUSIONS

Building Regulations in the UK are becoming more stringent in terms of thermal performance and air tightness requirements. As a result, it is likely that the use of artificial ventilation strategies, such as MVHR, will become more necessary to ensure good levels of air quality and healthy living conditions. Whilst it is relatively straightforward to install such systems in new build houses, it is more problematic to achieve high efficiency levels in retro-fit projects.

This study has enabled the detailed analysis of an MVHR system installed in the 1930's replica E.On House, which is representative of a large proportion of the current UK housing stock. The complexities and importance of correct installation and commissioning, and the heat losses associated with these stages in the supply chain, has been clearly highlighted. Whilst a manufacturer can design a very efficient system, the benefits of this can be easily negated through inadequate installation and commissioning in a property.

Initially, a design stage SAP model was constructed in order to predict the HLC for the E.On House with an MVHR system working at 90% efficiency. The subsequent co-heating test HLC result showed a large discrepancy when compared to the values predicted by the SAP methodology, largely as a result of the MVHR system only performing to 76% efficiency levels. The system manufacturer collaborated in the undertaking of system modifications and commissioning, in order to achieve the optimum 90% efficiency levels.

However, the HLC calculated at the design and post-construction stages were not the same in either the 76% or 90% MVHR efficiency scenarios. The baseline data, with no additional ventilation strategy, was consistent, leading to the conclusion that the inconsistency was attributable to the ventilation heat losses rather than the fabric of the property (i.e. U-values and construction). When the data were normalized to account for oversupply of air throughput due to system imbalances, an unaccounted heat loss of approximately 6 W/K was still apparent in both MVHR cases. In overall conclusion, high quality MVHR installation and commissioning work is critical to ensure that a system can perform to the optimum levels specified in manufacturer literature. Education and training throughout the supply chain is essential in order to achieve this, as system inefficiencies can lead to unnecessary heat losses resulting from increased levels of air infiltration or leakage, and also poor performance of the heat recovery unit. Whilst SAP 2009 and the co-heating test methodologies do provide a useful indication of predicted and as-built fabric performance, both techniques contain assumptions and potential sources of uncertainty that could impact upon the reliability of the generated HLC data. Additional research is required to fully understand the sensitivity of the techniques used to obtain the HLC value, both at the design and post-construction stages.

ACKNOWLEDGEMENTS

This work forms part of the E.ON funded Retrofit Research House Project and the CALEBRE Project which is funded by the Research Councils UK Energy Programme and E.ON, to whom the authors express their gratitude. For further information on the E.On Retrofit Research House Project, please email mark.gillott@nottingham.ac.uk, and for more details regarding the CALEBRE Project, contact Dennis L. Loveday, Loughborough University at d.l.loveday@lboro.ac.uk.

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