EVALUATING THE IMPACT OF AN ENHANCED ENERGY PERFORMANCE STANDARD ON LOAD-BEARING MASONRY DOMESTIC CONSTRUCTION

Partners in Innovation Project: CI 39/3/663

Interim Report Number 5 – Post-Construction Testing and Envelope Performance

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Executive Summary

1 This report forms deliverable 5 of the Stamford Brook PII project and details the results of a range of dwelling performance tests of masonry cavity dwellings. The tests included measurements of airtightness and ventilation flows. Two co-heating tests were also conducted to measure actual whole house heat loss coefficients. The results are discussed in the context of the performance requirements of the EPS08 enhanced performance standard being used at Stamford Brook and also in relation to Approved Documents Part L and Part F of the Building Regulations.

2 Pressure tests were conducted on 31 individual dwellings at Stamford Brook of various types between February 2005 and April 2006. The measured air permeabilities at 50 Pa pressure difference ranged from 1.8 m/h to 9.7 m/h, with a mean of 4.9 m/h. The mean is within the airtightness target stipulated in EPS08 of 5 m/h. However, 42% of those dwellings tested failed to meet the target. Nonetheless, all those tested would have met the 10 m/h target in ADL1A 2006. The dwellings at Stamford Brook compare well with two recent studies of the airtightness of dwellings built to meet the requirements of ADL1 2002 where mean permeability was found to be 9.2 m/h in one study and 11.1 m/h in the other, with a maximum permeability of around 17 m/h.

3 The developers have demonstrated that the use of a parged layer on all external and party walls in conjunction with plasterboard lining on adhesive dabs provides an effective airtight seal to the medium density concrete block walls. However, the developers chose to make several design compromises that would have likely resulted in poorer airtightness in favour of other factors such as improved buildability and perceived safety benefits. For example, it was decided to use built-in joists in preference to joist hangers despite evidence that joist hangers are a more robust airtight solution. It was also decided to install the top floor ceiling after the partitioning had been erected instead of erecting the ceiling first, resulting in multiple gaps in the plasterboard air barrier. In both these cases, the pressure test data indicate that better airtightness was achieved with the more robust alternative design strategy.

4 The developers had particular problems achieving the airtightness target for room-in-roof 2 ½ storey house designs. This was believed to be due to major discontinuities in the air barrier at the junction between the parging layer on the wall and the plasterboard wall in the room-in-roof. Attempts were made on-site to improve the airtightness of the room-in-roof dwellings by using a polythene damp proof membrane sheet to provide a link between the air barriers. However, the airtightness results indicated that these efforts were unsuccessful. Extensive remedial secondary sealing measures were carried out on the 2-½ storey dwelling that had been tested and had failed to meet the 5 m/h target, but in all cases these efforts proved futile and did not result in any significant improvement in airtightness. A change in the design of the attic trusses being used on site has since made it even more difficult in design terms to resolve issues of air barrier discontinuities for room-in-roof properties.

5 A general upward trend in airtightness was observed during the period that pressure tests were undertaken. It is believed that this trend indicates a possible reduction in the quality control of specific airtightness measures. It may also be a result of other factors such as a reduced focus on the refreshment of training, particularly when changes in personnel and subcontractors take place, and subtle on-site changes in design and product substitutions. This has implications for Part L in terms of when pressure tests are conducted on large developments where the developer has chosen to use accredited details as the compliance route. In such cases, the reduced level of pressure testing needed would normally be skewed to the first stages of the development and consequently would miss similar upward trends as those observed at Stamford Brook.

6 Co-heating tests were conducted on a 2-storey semi-detached house from Bryant and a 3-storey mid-terraced property from Redrow. In both cases, the measured heat loss coefficients were significantly higher than those predicted from the designed fabric U-values and measured air permeabilities. For the semi-detached dwelling the discrepancy was 75% and for the mid-terraced dwelling the discrepancy was 103%. Analysis by infra-red thermal imaging and from temperature measurements indicate that the most likely cause of the difference is related to a heat loss mechanism via the uninsulated party wall cavities into the loft space.

7 Heat bypass mechanisms have been proposed before in the literature, but the data collected at Stamford Brook is the first time we know of that convincing direct evidence has been obtained to confirm the presence of such a mechanism in party wall cavities. Such heat loss mechanisms are not covered by SAP 2005 or ADL1A 2006 and could lead to dwellings with party walls significantly underperforming their predicted dwelling carbon emission rates. It is believed that relatively simple

construction measures could be introduced that would eliminate party wall cavity heat losses. This could include either insulating the cavity wall or installing an insulated cavity sock horizontally at the level of the ceiling insulation. Further co-heating tests would be required to confirm the effectiveness of such measures and to assess the effect on other factors such as acoustic performance.

8 The results from measurements of air flows from the extract vents of the mechanical extract ventilation systems in several dwellings indicated that the flow rates were not achieving the expected design ventilation flows. Investigations revealed that the ventilation systems had not been fully commissioned. It was also found that there were several technical issues relating to the installations. This included a potential problem with the use of low profile roof tile terminal vents that had been substituted for the ridge vents originally specified by the system manufacturer. The low profile vents had a very high pressure loss associated with them and consequently the ventilation systems could not achieve their design flow rates. Investigations are ongoing and the developers and system manufacturer have in place a program to rectify the situation.

Introduction

9 Stamford Brook is a development of 710 cavity masonry dwellings being constructed on part of the National Trust's Dunham Massey Estate near Altrincham in Cheshire. The development is being carried out under a partnership agreement between the National Trust and the two developers Redrow and Bryant. The development partners are also participating in a Partners in Innovation (PII) project with Leeds Metropolitan University (Leeds Met) that will investigate various aspects of the design and construction processes. This report forms Deliverable 5 of the PII project, and details the results of a range of performance tests carried out to determine the as-built performance of dwellings built during the first phase of the development in 2005.

10 The partnership agreement between the National Trust and the developers includes a contractual requirement that the dwellings in the first phase meet a range of performance criteria described in a site specific Environmental Performance Standard (EPS). The EPS includes requirements for sustainability targets such as the use of sustainable timber, minimised use of PVC components and the control of site generated waste. The EPS also stipulates that the dwellings meet the requirements of a prototype Enhanced Energy Performance Standard (EPS08) developed by Leeds Metropolitan University (Lowe & Bell, 2001) in excess of what would normally be required under Approved Document Part L1 2002 (ODPM 2001). This report details a series of tests carried out by the Leeds Met research team to determine whether the dwellings as constructed achieved the design energy and ventilation performance targets set out in the energy performance standard. The tests carried out included the following measurements:

a) Pressure tests using a blower door to measure air permeability.

b) Electric co-heating tests to measure the combined fabric and infiltration heat loss coefficient.

c) Ventilation system extract vent air flow measurements.

d) Thermal imaging of the main elements and junctions between elements.

Energy and Ventilation Performance Standards

11 The EPS08 energy performance standard being used at Stamford Brook defines elemental target U-values for the main elements along with a target for air permeability and a limit on the carbon intensity of the heating system. EPS08 also makes requirements for the ventilation performance of the dwellings. Discussions between the National Trust and the developers, along with advice from Leeds Met, resulted in design parameters for the Stamford Brook development for each of the components in EPS08. Deliverable 2 of the PII project describes the process by which the partners arrived at the final energy standard and design values for Stamford Brook (Roberts, Bell and Lowe, 2004). A comparison of the final design target values with the EPS08 targets is summarised in Table 1. The design values for the main elements (wall, roof and floor) all fall inside the requirements of EPS08 as an allowance was made for each element for point thermal bridges and single-sided thermal bridging at the main linear junctions between elements for typical house types. In terms of air permeability, the final design value was fixed at 5 m/h, although there had been a lot of discussion in the early design meetings whether to set a lower target of 3 m/h.

Table 1 – Comparison of EPS08 Targets and Stamford Brook Design Target Values

Element/Parameter	EPS08 Requirement	Stamford Brook Design Target Values
Exposed Walls	U-value: 0.25 W/m^{2}K	U-value: 0.23 W/m^{2}K
Roof	U-value: 0.16 W/m^{2}K	U-value: 0.15 W/m^{2}K
Floor	U-value: 0.22 W/m^{2}K	U-value: 0.19 W/m^{2}K
Windows, Doors & Rooflights	U-value: 1.3 W/m^{2}K Max Area: 25% of gross floor area	Window U-value: 1.3 W/m^{2}K Door U-value: 1.0 W/m^{2}K
Air Permeability	5 m/h at 50Pa	5 m/h at 50Pa
Carbon Intensity of Heating System	70 kg CO_2/GJ Useful Heat – This equates to a gas condensing boiler efficiency of 85%	Gas condensing boiler efficiency: 91%

12 A summary of the main components of typical construction elements is given in Table 2. Also shown are the nominal U-values for the elements. In the case of the warm roof element, the construction details given in Table 2 reflect the actual construction technique used on site, which was an attic truss with rigid polyurethane insulation. The original calculations of U-values and thermal bridging carried out by Leeds Met on the warm roof details were for the original I-beam design with cellulose insulation (Roberts Bell & Lowe 2004). The U-value has not been calculated for the attic truss detail with polyurethane insulation, as the design has been continually changed and adapted on site. Observed gaps in the rigid urethane insulation layer would increase this significantly, probably by around 0.05 W/m^{2}K.

Table 2 – Nominal U-Values and Construction Details of Main Elements

Element	Nominal U-Value (W/m^{2}K)	Main Construction Details of Element
External Wall	0.230	103 mm Facing Brick 100 mm Medium Density Concrete Block (~1400 kg/m^3) 142 mm External Wall Cavity[1] 250 mm Glass-filled Polyester Wall Ties (External Wall) Fully Filled Blown Mineral Fibre Insulation Parging Plaster Layer (2-4 mm) on Blockwork of External and Party Walls Plasterboard Drylining on Adhesive Dabs
Ground Floor	0.172	150 mm In-situ Cast Reinforced Concrete Suspended Floor 100 mm Rigid Polyurethane Insulation below Slab
Cold Roof	0.142	250 mm Blown Recycled Cellulose Insulation at Ceiling Level 12.5 mm Plasterboard
Warm Roof	-	Attic Truss Room-in-roof Construction with 75mm Rigid Polyurethane Insulation between Rafters and 50mm Rigid Polyurethane Insulation above Rafters 12.5 mm Plasterboard
Windows[2]	1.30	Double Glazed Timber Frame Units Glazing configuration: 4mm glass - 18mm cavity - 4mm glass Ultra Low Emissivity Soft Coating (e = 0.04) Centre Pane Glazing U-value 1.175 W/m^{2}K Solar Energy Transmittance (g-value) 0.63 Argon Filled (90% argon, 10% air) Warm Edge Spacerbar

13 THERM modelling software (LBNL 2003) was used to estimate the values of 2-d linear thermal transmittance (Ψ value) for the various thermal bridges at junctions between elements. The Ψ

[1] For semi-detached and terraced dwellings, the party wall cavity thickness was maintained at the same depth as the external wall cavity at 142mm in the case of dwellings built by Bryant but reduced to 75mm in the case of dwellings built by Redrow. In both cases, the party wall was not filled with any insulation except for where the acoustic cavity mineral wool socks installed at the vertical junction between the party wall and external wall may have protruded sideways into the party wall cavity.

[2] The windows were also required to have a BFRC domestic window energy rating (DWER) rating of 70 or better (Roberts, Bell & Lowe 2004). The Rationel windows used at Stamford Brook achieved a DWER rating of 71 (Chiltern Dynamics 2003). This DWER value is a rating obtained from a combination of the U-value, window air infiltration losses and the solar heat gain coefficient, and was originally based on a scale of 1-100 (BFRC 2001). The DWER calculation methodology has changed since these calculations were originally performed, and the DWER rating now reflects the energy performance in kWh/m^2/annum, depending upon whether the window gives a net gain or net loss of energy.

values obtained are given in Table 3. Also given in Table 3 are the default Ψ values from Table K1 in SAP for accredited details that can be used as part of compliance with ADL1A 2006 (BRE 2006).

Table 3 – Linear Thermal Transmittance of Main Thermal Bridges at Element Junctions

Location of Thermal Bridge	**Linear Thermal Transmittance Stamford Brook Details (W/mK)**	**SAP Table K1 Accredited Details Ψ Values (W/mK)**
Cold Roof-External Wall – Gable	0.061	0.24
Cold Roof-External Wall – Eaves	Redrow: 0.023, Bryant: 0.033	0.06
External Wall-External Wall	0.070	0.09
External Wall-Party Wall	Redrow: 0.048, Bryant: 0.053	0.03
External Wall-Ground Floor	0.112	0.16
External Wall-Intermediate Floor	0.004	0.07
Party Wall-Ceiling	Redrow: 0.130, Bryant: 0.157	Not in Table
Window/Door Sill	0.022	0.04
Window/Door Jamb	0.018	0.05
Window/Door Lintel	0.016	0.30

14 Changes as a result of the 2005 review of Part L of the building regulations came into force on the 6th April 2006. The compliance methodology for the new Part L1A 2006 (ODPM 2006a) for new dwellings is a whole building energy performance target based on a dwelling carbon dioxide emission rate (DER) in $kgCO_2$ per m^2 of gross floor area. The energy performance target for the new regulations is based on a percentage improvement (20%) in the emission rate of a notional dwelling of the same form constructed to the same dimensions and with a set of elemental U-values and air permeability given in Appendix R of Part L1A 2006 (ODPM 2006a). The elemental U-values in Appendix R are broadly equivalent to a dwelling that would be complaint with the requirements of ADL1 2002 (ODPM 2001). The energy performance target is termed the target emission rate (TER). The calculation methodology used to determine the DER is defined in the SAP 2005 (BRE 2005). Stamford Brook fabric parameters were used to calculate heat loss coefficients and carbon emission ratings for 3 standard house types as defined in the Leeds Met Parametric SAP Energy Calculator (Lowe, Bell, Roberts & Wingfield, 2005), in order to give an indication of how they would perform relative to the requirements of ADL1A 2006. The resultant indicative dwelling emission rates are given in Table 4. These calculations assumed a rectilinear form, plan-aspect ratio of 1.4, glazing-floor area ratio of 0.25, design air permeability of 5 m/h, 91% boiler efficiency, mechanical extract ventilation system (MEV) and used the Ψ values for linear thermal bridges given in Table 3 and the nominal elemental U-values given in Table 2.

Table 4 – Indicative Dwelling Carbon Emission Rates (ADL1A 2006) for Standard Dwelling Types Built to Stamford Brook Fabric and Permeability Specification

House Form	**Gross Floor Area (m^2)**	**Total Thermal Bridging (W/K)**	**C_f (W/K)**	**C_v (W/K)**	**TER ($kgCO_2/m^2$)**	**DER ($kgCO_2/m^2$)**	**Difference TER-DER %**
2-Storey Mid-terrace	55	5.1	37.9	26.1	23.8	22.0	-7.6 %
2-Storey Semi	80	6.5	60.1	37.2	23.2	20.5	-11.6 %
2-Storey Detached	100	7.6	81.5	46.1	23.9	20.2	-15.5 %

15 It can be seen from the indicative DER values in Table 4 that they exceed the requirements of their equivalent TER values by between 8% and 15%. This shows that dwellings constructed to meet the EPS08 standard have an energy performance that equates to around a 10% improvement over the requirements of ADL1A 2006. The exact difference will depend upon the house form, with detached dwelling types performing better in relation to ADL1A 2006 than semi-detached or mid-terraced properties, mainly due to the influence of energy requirements for the MEV system which will impact more on smaller sized dwellings. This performance would place the EPS08 standard

roughly halfway between the requirements of ADL1A 2006 and what would be anticipated from a further 20% improvement in performance requirements for Part L1A in 2010. The DER values of actual dwelling types constructed at Stamford Brook will differ from those given in Table 4 depending upon the actual dwelling form, aspect ratio, glazing ratio and measured permeability.

16 The background ventilation performance requirements of EPS08 are based on the maximum of either the sum of the minimum supply rates to all the main habitable rooms, or the sum of the minimum extract rates from all the wet rooms, as given in Table 5. A spreadsheet was developed by Leeds Met (Lowe & Roberts 2004) to determine the overall ventilation requirement for each dwelling type at Stamford Brook based on the ventilation performance specification in EPS08.

Table 5 - EPS08 Ventilation Requirements

Minimum Air Supply Requirements for Main Habitable Rooms (l/s)		**Minimum Air Extract Requirements for Main Wet Rooms (l/s)**	
Double Bedroom	10	Kitchen	20
Single Bedroom	5	Bathroom	10
Living Room	5	Separate WC	10
Dining Room	5		
Other Habitable Room	5		

17 The requirements of the new Approved Document Part F1 2005 on ventilation (ODPM 2006b) specify minimum extract rates for dwellings with continuous extract systems. Approved document F1 2005 requires a whole building ventilation rate of 15 l/s for a one-bedroom dwelling, increasing by 4 l/s for each additional bedroom. Part F1 2005 also specifies minimum continuous extract boost extract rates in of 13 l/s for kitchens, 8 l/s for bathrooms and utility rooms and 6 l/s for any other sanitary accommodation.

Co-heating Tests

18 Two co-heating tests were carried out on newly constructed dwellings at Stamford Brook, with one dwelling provided by each of the two developers. The co-heating test is a method of determining the actual heat loss due to combined fabric and infiltration losses of an unoccupied dwelling. The measured heat loss can then be compared to that predicted by a thermal model[3].

19 The co-heating test involved heating the inside of each dwelling to a set temperature (typically around 25°C) over a period of at least a week using electrical resistance heaters. The heat loss in W/K could then be determined by measuring the daily electrical energy used to maintain the inside temperature relative to the daily mean difference between the internal and external temperature (delta-T). In order to minimise contributions from other heat loss or heat gain mechanisms during the test, all electrical and heating systems inside the dwelling were turned off (e.g. boiler, heating system, fridge, lights, ventilation fan, etc) and all ventilation system vents and other openings were closed (windows, doors, tickle vents, extract vents, cooker hood etc). In order to maintain an even temperature profile throughout the dwelling, circulation fans were used to mix the internal air. The energy used by the fans was also included in the calculations of energy used to maintain internal temperature. In order to maximise the delta-T value, the co-heating tests were carried out in winter when the external temperatures are lower. The two co-heating tests at Stamford Brook were carried out between December 2005 and February 2006.

20 The use of co-heating tests to determine heat loss coefficients of dwellings has been previously reported in the literature. For example, a co-heating test was used to determine the effectiveness of a series of energy improvement measures carried out on some existing dwellings in York (Bell & Lowe 1998).

[3] The thermal model used in this study was SAP. For the purposes of the comparison, the model assumed a naturally ventilated dwelling as the mechanical ventilation system installed in the dwellings was turned off during the co-heating test.

Co-heating Test Equipment and Instrumentation

21 The various items of test equipment and instrumentation used for the co-heating tests at Stamford Brook are listed in Table 6. The datalogger used for the test was an Eltek wireless system with GSM modem which allowed for flexibility in the placement of temperature sensors and kWh meters without the need for extensive wiring. Each floor of the test dwelling was equipped with one pulse output kWh meter connected to an electromechanical in-line thermostat and wireless pulse transmitter. This was done to minimise the load on the electrical system and to allow for temperature control of each floor as a zone. On each floor, the fan heater and circulation fans were connected to the kWh meter via a 4-gang extension lead. Each kWh meter was connected to a mains socket via the in-line thermostat and an RCD socket adapter.

Table 6 - Co-heating Test Equipment Specification

Component	Equipment Used	Equipment Specification
Datalogger	Eltek RX250 Receiver Logger	250 channel radio receiver logger Set at 10 minute logging interval
GSM Modem	Wavecom M1206B GSM Modem	
Temperature Sensor	Eltek GC-10 Temp/RH Radio Transmitter	Minimum of 1 per floor
kWh Meter	Schlumberger SPA02	10 Wh pulse output 1 per floor
Pulse Transmitter	Eltek GS-62 Pulse Radio Transmitter	1 per kWh meter
Thermostat	Honeywell T4360B Thermostat	16A load capacity Mounted on a tripod at 1m 1 per kWh meter
Fan Heater	Delonghi THE332-3 3kW Fan Heater	3 kW max heat output 1 per floor
Circulation Fan	Prem-I-Air HPF-4500 Air Circulator	18” fan blade Minimum of 2 per floor

22 In addition to the equipment listed in Table 6, the co-heating test required the collection of external weather data. These were obtained from the Leeds Met weather station located on site at Stamford Brook. The weather measurements needed for the co-heating test were the external temperature and the vertical south facing solar insolation. The external temperature/humidity sensor and pyranometer fitted to the Leeds Met weather station are listed in Table 7. The weather station data were also collected by an Eltek wireless datalogger system.

Table 7 - Leeds Met Weather Station Equipment Specification

Weather Station Component	Equipment Used	Specification
Datalogger	Eltek RX250 Receiver Logger	250 channel radio receiver logger Set at 10 minute logging interval
GSM Modem	Wavecom M1206B GSM Modem	
Temperature/Humidity Gauge	Rotronic Hygroclip S3 External Temperature/Humidity Sensor	Positioned at 2m on 4m mast Protected by Stephenson Radiation Screen
Temperature/Humidity Transmitter	Eltek GS-13 Hydroclip Radio Transmitter	
Pyranometer	Kipp & Sonnen CM3 pyranometer	Vertical Orientation South Facing Positioned at 3m on 4m mast
Pyranometer Transmitter	Eltek GS-42 Voltage Radio Transmitter	Voltage Range 0-50mV

23 The co-heating test equipment is illustrated in Figure 1. This photograph shows the fan heater, kWh meter, pulse transmitter, thermostat and one of the circulation fans in position on the ground floor of one of the test plots.

Figure 1 - Co-heating Equipment on Location in Test Dwelling at Stamford Brook

Co-heating Testing Procedure

24 The test procedure used for the co-heating tests was as follows:

a) All electrical systems not used during the test were switched off (at the mains switch where applicable). These included the fridge, freezer, heating controls, oven, ventilation fans, cooker hood and all lights.

b) All ventilation extracts or inlets were either closed or sealed with plastic film. These included trickle vents in windows and mechanical extract system vents. It was not necessary to seal the cooker extracts as these were recirculating systems with no external extract.

c) All heating systems such as the gas boiler and immersion tank were turned off.

d) All external openings such as windows, doors and loft hatches were inspected to ensure that they were tightly closed.

e) All traps in sinks, baths, toilets and showers were filled with water.

f) All internal doors were wedged open. These included doors to the cylinder cupboard and built-in wardrobes and cupboards.

g) Each floor in the test dwelling was fitted with a kWh meter which was plugged into a mains socket via an in-line thermostat mounted on a tripod. For health and safety reasons, the mains circuit was protected with a plug-in RCD socket adapter. The pulse output of the kWh meter was connected to the input of a pulse radio transmitter. A fan heater was then connected to the kWh meter via an extension lead wired directly to the output of the kWh meter and located so as to provide heating to as much of the floor as possible. Two or three circulation fans (depending upon the floor size) were also connected to the extension lead output of the kWh meter and located at appropriate positions in the dwelling to provide good mixing of the internal air.

h) The thermostat on each floor was set initially at 25°C.

i) Between one and two temperature/humidity sensors were positioned on each floor, out of direct sunlight and out of direct line of the fan heater.

j) The test commenced by turning on the fan heaters to their maximum heat and fan speed settings. The circulation fans were also turned on to their maximum speed setting. The datalogger was set to log at 10 minute intervals.

k) For the first couple of days of the test, the logged temperatures were observed to ensure that the internal temperatures recorded by all the sensors were increasing to the set point. Once the set point had been reached, observation continued to determine the stability and spread of internal temperature. Where necessary the thermostats on the different floors were adjusted to give an even temperature throughout the dwelling. Where the internal temperatures had drifted slightly from the 25°C set point but were stable and even, the test was allowed to continue at the different set point as stability was more important than the actual temperature.

l) During the tests, access to the test dwellings was restricted to a minimum. Where visits were necessary to adjust thermostats or check equipment, these were kept as short as possible and care was taken not to leave outside doors open for longer than necessary and lights were not turned on.

m) The internal temperatures, kWh readings and external weather data were downloaded from the loggers by GSM modem on a regular basis.

n) The test was allowed to run for around one week after the internal temperatures had stabilised and when data had been recorded from days with a sufficient range of delta-T values so as to give a reasonable plot of delta-T against power input.

o) The fan heater and circulation fans were then turned off. Logging of the internal temperatures continued for several days so as to record the temperature decay rate. The decay data could potentially be used to obtain a value for the thermal decay constant for the dwellings.

p) At the end of the co-heating test a blower door pressure test was carried out.

Specification of Co-heating Test Dwellings

25 The two test houses were selected by the developers from the available stock. The dwelling selected by Bryant for test was a two-storey semi-detached property designated as a “Chatsworth” type and was located at plot 13. This dwelling was one of the Bryant show houses (as was the adjacent semi) and was carpeted and fully furnished. The dwelling selected by Redrow for test was a three-storey mid-terrace property designated as a “Wye” type and was located at plot 402. This dwelling was from Redrow’s stock and was unfurnished with no floor coverings. The construction details for the two properties are summarised in Table 8.

Table 8 - Construction Details and Permeabilities of Co-heating Test Dwellings

Developer	Plot No.	Developer House Type	Form	Gross Floor Area (m^2)	Vol (m^3)	Plan Aspect Ratio	Glazing Ratio (window area/ GFA)	General Orientation of Main Facade	Glazing Asymmetry (% glazing on front)	Initial Air Permeability (m/h)
Bryant	13	Chatsworth	Semi 2-storey 3-bed	73	190	1.64	0.17	South Facing	0.5	3.3
Redrow	402	Wye	Mid-terrace 3-storey 3-bed	106	267	1.37	0.19	East Facing	0.4	5.3

26 Photographs of the two co-heating test houses are illustrated in Figure 2. Plan, elevation and section drawings for the two different house types are illustrated in Figures 3 and 4.

Plot 13 **Plot 402**

Figure 2 - Photographs of the Co-heating Test Dwellings Plot 13 and Plot 402

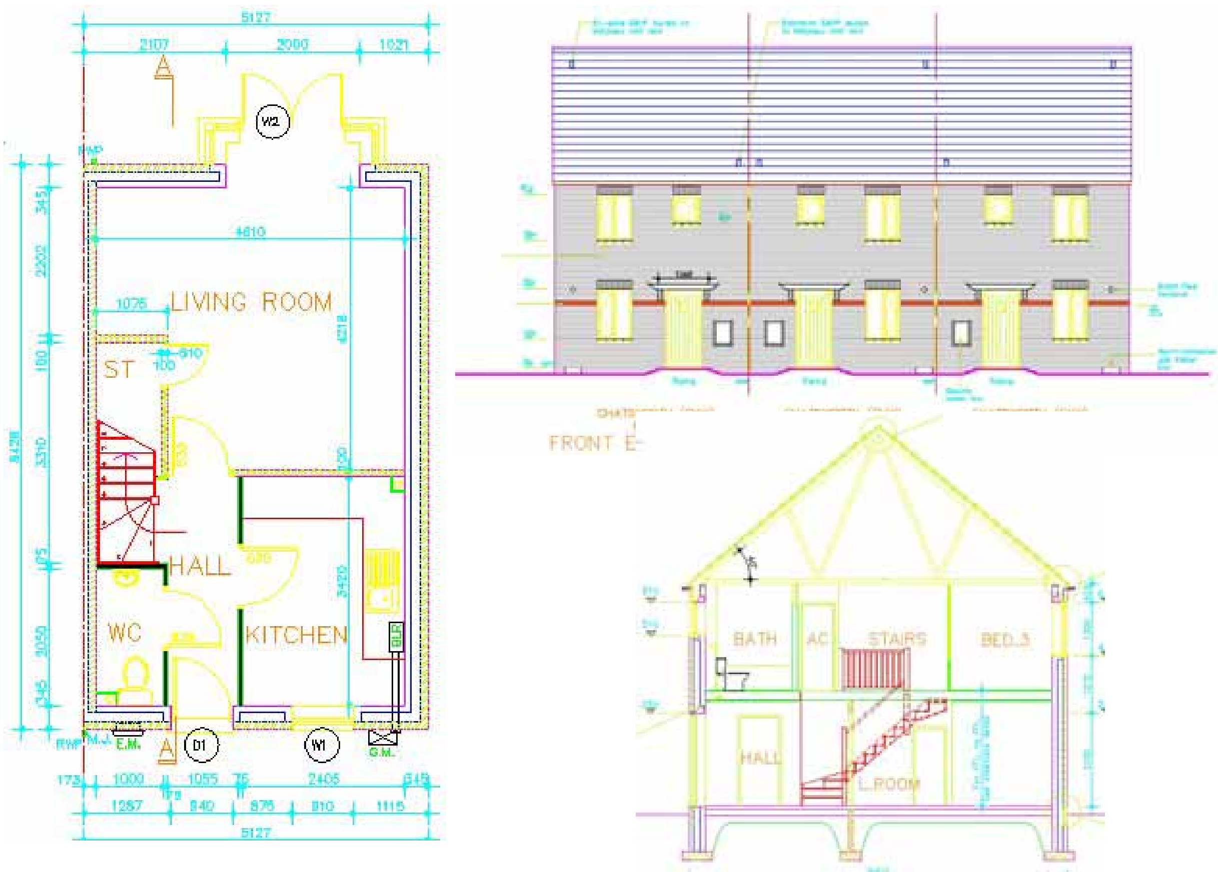

Figure 3 - Plan, Elevation and Section Drawings for Bryant "Chatsworth" House Type (Plot 13)

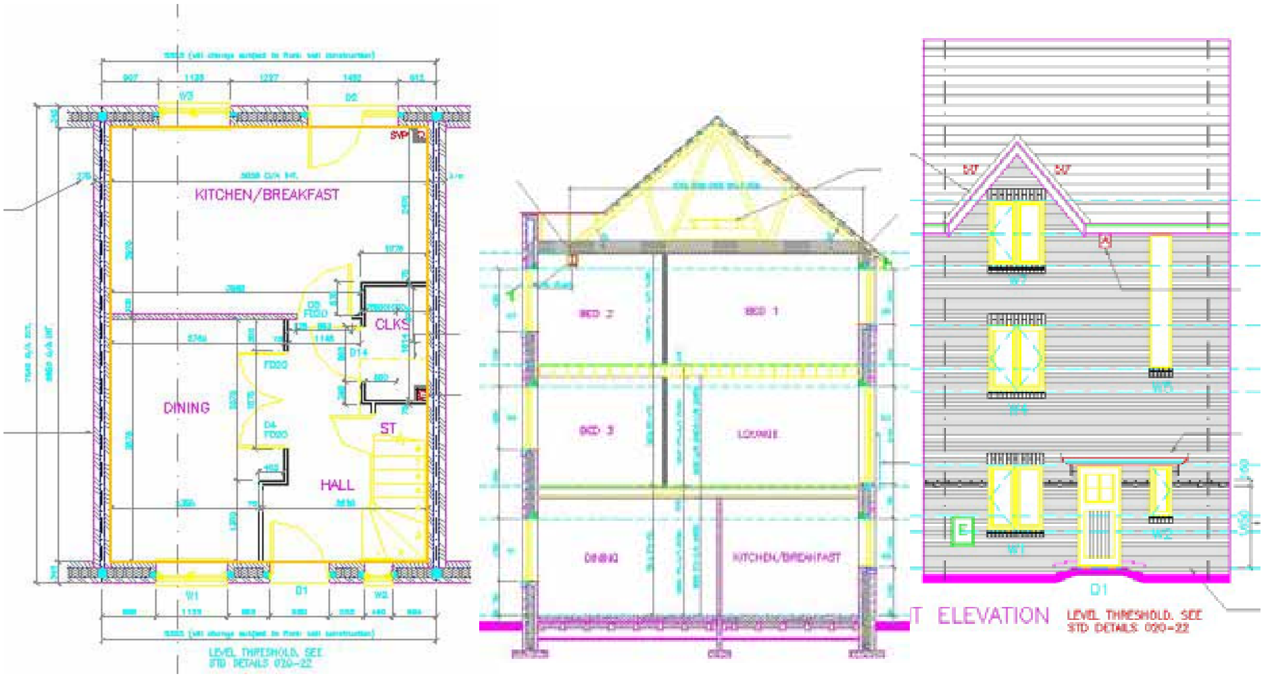

Figure 4 - Plan, Elevation and Section Drawings for Redrow "Wye" House Type (Plot 402)

27 The location of the two co-heating test dwellings on the Stamford Brook site are shown on Figure 5.

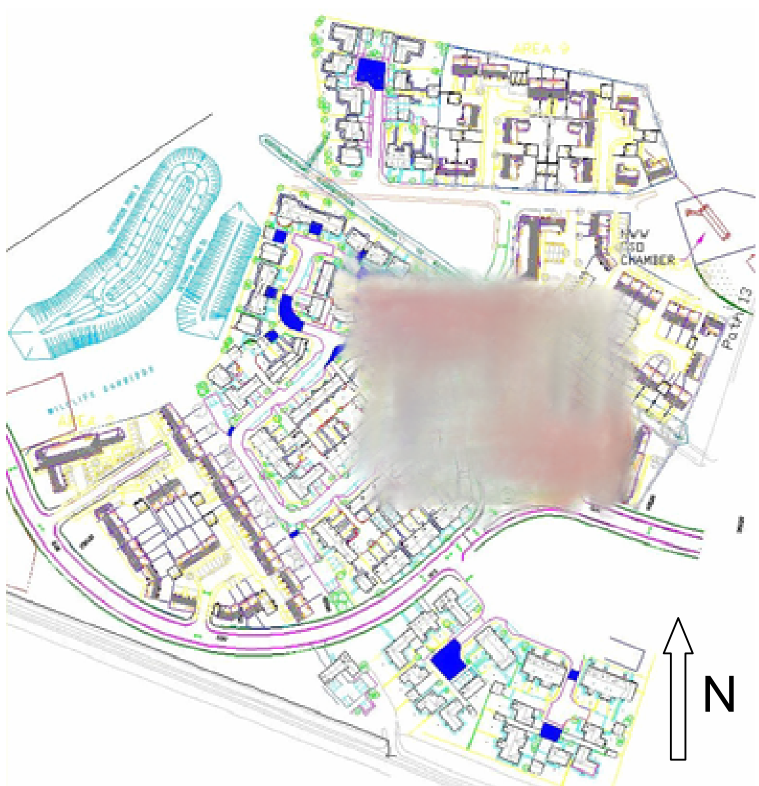

Figure 5 - Locations of Plot 13 and Plot 402 on Stamford Brook Site (locations obscured to preserve anonymity)

28 The ventilation and fabric heat loss coefficients for the two test properties were predicted by the Leeds Met parametric SAP energy model using the construction details in Table 8 and using actual air permeabilities measured using a blower door before commencement of the co-heating tests. The permeability of plot 13 was 3.3 m/h and the permeability of plot 402 was 5.3 m/h. The calculated heat loss parameters are given in Table 9. For the purposes of the predictions the "ventilation type" parameter in the Leeds Met parametric SAP model was set to natural ventilation as the installed MEV systems were not in operation during the tests[4]. The spreadsheets from the Leeds Met parametric SAP for the two plots are shown in Appendix 1.

Table 9 - Predicted Heat Loss Parameters

Plot No.	Ventilation Heat Loss Coefficient C_v (W/K)	Fabric Heat Loss Coefficient C_f (W/K)	Thermal Bridging (included in C_f) (W/K)	Total Heat Loss Coefficient $C_v + C_f$ (W/K)
13	13.2	50.6	6.0	63.8
402	20.3	54.9	5.8	75.2

Results of Co-heating Tests

29 The data from the two co-heating tests can be plotted as the daily power input in watts obtained from the kWh meter readings versus the daily mean delta-T. These raw data plots are illustrated in Figures 6 and 7. The predicted heat losses from Table 9 are also shown on the graphs.

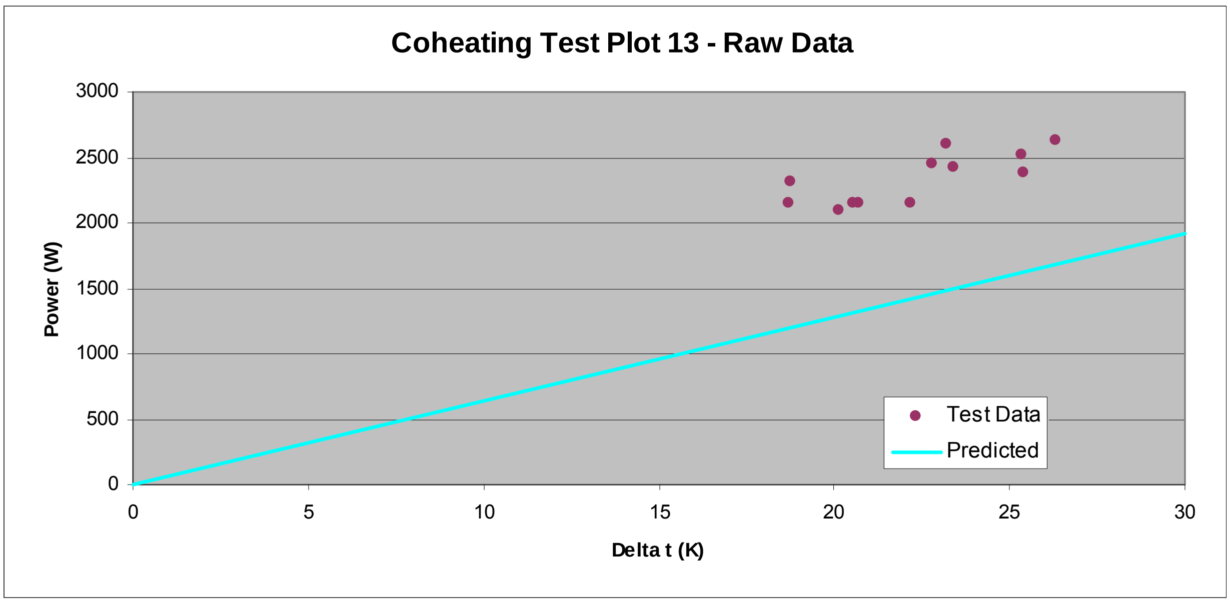

Figure 6 - Co-heating Test Plot 13 - Plot of Power (W) versus Delta-T (K)

[4] In addition to using the natural ventilation algorithm in Parametric SAP, the ventilation rate due to intermittent fans that would normally be added to the total ventilation rate for a naturally ventilated dwelling in Parametric SAP was set to zero. For both test dwellings, the shelter factor in the ventilation algorithm was set to 0.85, assuming that two sides were sheltered. The adjustment factor in SAP for window opening behaviour was also ignored.

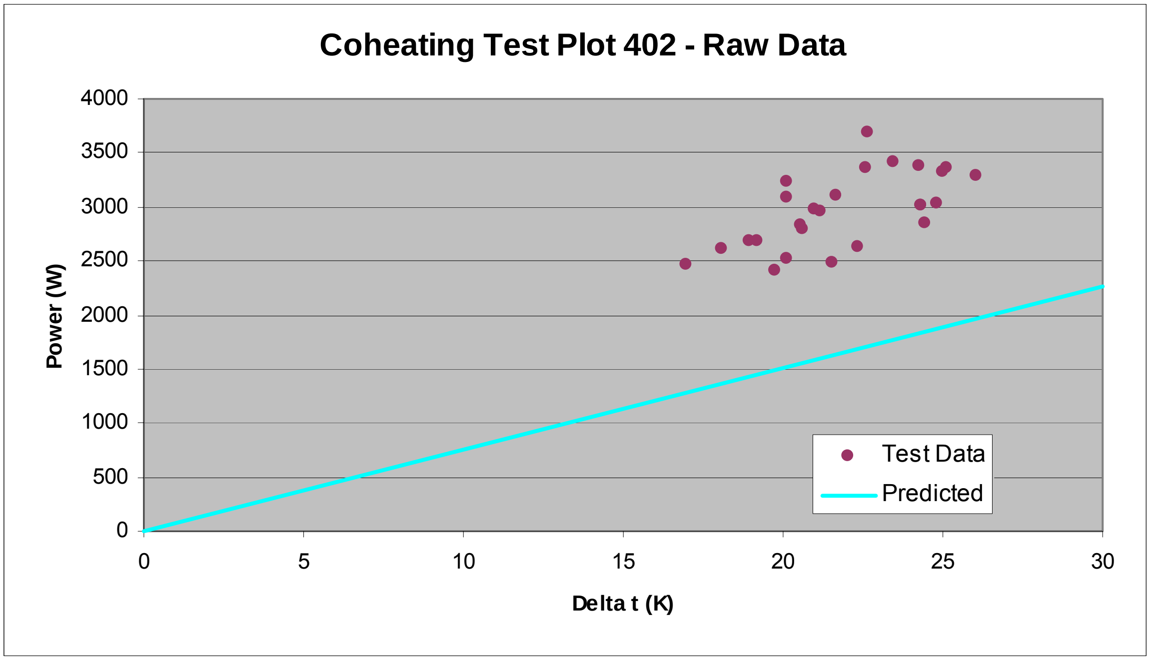

Figure 7 - Co-heating Test Plot 402 - Plot of Power (W) versus Delta-T (K)

30 It can be seen from Figures 6 and 7 that in, the case of both test plots, the measured heat loss factors from the raw data are significantly higher than the predicted values. These raw data now need to be corrected to account for the effect of heat gains due to solar radiation during the tests. This will have the result of increasing the difference between the predicted and measured values. The magnitude of the difference will depend upon how much solar radiation there was during the days of the tests.

31 The procedure for correcting for the effect of solar gain was first to analyse the pyranometer data from the weather station for the period of the tests to obtain the daily mean solar insolation values. A multiple regression analysis was then carried out on the co-heating data sets with the total daily power consumption in Watts set as the dependent variable and mean daily delta-T (K) and mean daily solar insolation (W/m^2) as the two independent variables. The output from the multiple regression analysis was a regression equation of the form:

$y = m_1x_1 + m_2x_2 + c$ …Equation 1

Where y is the dependent variable, x_1 and x_2 are the independent variables, m_1 and m_2 are the two regression coefficients and c is the intercept constant. The daily power consumption can then be corrected for solar gain according to the following equation:

$Power(c) = Power(r) - (m_2 . x_2)$ …Equation 2

Where Power(c) is the corrected daily power consumption, Power(r) is the daily power consumption, m_2 is the regression coefficient for solar insolation and x_2 is the mean daily solar insolation value.

32 The results of the multiple regression analysis are given in Table 10. The calculated heat loss coefficients are shown in Table 11 and compared to the predicted values. Plots of corrected daily power output versus delta-T are illustrated in Figures 8 and 9. The corrected data are shown with the regression line (regression forced through origin). It can be seen from the two graphs that, in both cases, the fitted line would not pass through the origin as would be expected. An alternative method of correcting for solar insolation using the SAP solar gain algorithm is discussed in Appendix 2 and gives similar results. The fact that the data corrected for solar gain lie above the raw data is as expected. The solar gain over the duration of the co-heating test is an additional source of heat which is not measured by the test rig's electricity meter. The effect of the solar gain is therefore to depress the measured electricity consumption. Correcting for this effect moves the data points upwards and reduces the scatter about the trend line.

Table 10 - Results of Multiple Regression Analysis

Test Plot	Multiple Regression Intercept (y)	Regression Coefficient for delta-T (m_1)	Regression Coefficient for Solar Insolation (m_2)	Standard Error on Solar Regression Coefficient m_2	R^2 Correlation Coefficient
Plot 13	967.7	66.2	-5.5	4.9	0.63
Plot 402	553.1	127.4	-9.0	1.5	0.77

Table 11 - Calculated Heat Loss Coefficients

Test Plot	Predicted Heat Loss Coefficient (W/K)	Mean Heat Loss Coefficient from Raw Data (W/K)	Mean Heat Loss Coefficient from Corrected Data (W/K)	Difference between Predicted Heat Loss and Corrected Heat Loss (W/K)
Plot 13	63.8	105.4	111.7 ± 5.9	47.9 (75%)
Plot 402	75.2	136.3	153.4 ± 3.3	78.2 (103%)

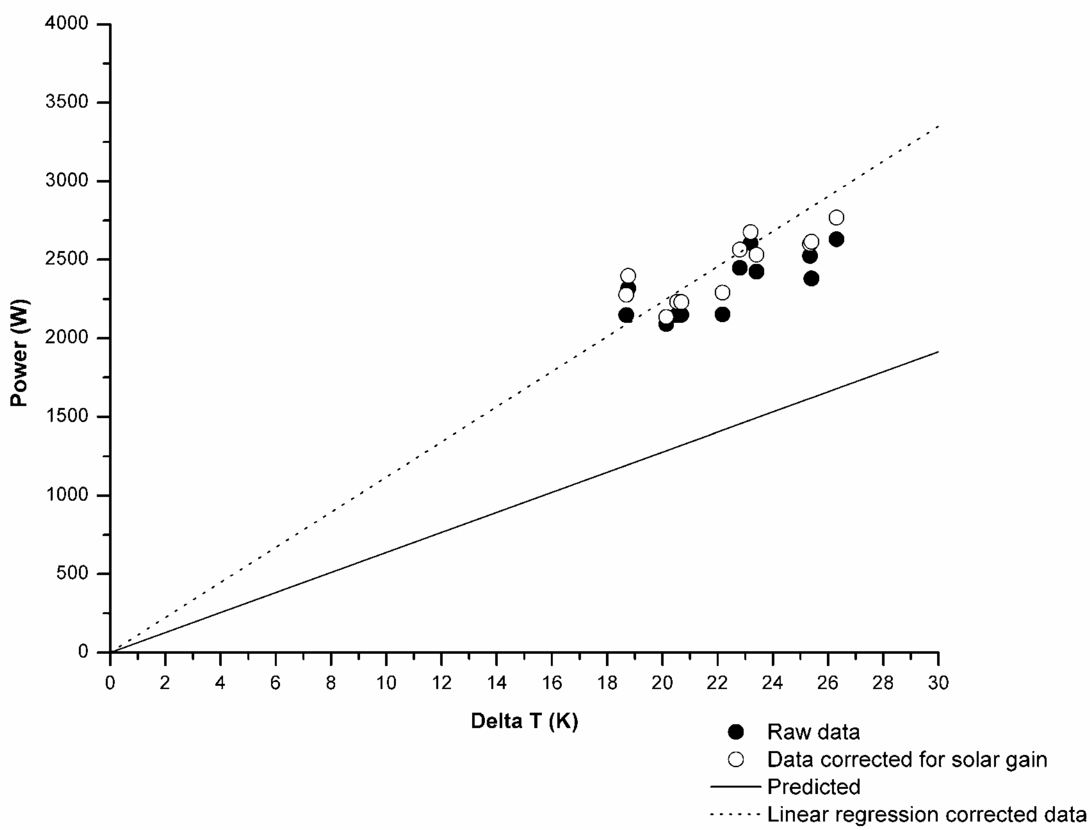

Figure 8 - Co-heating Test Plot 13 - Plot of Power (W) versus Delta-T (K) Corrected for Solar Gain

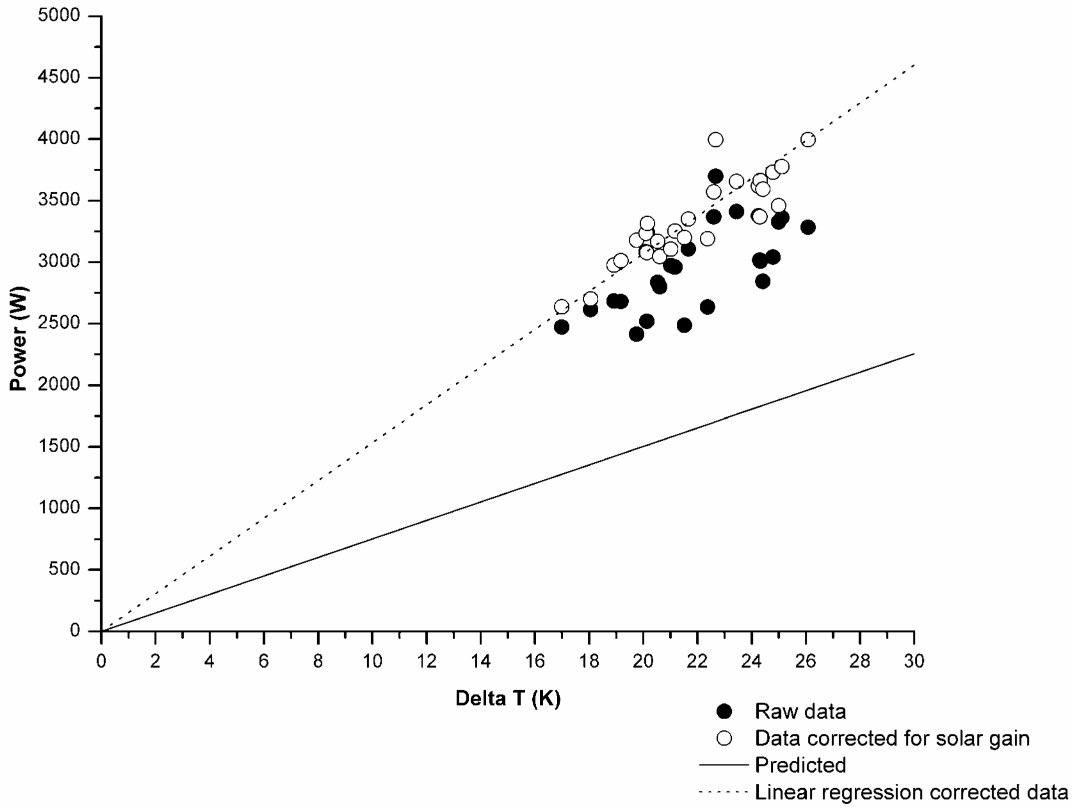

Figure 9 - Co-heating Test Plot 402 - Plot of Power (W) versus Delta-T (K) Corrected for Solar Gain

33 From Table 11 it can be seen that there is a significant discrepancy between the solar corrected heat loss coefficient and the predicted heat loss coefficient for both co-heating tests. In the case of the semi-detached plot 13 the difference is 75%, and for the mid-terraced plot 402 the difference is 103%. There could be several potential reasons, possibly in combination, which might explain the observed differences between measured and predicted values.

34 There will be a significant horizontal heat flow from the test dwellings to the adjacent dwellings. The SAP thermal model disregards heat flows across party walls between adjoining properties such as in the case of semi-detached dwellings, terraced houses and apartments, as it is assumed that the internal temperatures of different dwellings will be similar. However, whereas the co-heating test houses were heated to a controlled temperature of around 26°C, the internal temperatures of adjoining properties were not controlled by Leeds Met during the test period as they were either occupied or being used as a show house. This would have given rise to a delta-T between the adjoining dwellings of around 6°C, if it is assumed that the mean internal temperatures of the occupied dwellings and show home is around 20°C. The horizontal heat flux through the party walls can be estimated for both test plots using the U-value of the party wall, area of the party wall(s) and the delta-T between the test dwelling and adjacent properties. The U-value of the uninsulated party walls at Stamford Brook was calculated to be 1.11 W/m^{2}K. In the case of semi-detached plot 13 there is only one party wall to consider. In the case of the mid-terrace plot 402 there are two party walls. We can estimate the unaccounted for whole house heat flux using the heat loss coefficients and a nominal delta-T between inside and outside of the test dwellings of 26°C, if it is assumed that the mean external temperature during the test was around 0°C. The calculated heat fluxes are given in Table 12. It can be seen from the data in Table 12 that the horizontal heat flux between adjoining dwellings would account for between 18% and 30% of the discrepancy between predicted and measured heat loss. This still leaves a heat flux discrepancy of 1183 W in plot 13 and 1594 W in plot 402 that cannot be immediately explained.

Table 12 - Total Heat Flux and Horizontal Party Wall Heat Flux

Plot No.	Predicted Total Heat Flux - assuming delta-T of 26°C (W)	Measured Total Heat Flux - assuming delta-T of 26°C (W)	Unaccounted for Heat Flux (W)	Estimated Horizontal Heat Flux across Party Wall(s) - assuming delta-T of 6°C between dwellings (W)	% of Unaccounted for Heat Flux due to Horizontal Heat Flow across Party Walls
13	1426	2865	1439	256	17.8%
402	1692	3975	2283	689	30.2%

35 Other possible explanations for the remaining unaccounted for difference between measured and predicted heat loss are as follows:

a) The U-values of the various construction elements may not have been achieved in practice due to quality or technical problems during construction.

b) The values for linear thermal bridging obtained by thermal modelling and used in parametric SAP may have been unrealistic due to either quality or technical issues during construction.

c) The air permeability of the test dwellings may have increased significantly during the test due to the high thermal stresses imposed on the building fabric, joints and junctions.

d) There may be other, as yet unidentified heat loss mechanisms, which are not included in the parametric SAP model.

36 It can be seen from Figures 8 and 9 that there is still some scatter of the solar corrected data. This is likely due to other factors that can affect heat loss such as the day to day variation in air infiltration caused by changes in wind conditions and barometric pressure.

Post Co-heating Air Permeability Tests

37 A comparison of the results of blower door pressure tests carried out immediately after the co-heating tests with the air permeabilities before the test commenced is shown in Table 13. It can be seen from these data that there is a small increase in air permeability after co-heating. However, the increase in permeability of between 0.6m/h and 0.9 m/h is not large enough to have resulted in a significant increase in infiltration heat loss, which in both cases is less than 1 W/K. Airtightness cannot therefore explain the difference between the predicted and measured heat loss coefficients.

Table 13 - Airtightness Before and After Co-heating Tests

Test Plot	Permeability Before Co-heating Test (m/h)	Permeability After Co-heating Test (m/h)	Increase in Permeability (m/h)	Increase in Predicted Heat Loss Coefficient Due to Increase in Permeability (W/K)
Plot 13	3.3	4.2	0.9	0.6
Plot 402	5.3	5.9	0.6	0.8

38 It is interesting to note that when the two dwellings were inspected visually after the co-heating tests, a large number a cracks were observed at internal junctions such as around the staircase and in corners, possibly due to shrinkage caused by the high internal temperatures during the tests. Some of these cracks are illustrated in Figures 10. However, as the air permeabilities did not increase significantly these internal cracks did not therefore indicate the presence of any large scale movement or cracking of junctions in the main air barrier such as the blockwork or parging layer.

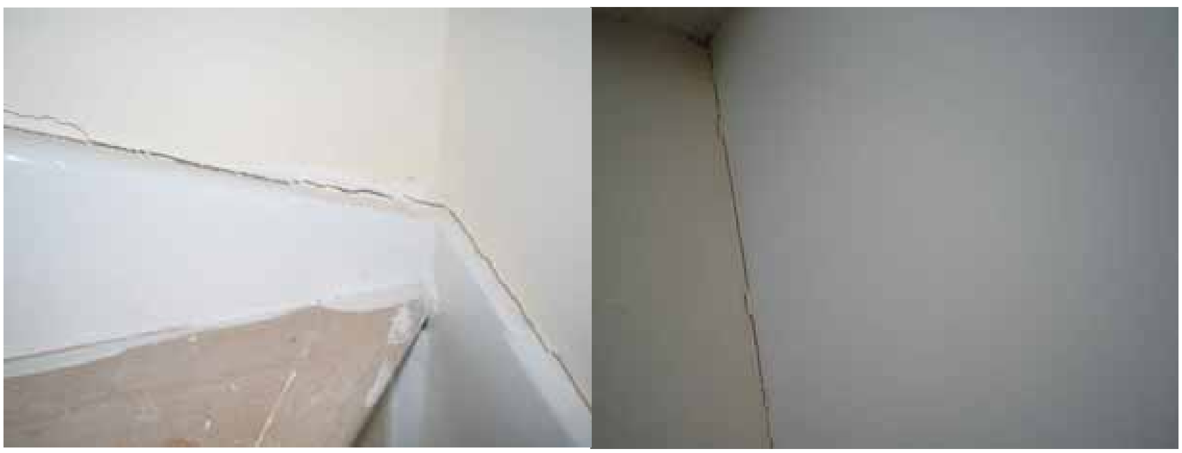

Figure 10 - Cracks in Internal Walls of Plot 402 following Co-heating Test

Thermal Imaging During Co-heating Tests

39 A thermal imaging camera was used to observe the surface temperatures of the main elements of the two test houses during the co-heating tests. Imaging was carried out from both outside and inside the dwelling and also from inside the attic space. The infrared camera used was a FLIR Systems Thermacam P65 model. This camera had a 320x240 pixel microbolometer array with a thermal sensitivity of 0.08°C at 30°C and spectral range of 7.5-13 µm.

Thermal Imaging of Plot 13

40 Infrared images of the external envelope of plot 13 taken during the co-heating test did not reveal any significant heat loss patterns that might have indicated large areas of missing insulation or higher than expected thermal bridging at junctions. For example, the thermal image shown in Figure 11 of the gable end of plot 13 does not show any unusual features. Infrared images of patio doors and windows taken from the outside showed the expected edge losses as illustrated by the thermal image of the patio door in Figure 12.

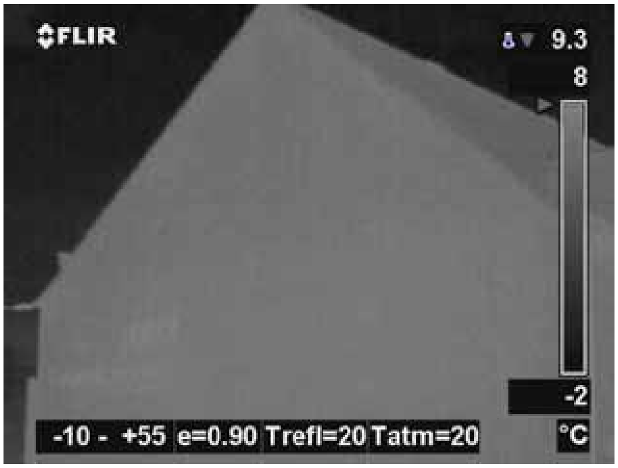

Figure 11 Infrared Image of Plot 13 Gable Wall

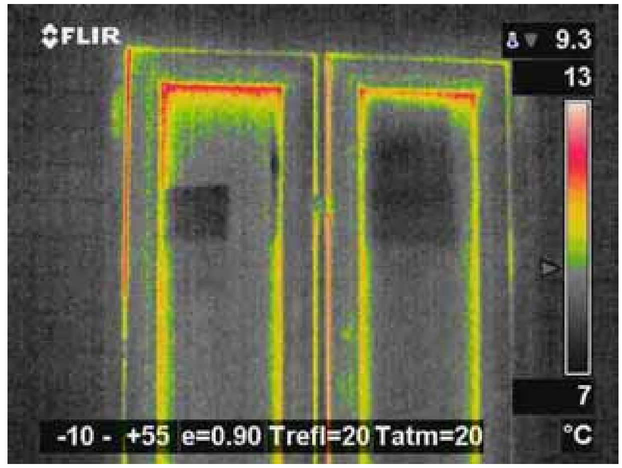

Figure 12 Infrared Image of Plot 13 Patio Door

41 An infrared image of the party wall in the attic space of plot 13 is shown in Figure 13 alongside the equivalent normal image of the same area in Figure 14. The thermal image of the attic party wall shows a wall surface temperature of between 10°C and 14°C. This is higher than would be expected from normal theory, which assumes that the attic space and surfaces would be close to external temperatures (around 5°C to 7°C at the time). Along the bottom of the wall is a strip of higher temperature of around 15°C. This is likely due to the conductive thermal bridge at the junction between the ceiling and party wall.

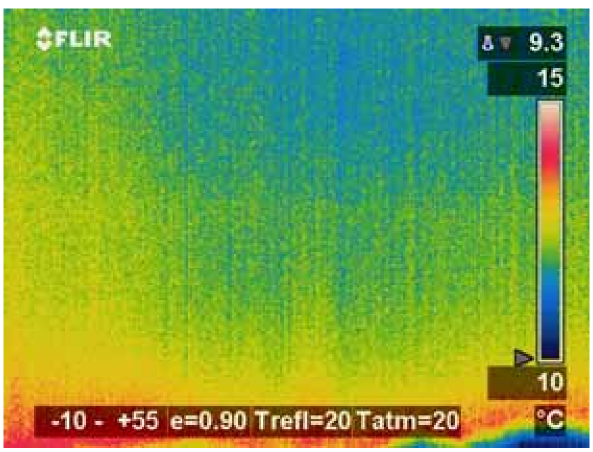

Figure 13 Infrared Image of Plot 13 Attic Party Wall

Figure 14 Photograph of Plot 13 Attic Party Wall

42 In comparison, an infrared image of the gable wall in the attic of plot 13 can be seen in Figure 15 alongside the equivalent photograph of the same location in Figure 16. The thermal image of the gable wall shows that its surface temperature is around 7°C, which is much closer to external conditions. The surface temperature of the waste pipe air admittance valve in Figure 15 is 11°C, which indicates another potential heat loss mechanism, although it is unlikely to be significant due to its small size. The thermal bridge at the junction between the ceiling and gable wall can be seen at the bottom of Figure 13 at around 12°C. This is at a lower temperature than the equivalent thermal bridge along the party wall. This difference is consistent with that predicted by the THERM modelling of these two junctions which gave a Ψ value for the ceiling-gable wall junction of 0.061 W/m^2K and a Ψ value for the Bryant ceiling-party wall junction with 142mm cavity of 0.157 W/m^2K.

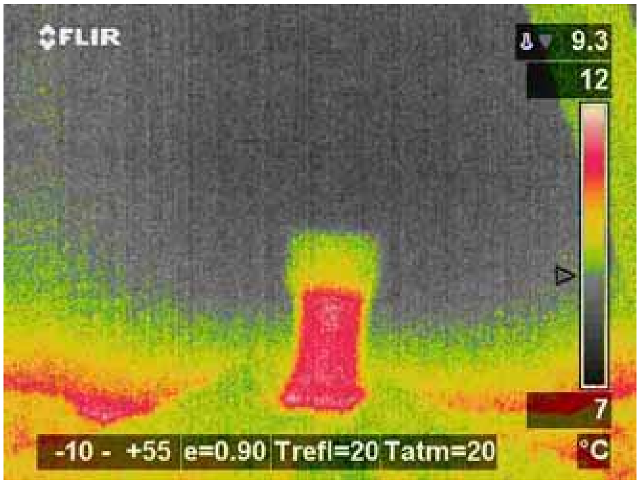

Figure 15 Infrared Image of Plot 13 Attic Gable Wall

Figure 16 Photograph Plot 13 Attic Gable Wall

43 The higher than expected surface temperature of the attic party wall during the co-heating test in plot 13 suggests that there may be some mechanism of heat loss involving the party wall and party wall cavity. However, it was not possible to investigate this further in plot 13 as the dwelling was due to be handed back to the developer.

Thermal Imaging of Plot 402

44 In order to follow up on the interesting results in plot 13, more extensive thermal imaging of the attic in plot 402 was carried out. Infrared images were taken during the co-heating test of the whole height of both the left hand side attic party wall (between plots 402 and 403) and the right hand side attic party wall (between plots 402 and 401). The resultant series of thermal images and equivalent photographs are illustrated in Figures 17 to 26.

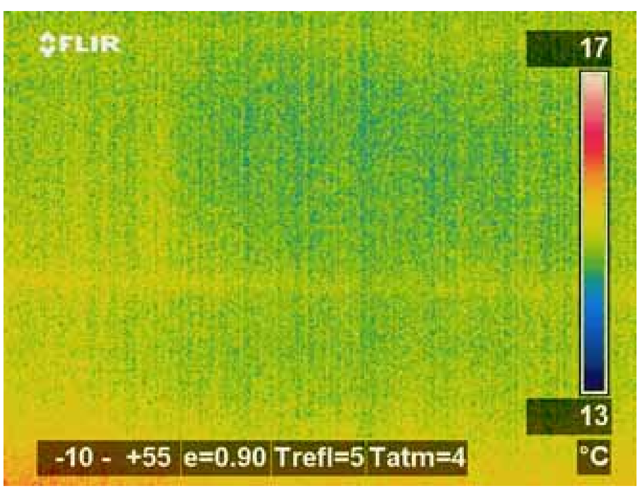

Figure 17 Infrared Image Bottom Attic Wall 401-402

Figure 18 Photo Bottom Attic Wall 401-402

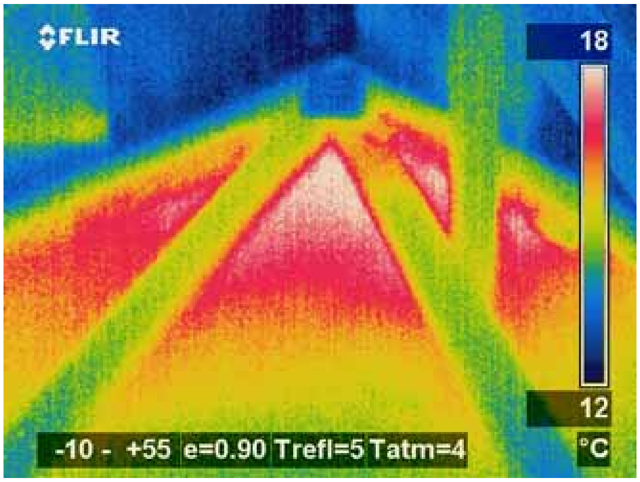

Figure 19 Infrared Image Top Attic Wall 401-402

Figure 20 Photo Top Attic Wall 401-402

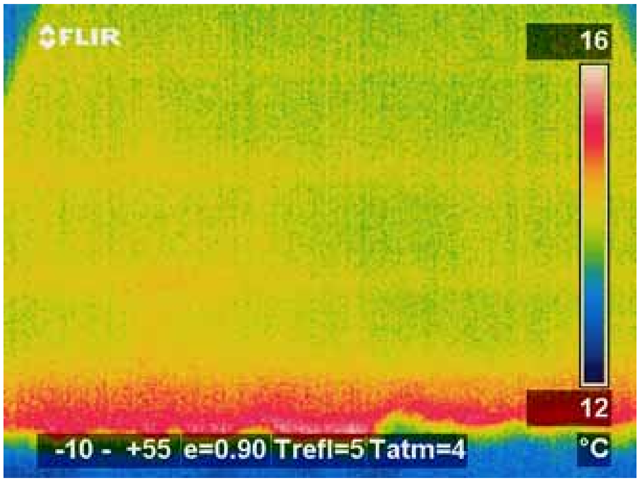

Figure 21 Infrared Image Bottom Attic Wall 403-402

Figure 22 Photo Bottom Attic Wall 403-402

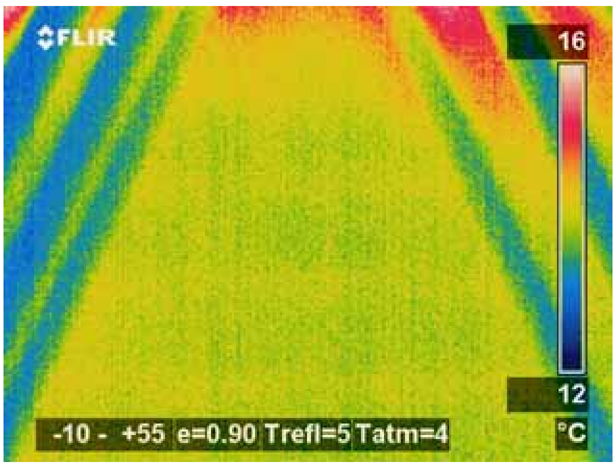

Figure 23 Infrared Image Middle Attic Wall 403-402

Figure 24 Photo Middle Attic Wall 403-402

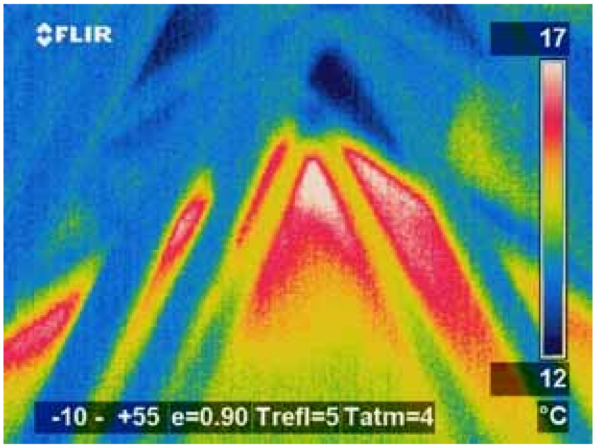

Figure 25 Infrared Image Top Attic Wall 403-402

Figure 26 Photo Top Attic Wall 403-402

45 The thermal images show that the surface temperatures of the bulk of the surface of both attic party walls ranged from around 13.5°C to 15°C, with indications of increasing temperature towards the top. With the external temperature ranging between 3°C and 5°C at the time these images were taken, these attic wall surface temperatures are further evidence of a heat loss mechanism involving the party wall cavity as first indicated in plot 13.

46 Along the bottom of both attic party walls, is a higher temperature strip of around 16°C. This would correlate with heat loss from the inside of the dwelling to the attic via the thermal bridge at the junction between the ceiling and party wall.

47 At the apex of both party walls and along the gap between the roof and blockwork there is another high temperature zone of around 16° to 17°C. The gap between the party wall and roof is filled with mineral wool batts in order to comply with the requirements to reduce to risk of the spread of fire as detailed in Approved Document B of the Building Regulations (ODPM 2000). However, mineral wool is not a very good air barrier, so the high temperature at the top of the party wall would indicate the movement of warm air through the gap. This moving warm air would heat up the surrounding blockwork.

48 It can be seen from the thermal images of the attic blockwork party walls that it is possible to distinguish between the surface temperature of the medium density concrete blocks and the surface temperature of the mortar. In all cases, the mortar is at a slightly higher temperature than the blocks by around 1°C. The thermal conductivity of mortar at 0.9 W/mK is 50% higher than that of medium density concrete blocks (0.5 W/mK). Therefore, as mortar is a better conductor of heat than the blocks, and the cavity is at a higher temperature than the attic space, the fact that the surface temperature of the mortar in the attic is higher than that of the blocks indicates that there is heat flux through the blockwork in the direction of the camera - in other words, from the party wall cavity through the blockwork and into the attic. This is further evidence for conductive heat flow from the party wall cavity into the attic space.

Party Wall Cavity and Loft Temperature Measurements

49 Taken together, the data from the thermal imaging of plot 13 and plot 402 are strong evidence of some mechanism of heat flow via the party wall cavity into the loft space possibly involving both bulk air movement over the top of the party wall and conduction through the party wall. In order to test this theory, a series of additional measurements were carried out during the co-heating test in plot 402 to measure the temperature of the attic space of plot 402 and inside the party wall cavities.

50 In order to measure the temperature of the party wall cavity, a technique was developed that used small datalogging temperature-humidity sensors attached to lengths of wire. These temperature sensors could then be inserted into the party wall cavity at the gap between the party wall and roof, and then lowered down into the cavity. The sensors used in these experiments were Tinytag Ultra TGU 1500 dual channel temperature humidity sensors manufactured by Gemini Dataloggers Ltd. With external dimensions of only 72 mm x 60 mm x 33 mm these loggers are small enough to fit inside the cavity with a low risk of them becoming jammed between the walls of the cavity. The

curved profile of the logger also meant that they were less likely to become snagged on the wall ties between the two sides of the party wall, particularly during retrieval.

51 Photographs of a Tinytag Ultra sensor and a Tinytag Ultra sensor attached to a cable on location in the loft of plot 402 are illustrated in Figures 27 and 28. The internal temperatures inside the loft of plot 402 were logged by a combination of Tinytag Ultra sensors and Eltek GC-10 radio transmitter temperature sensors. For the temperature measurements in plot 402, the Tinytag and Eltek sensors were set to log both temperature and humidity at intervals of 10 minutes.

Figure 27 Tinytag Ultra Temperature Sensor

Figure 28 Tinytag Ultra Sensor in Plot 402 Loft

52 For the initial set of temperature measurements, the fan heaters in the test dwelling were temporarily turned off and the test dwelling allowed to cool down slightly. A length of cable with six Tinytag sensors attached every half metre was then inserted in to the loft party wall cavity between plots 401 and 402. The cable was lowered into the cavity such that the bottom sensor was inline with the level of the ceiling insulation. Three sensors were located at half metre intervals up the attic party wall cavity, one sensor was positioned in the gap between the party wall and roof (two metres above the line of the ceiling) and one sensor was located in the attic space itself. The fan heaters were then turned back on and the temperatures recorded for 2 days until the internal conditions in plot 402 had stabilised. A graph of the temperatures over time is shown in Figure 29.

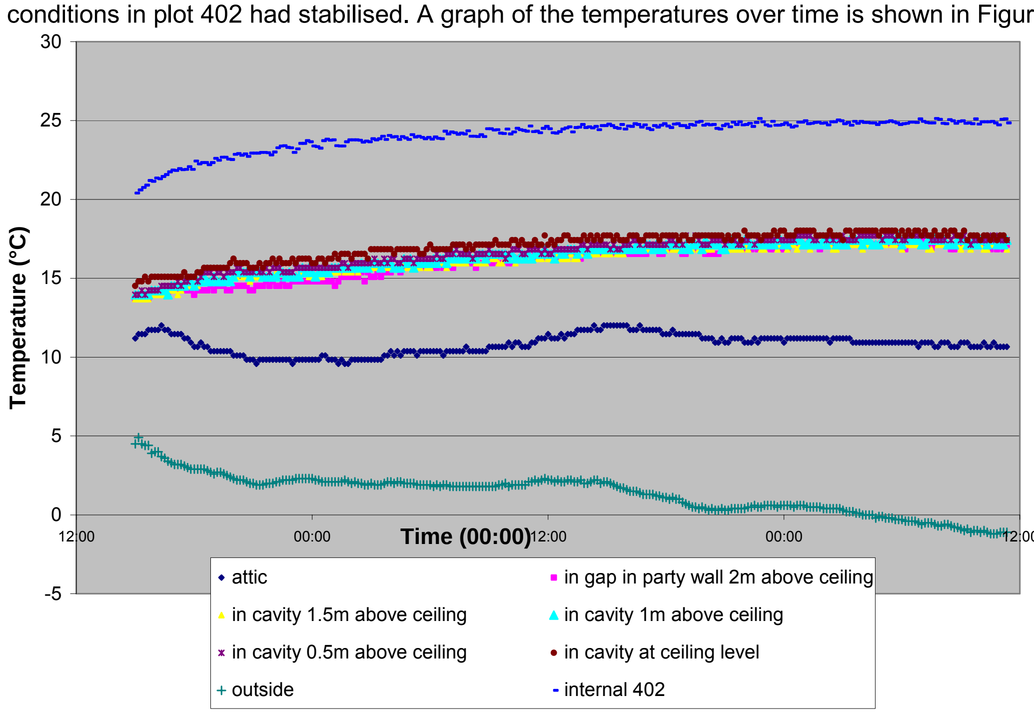

Figure 29 - Temperatures in Attic Party Wall Cavity between Plots 401 and 402

53 It can be seen from Figure 29 that the attic space was significantly warmer than the outside by between 7°C and 12°C. This is a much bigger difference than the 2 to 3 degree difference normally assumed in thermal models. The temperatures inside the attic party wall cavity at the time the internal temperature in 402 had stabilised at 25°C, ranged from around 18°C for the sensor inline with the ceiling, to around 17°C for the sensor in the gap between the party wall and roof at 2 metres above the ceiling line. These high temperatures in the cavity above the ceiling line are indicative of heat flow upwards from the party wall cavity below the ceiling line.

54 A second, more comprehensive set of temperature measurements were undertaken during the last week or so of the co-heating test in plot 402. This involved inserting sensors in both party wall cavities in positions both above and below the ceiling line. Temperature sensors were also placed in the occupied adjoining property plot 403 with the permission of the householder. The temperatures were recorded for a period of 11 days. A schematic of the location of the sensors in the cavities and loft of plot 402 is illustrated in Figure 30.

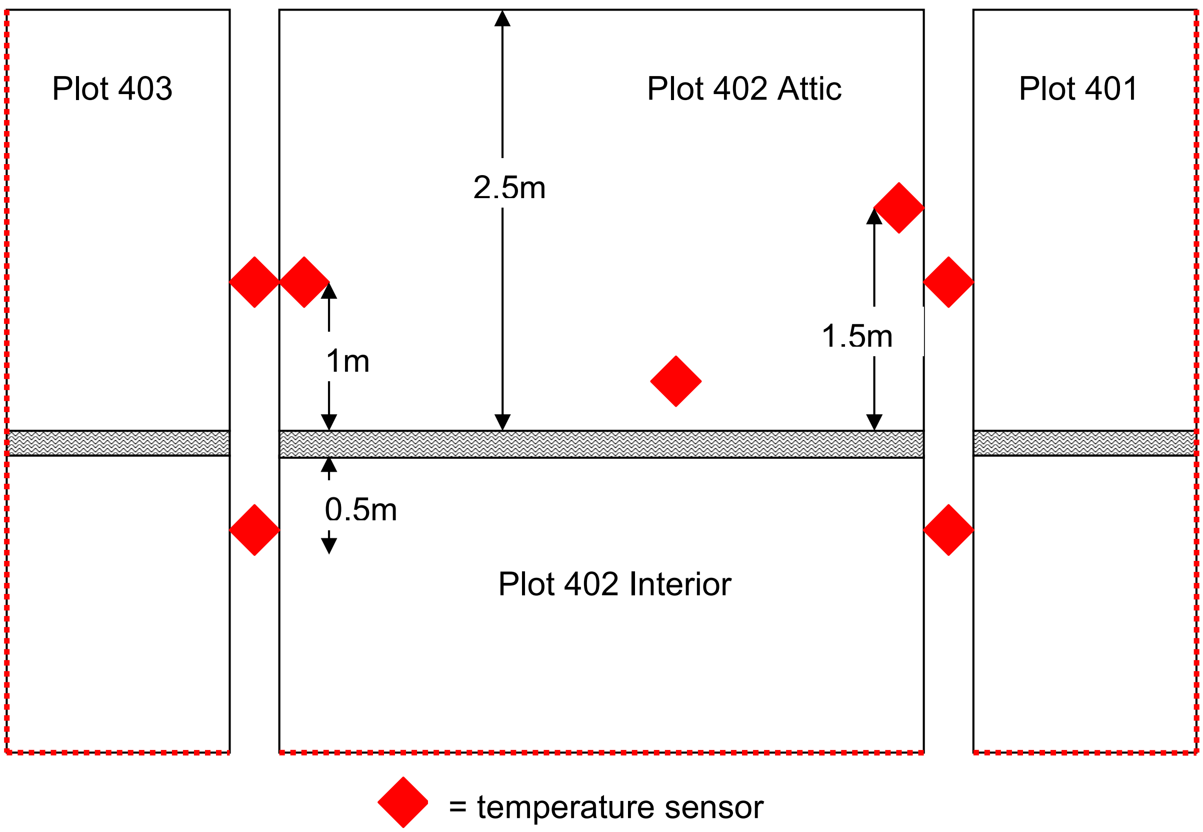

Figure 30 - Schematic of Location of Temperatures Sensors in Plot 402 Attic and Party Wall Cavities

55 The daily means for the various sensors are shown in Table 14. From the data given in Table 14 it can be seen that the overall mean temperature of the loft in the co-heating test house plot 402 at 13.3°C exceeded the mean external temperature by 8.5°C. The mean temperature of the loft in the occupied adjacent property for the 4 days when the sensor was in position exceeded the mean external temperature over the same 4 days by 5.5°C. As found previously, these loft temperatures are higher than would normally be expected. It can also be seen from the data that for days with lower mean external temperatures, the difference between the external temperature and loft temperature increases. This can be seen in the plot of the delta-T between external temperature and loft temperature versus the external temperature shown in Figure 31. The measured delta-T between outside and the loft ranged from 6°C to 12°C. Note that the intercept on the horizontal axis of the graph in Figure 31 is at about 20-25°C and the slope is negative. This is consistent with the hypothesis that the attic can be represented by an intermediate point on a network of conductances

that run between an internal node at 25°C and the external air temperature. Had direct solar heating of the loft space been a significant factor, then the intercept would have been at an external temperature significantly higher than the internal temperature of plot 402. Indeed if solar gain were the dominant factor, the slope of the line would be reversed, since high solar gain into the attic would correlate with high external temperatures.

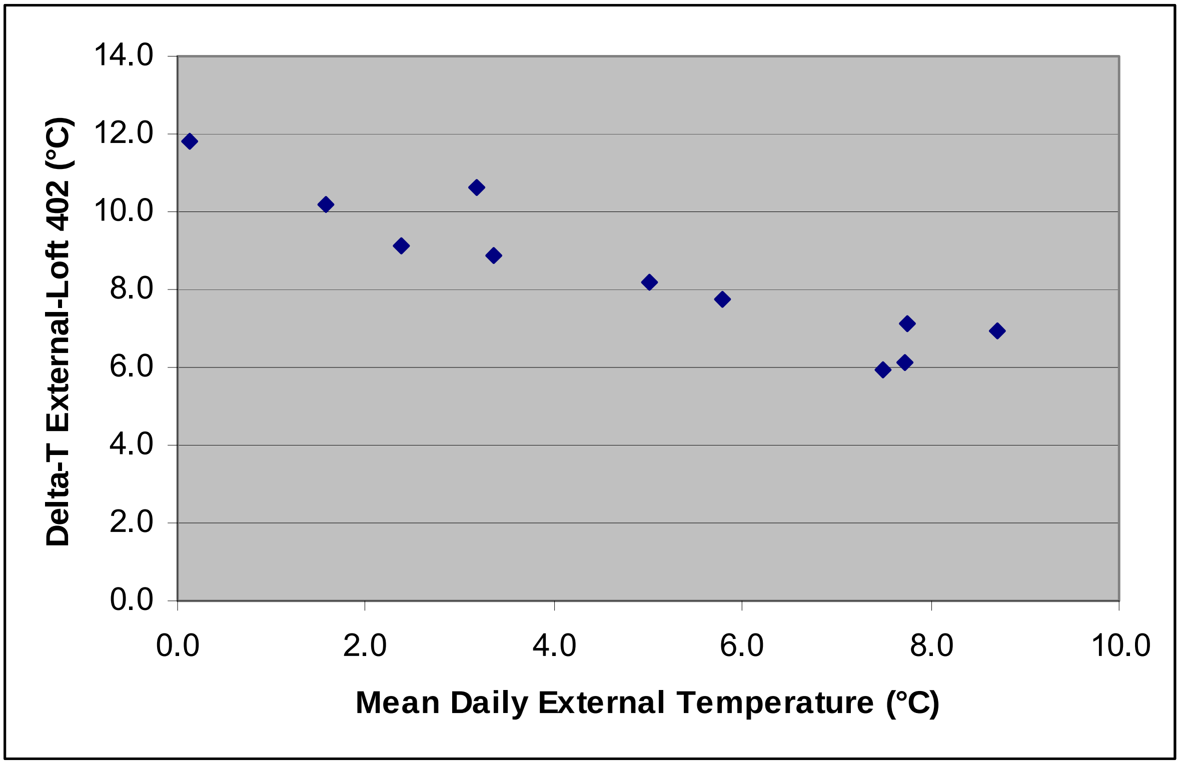

Figure 31 - Graph of External Temperature versus Delta-T between External and Loft of Plot 402

56 The mean temperature of the party wall cavity between plots 402 and 403 below the ceiling line was 21.6°C. This is lower than would have been expected from the internal temperatures of 402 and 403. The predicted temperature of the party wall cavity between the main living spaces in adjoining properties would be the mean of the two internal temperatures, which in this case would have given 23.8°C. The discrepancy of 2.2°C would suggest that the direction of the heat flux is not just horizontal through the cavity and that in all probability some heat is being lost from the cavity vertically.

57 The mean temperature in the party wall cavity at one metre above the ceiling line was 18.9°C between plots 401 and 402 and 17.7°C between plots 402 and 403. These high temperatures are again indicative of vertical heat flow up the party wall cavity past the level of the ceiling.

58 The data from the three temperature sensors in the loft of plot 402 indicate temperature stratification, with a tendency to higher temperatures towards the top of the loft. A graph of the temperature trends is shown in Figure 32. The degree of stratification can be seen to decrease as the mean temperature in the loft increased. It is likely that the temperature profile in the loft is very complicated, involving convection loops, bulk air movement from the cavity and also solar gain via the roof covering.

Table 14 - Mean Temperatures in Attic of Plot 402, 403 and Party Wall Cavities during Co-heating

Date	Mean Temp External (°C)	Mean Temp Loft 402 (°C)	Mean Temp Loft 403 (°C)	Mean Temp Internal 402 (°C)	Mean Temp Internal 403 (°C)	Mean Temp Cavity Party Wall 402-403 (°C)	Mean Temp Cavity Party Wall 401-402 (°C)	Mean Temp Cavity Loft Party Wall 402-403 (°C)	Mean Temp Cavity Loft Party Wall 401-402 (°C)
09-Feb	1.6	11.8	-	26.4	19.8	20.9	20.5	16.9	18.2
10-Feb	0.1	12.0	-	26.2	19.6	20.3	19.6	16.4	17.5
11-Feb	2.4	11.5	-	26.6	19.9	20.7	19.8	16.5	17.6
12-Feb	7.5	13.4	-	27.6	20.8	21.7	20.9	17.8	18.6
13-Feb	8.7	15.6	-	27.9	21.4	22.6	22.0	19.1	20.1
14-Feb	7.8	14.9	-	27.9	21.1	22.8	22.3	19.1	20.2
15-Feb	7.7	13.8	-	27.5	20.5	22.3	21.6	18.2	19.6
16-Feb	5.8	13.5	10.5	27.3	20.3	22.0	21.4	18.1	19.1
17-Feb	5.0	13.2	10.3	27.4	20.4	21.9	21.4	18.0	19.1
18-Feb	3.2	13.8	10.2	27.6	19.5	21.5	21.1	17.7	18.9
19-Feb	3.4	12.3	8.6	27.7	19.7	21.2	21.0	17.2	18.6
MEAN	**4.8**	**13.3**	**9.9**	**27.3**	**20.3**	**21.6**	**21.1**	**17.7**	**18.9**

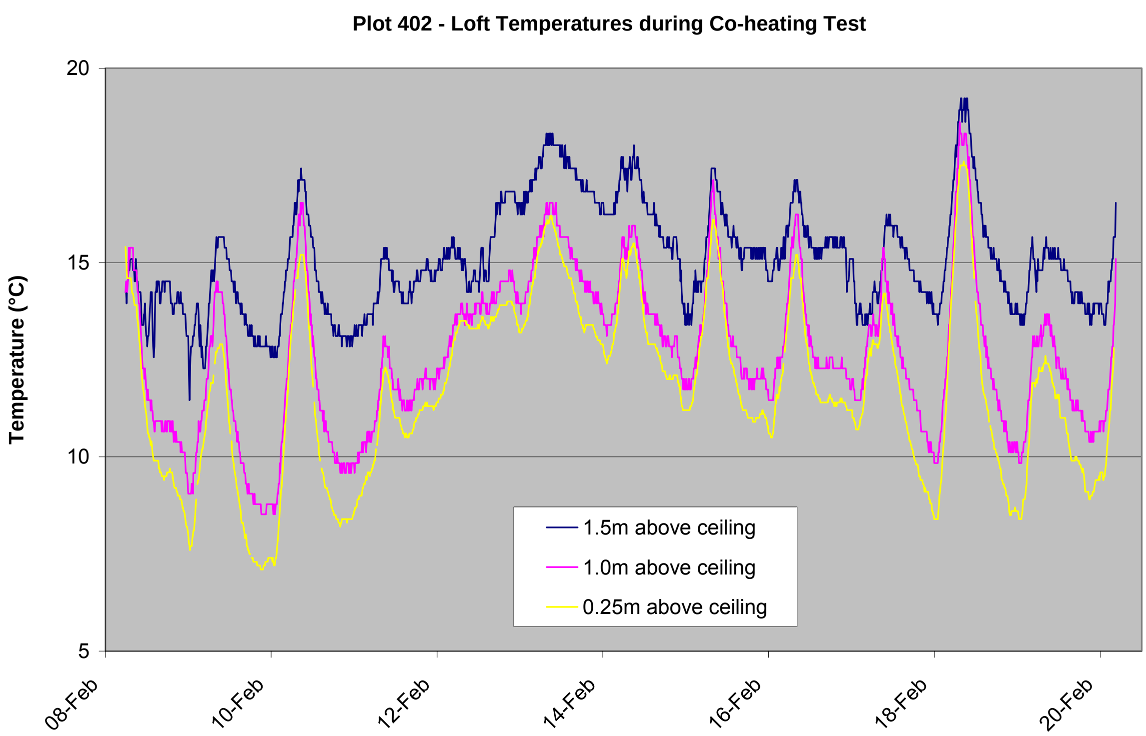

Figure 32 - Loft Temperatures at Different Heights above Ceiling in Plot 402 during Co-heating Test

59 The pyranometer data from the Leeds Met weather station was analysed to determine whether the high attic temperatures could be due substantially to solar gain through the roof. The mean daily solar insolation was plotted against the mean daily attic temperature and mean external temperature (Figure 33). It can be seen from Figure 33 that there is no correlation between the

level of solar insolation and the attic temperature. For example, for the period 10th February to 12th February the mean solar insolation dropped from around 70 W/m^2 to around 20 W/m^2, but over the same period the attic temperatures actually increased from around 12°C to 14°C. The data in Figure 33 show that the trend in loft temperature closely tracks the trend in external temperature. This would be expected due to the fact that the heat flux from inside to outside will increase as external temperatures drop and will decrease as external temperatures increase. The actual heat flux into the loft due to solar gain has not been estimated. The temperature rise due to insolation on the opaque roof covering will depend on the sol-air temperature over the period. With mean insolation at around 80 W/m^2, and mean outgoing long wave radiation at about 100 W/m^2, the sol-air temperature will be approximately 1K below air temperature.

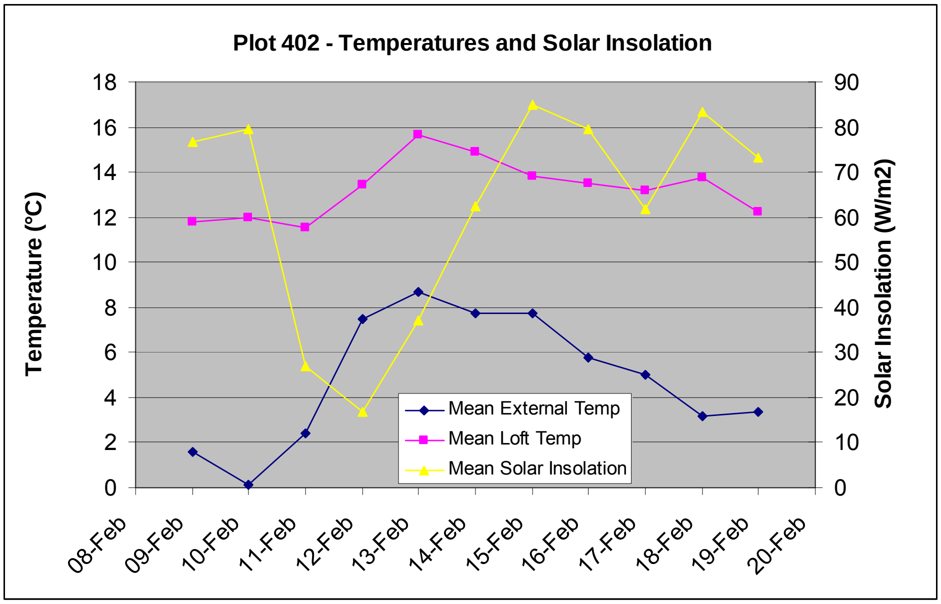

Figure 33 - Mean Loft Temperature, External Temperature and Solar Insolation during Co-heating

Discussion of Co-heating Test Results

60 The two co-heating tests gave heat loss coefficients that were greater than their predicted values by between 34% and 51%. Approximately half this difference could potentially be attributed to horizontal heat loss across the party wall from the co-heat test houses to adjacent properties. The data from thermal imaging and temperature measurement in the loft and party wall cavities all indicate that the most likely route for the unexplained heat loss is via the party wall cavity into the loft space. The mechanisms for heat loss up the party wall cavity could be via a convection loop, by bulk air movement or some combination of the two.

61 An excel spreadsheet model was developed that modelled the various heat flows into the attic space for plot 402 using the actual recorded temperatures. What are believed to be the most significant heat flow paths from the inside of the dwelling to the attic, and from the attic space to outside, are illustrated in the schematic diagram shown in Figure 34. The various heat flow mechanisms are described in the key to the schematic diagram given in Table 15. This is not intended to be a comprehensive list of all heat flows. For example, the potential infiltration path from the inside of the dwelling through the party wall has been ignored as it is expected that at Stamford Brook this would be very small due to the specific airtightness measures such as parging that have been undertaken on these dwellings[5]. We have also not included infiltration through the blockwork wall from the cavity to the attic space. There will also be other horizontal heat flows such as from the party wall to outside that are not shown on this diagram. There may also be other air flows paths from the outside into the party wall cavity that may be driven by the bulk air movement or convection loop.

[5] Air movement between adjoining dwellings was measured by an inter-dwelling pressure test on a pair of semi-detached dwellings at Stamford Brook. This test showed that there was no measurable air leakage between the two dwellings and supports the view that infiltration losses across party walls on dwellings at Stamford Brook are likely to be negligible. The results of the inter-dwelling tests are described in detail in a later section of this report.

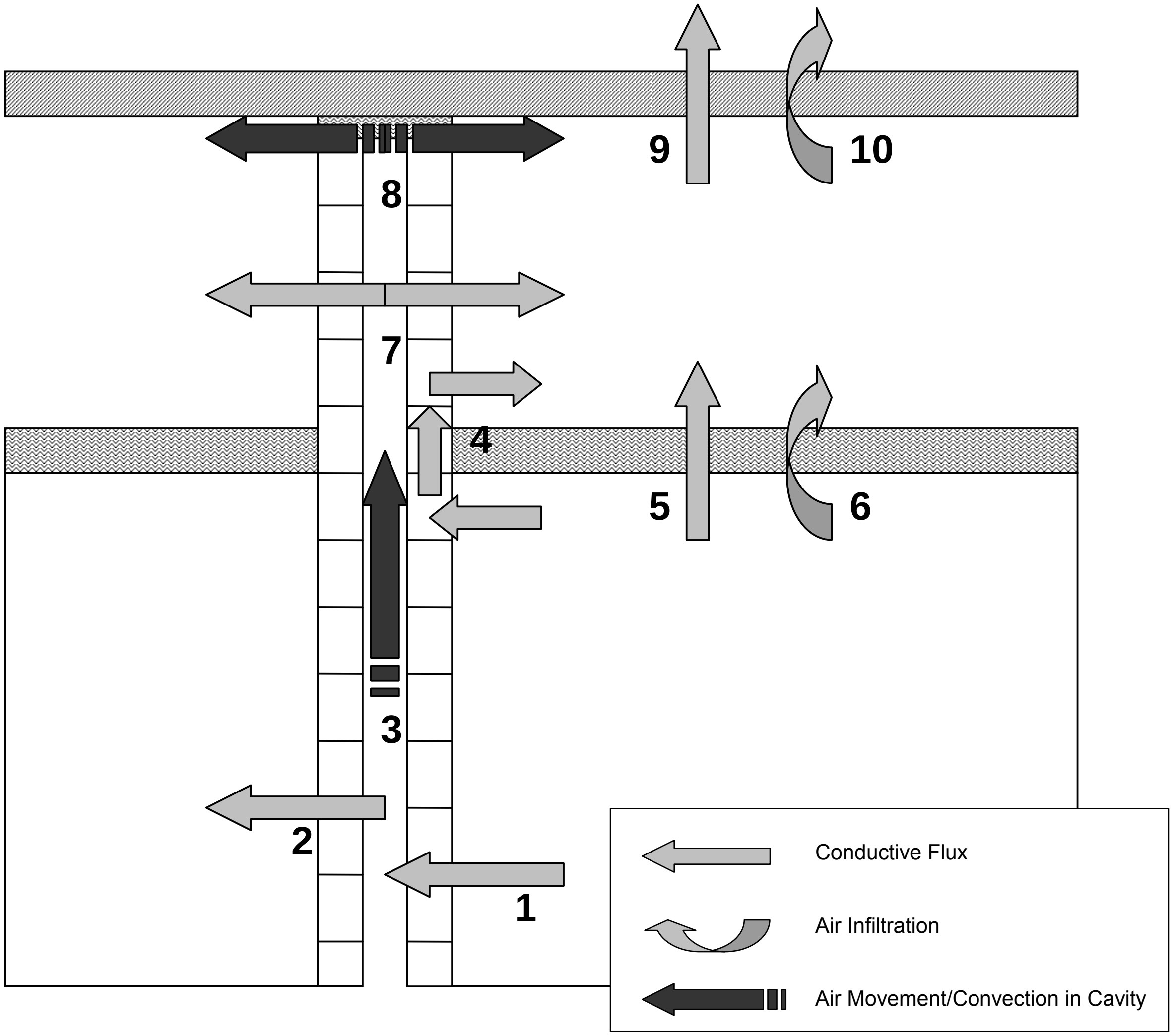

Figure 34 - Schematic of Major Heat Flows into Attic of Dwelling with Masonry Cavity Party Wall

Table 15 - Key to Figure 33 - Descriptions of Major Heat Flow Mechanisms

Flow No.	Description of Heat Flow Mechanism
1	Conductive heat flow through blockwork from inside dwelling to party wall cavity
2	Conductive heat flow through blockwork from party wall cavity to adjacent property
3	Convective heat flow or bulk air movement vertically up party wall cavity
4	Conductive heat flow through thermal bridge at ceiling-party wall junction
5	Conductive heat flow through ceiling from inside dwelling to attic space
6	Infiltration into attic space through ceiling from inside dwelling to attic space
7	Conductive heat flow through blockwork from party wall cavity to attic space
8	Air movement into attic space at gap between top of party wall and roof
9	Conductive heat flow through roof from attic space to outside
10	Infiltration through roof from attic space to outside

62 The overall heat loss through the roof can be estimated from the mean attic temperature and mean external temperature given in Table 15. The total heat loss is given by the equation:

$Flux_T = A_{roof}.(T_{attic}-T_{out})/R_{roof}$ …Equation 3

Where $Flux_T$ is the total heat loss through the roof, A_{roof} is the area of the roof covering, T_{attic} is the mean temperature of the attic, T_{out} is the mean external temperature and R_{roof} is the thermal resistance of the roof covering. R_{roof} can be taken to be the sum of the thermal resistance of a tiled roof space (0.2 m^2K/W) and the external surface resistance (0.04 m^2K/W) as given in EN6946 (BSI 2003). This gives a value for R_{roof} of 0.24 m^2K/W. Using this value for the thermal resistance of the roof, the temperature data from Table 14, and assuming that the roof area is approximately equal to the ceiling area, the total heat loss through the roof of plot 402 is estimated to be 1222 W.

63 The various heat flows that contribute to this total loss of 1222 W can be estimated using the mean temperatures given in Table 14 and are summarised in Table 16. The infiltration loss through the ceiling into the attic was estimated to be two thirds of the total predicted ventilation loss (20.3 W/K) from the parametric SAP. The total explainable heat flux is 396 W. This leaves 826 W of unexplained heat flux from the roof space. Some of this heat loss could be accounted for by conduction from the party wall cavity through the blockwork party wall into the loft of plot 402. This is estimated to be 217 W, based on a temperature in the party wall cavity in the loft space above the level of the ceiling ranging from 17.5°C to 18°C and assuming a U-value for the single leaf blockwork wall of 2.38 W/m^2K. The leaves a value for the remaining unexplained heat flux of 609 W, which could potentially be due to bulk air movement over the top of the party wall.

Table 16 - Estimates of Heat Flux from Roof of Mid-Terrace Plot 402 Calculated from Temperature Differences

Heat Flow Mechanism	**Heat Flux (W)**
Total heat flux through roof - based on delta-T between attic and outside of 22.5	1222
Conductive heat flow through thermal bridge at ceiling-party wall junction - total for 2 junctions	22
Conductive heat flow through ceiling from inside dwelling to attic space - based on delta-T of 14	69
Infiltration into attic space through ceiling from inside dwelling to attic space (2/3 of Cv at delta-T of 22.5)	305
Total explained heat flux (22 + 69 + 305)	396
Total unexplained heat flux (1222 - 396)	826
Conductive heat flow through blockwork from party wall cavity to attic space - for both party walls	217
Remaining unexplained heat flux (826 - 217)	609

64 If we take the delta-T between inside and outside of 22.5°C from Table 14, then the difference between the whole house heat loss predicted by Parametric SAP and that obtained from the measured heat loss coefficient from the co-heating test gives a discrepancy of 1748 W as shown in Table 17. We know that some of this discrepancy will be due to heat loss across the party wall to the adjacent terraced dwellings. This heat flux can be calculated from the delta-T between the cavity and the inside of the adjacent properties (1.1°C) and the U-value of a single leaf of the party wall (2.08 W/m^2K). This heat loss is 237 W as shown in Table 17. This is much lower than the loss across the party walls indicated in Table 12 and lower than the value that is calculated on the basis of the difference in temperature between the inside of plot 402 (27.3°C) and the inside of the adjacent plots (20.3°C) which gives an expected loss of 804 W based on a U-value for the whole party wall of 1.11 W/m^2K. This is an indication that a large proportion of the expected heat flux across the party wall to the adjacent properties is actually going elsewhere.

65 The unexplained heat loss discrepancy of 1511 W in Table 17 calculated from the whole house heat loss coefficients measured in the coheating tests is higher than the heat flux of 1033 W in Table 17 calculated from the temperature values. This is further evidence that for the theory that the additional heat loss measured in the co-heating tests can be partly explained by a heat bypass mechanism via the party wall cavities into the attics. The sum of all the various heat flows into the attic of 402 is calculated to be 855 W taking into account the heat flows through the ceiling and the proportion of the heat flow up the cavity going into the loft of 402. This is less than the estimated heat flux through the roof of 1222 W given in Table 16.

Table 17 - Estimates of Whole House Heat Loss Mid-Terrace Plot 402 Calculated from Parametric SAP and Co-heating Test Data

Heat Flow Mechanism	Heat Flux (W)
Whole house heat loss (fabric + ventilation) as predicted by Parametric SAP - based on delta-T of 22.5°C	1692
Whole house heat loss from co-heating test heat loss coefficient - based on delta-T of 22.5°C	3440
Unexplained discrepancy between predicted and measured whole house heat loss (3440 - 1692)	1748
Heat flux from party wall cavities to adjacent dwellings - based on delta-T of 1.1°C	237
Remaining unexplained discrepancy in whole house heat loss (1748 - 237)	1511
Heat flux from dwelling to party wall cavities - based on delta-T of 5.9°C	1270
Remaining heat flux going up party wall cavities (1270 - 237)	1033

66 The data show that most of the additional heat losses observed in the co-heating tests above that predicted from the SAP could be explained by the proposed party wall-attic bypass mechanism. We have seen no evidence of any other major problems that could give rise to the discrepancy. These results indicate that party wall cavities can provide a pathway for potentially very significant heat losses from the living space to the attic of semi-detached and terraced properties. These losses are not properly accounted for in the SAP thermal model. Consequently, it is likely that such paths are routinely ignored in the design of new dwellings, as was the case at Stamford Brook.

Previous Studies of Party Wall Losses and Attic Temperatures in the Literature

67 The potential for major heat losses into the attic space via bypass mechanisms such as party wall convection losses has been identified at least twice before in the literature. The first study we have found to propose such a mechanism was the Twin Rivers retrofitting project carried out by Princeton University in the 1970's. The researchers in this project reported a range of anomalous bypass heat loss paths (Harrje Dutt & Beyea 1979). One of the mechanisms they describe is a party wall convection bypass, whereby there is heat transfer from the living space of a terraced property into the attic via convection and air movement within the cavities of the party walls. The cavities they describe were not true party wall cavities between two block walls, but instead were formed by interconnecting vertical perforations in cinder blocks. They estimated that, for the houses in the study, the heat loss via the party wall cavities accounted for 35% of the total heat loss. They were able to show that the heat loss could be reduced either by insulating the party wall in the attic space with mineral wool batts, or by injecting cellulose insulation into the cavity at the level of the ceiling to form a cavity stop.

68 The second study to identify the potential for major heats losses via party walls was reported by Siviour as part of an investigation of the measurement of the U-values of walls in real dwellings (Siviour 1994). Measurement of heat flows through various party walls by infrared thermography indicated that they had U-values of between 0.4 W/m^2K and 0.8 W/m^2K. The suggested mechanism for the heat loss through the party walls was one of air movement between the cavity and the loft. It was proposed by Siviour that fire-stopping the cavities would be expected to minimise heat losses by reducing the air flow.

69 Reported roof space temperature data in detached dwellings (where no party wall exists) contrasts sharply with the results obtained in the semidetached and terraced dwellings in this study. A recent PII project that investigated the thermal performance of attic spaces (Sanders 2005), reported mean attic temperatures of detached test houses that were only 2°C to 3°C higher than the mean external temperature. Likewise, the mean attic temperatures of real detached dwellings they reported were of the order 2°C higher than external conditions and there was no noticeable stratification of temperature within the attic. These contrasting results provide general support to the role of the party wall as a significant heat loss mechanism in semidetached and terraced dwellings.

Heat Input Split between Floors

70 The heat input to each floor of the dwellings in both co-heating tests was measured independently. This means it was possible to obtain the percentage split of total heat input per floor. The heat split data is given in Table 18. In the case of the 2-storey plot 13, the split was around 72% to the

ground floor and 28% to the first floor. For the 3-storey plot 402, the split was 42% to the ground floor, 33% to the first floor and 25% to the first floor. These data are consistent with expected heat flows from the ground floor to upper floors due to thermal stack effects. The differences in heating requirements between floors could be used to better estimate the heat output required from the radiators on each floor when designing domestic heating systems. This could potentially lead to cost savings by reducing the size of radiators on upper floors to a closer match for the required heat output.

Table 18 - Heat Input Split between Floors during Co-heating Tests

Plot No.	Heat Input to Ground Floor as % of Total	Heat Input to First Floor as % of Total	Heat Input to Second Floor as % of Total
13	71.8 %	28.2 %	
402	42.2 %	32.7 %	25.1 %

Cool Down and Thermal Mass

71 Temperature data were collected for several days for both co-heating tests after the fan heaters and circulation fans were switched off. The cooling curve for semi-detached plot 13 is shown in Figure 35. Also included in Figure 35 are the vertical solar insolation and external temperature measurements from the Stamford Brook weather station and the internal temperature from the adjacent semi plot 14. It can be seen in Figure 35 that it took around 130 hours for the internal temperature to fall from 26°C to 15°C. This time would have been influenced not just by the thermal mass of plot 13, but also by solar gain during the day, and also by heat gains from plot 14 once the internal temperature in 13 had dropped below that of plot 14.

72 The thermal capacity of a building is a measure of the ability of a building to store heat (Lowe 2005). It can be calculated from the product of the specific heat capacity and mass of all the materials within the thermal envelope of a building. Alternatively, it may also be calculated from the measured heat loss coefficient of a building and the thermal half life. The 1/e half-life constant of plot 13 was calculated from the first order exponential fit to the cooling decay curve as shown in Figure 36 to be 31.3 hours. The solar corrected building heat loss coefficient for plot 13 was measured to be 110.2 W/K. This gives a measured thermal capacity of 12417 kJ/K. This compares to a value of around 24000 kJ/K predicted from the thermal mass of the concrete block work and concrete slab. The thermal capacity value predicted from the thermal half life is therefore around half that we would have expected from the thermal mass of the dwelling. The reason for the discrepancy is likely due to the fact that the internal temperature had not yet reached the external temperature, giving rise to an underestimate of the 1/e constant.

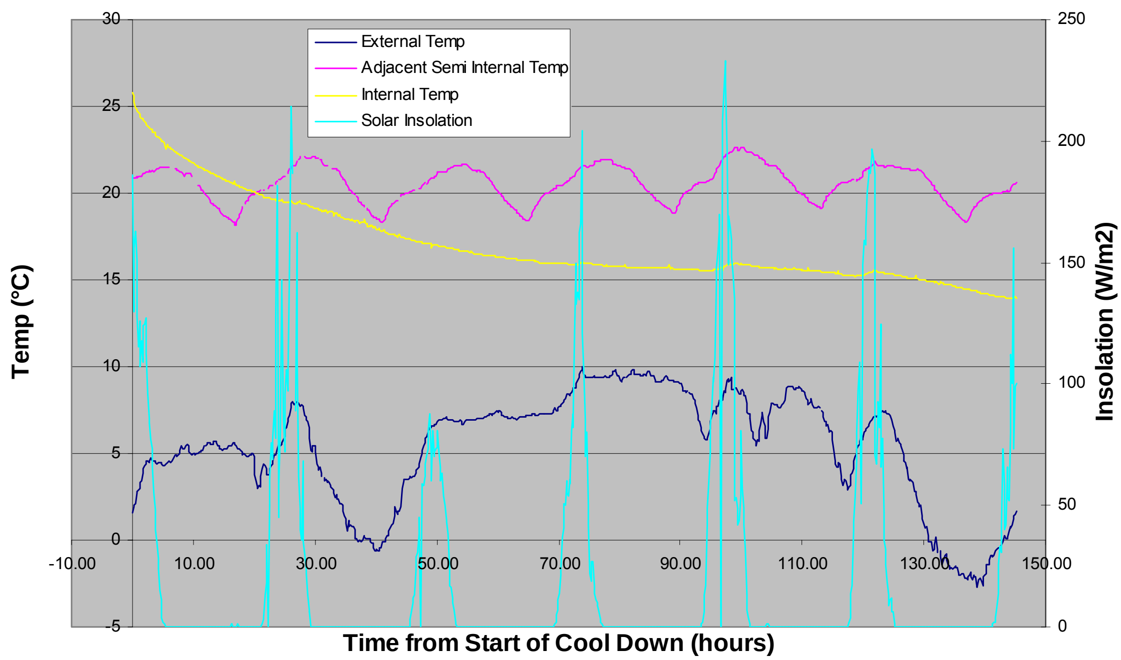

Figure 35 - Co-heating Cool Down Curve for Plot 13

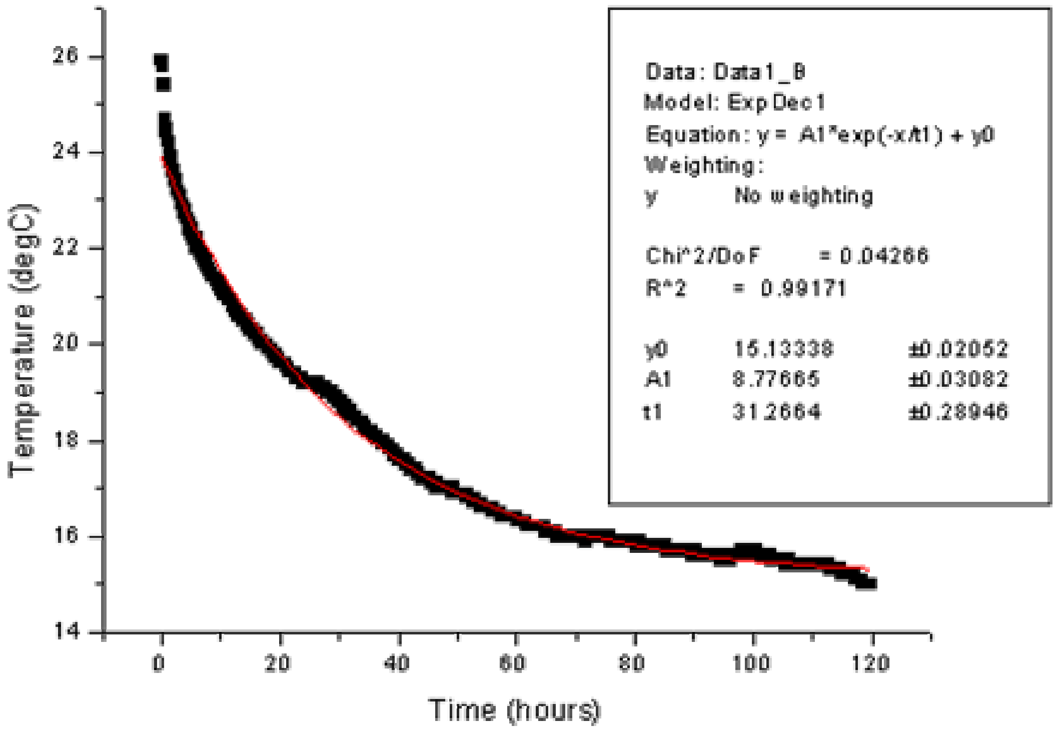

Figure 36 - First Order Exponential Decay Curve Fit to Plot 13 Co-heating Cool Down

Implications of Co-heating Test Results

73 The main implication of the results of the co-heating tests for the Stamford Brook development is that any properties with similar party wall details to the two test houses will underperform their predicted heat loss coefficients by similar margins as those observed in the tests. This would include semi-detached properties, terraced dwellings and apartments where there are uninsulated and unstopped cavity walls that link directly with the attic space. The co-heating data indicate that the true heat loss coefficients will exceed those calculated by SAP by at least 25 W/K for semi-detached and end-terrace dwellings, and at least 50 W/K for mid-terraced properties. The actual difference will depend upon the area of the party wall(s) and attic party wall(s) relative to the gross floor area for each dwelling type. One of the most worrying consequences of this is that mid-terraced dwellings become one of the worst performing house types in terms of fabric losses, whereas they are normally assumed to be amongst the best performing. The carbon emission rate for the Leeds Met standard 55 m^2 mid-terraced dwelling built to the Stamford Brook specification is 22.0 $kgCO_2/m^2$ as given in Table 4. The carbon emission rate increases to 32.0 $kgCO_2/m^2$ if a factor of 50 W/K is added to the heat loss coefficient to account for the party wall losses. This compares to a carbon emission rate for the Leeds Met standard 100 m^2 detached dwelling built to the Stamford Brook specification of 20.2 $kgCO_2/m^2$ as shown in Table 4.

74 The information given in SAP does not properly reflect the situation with respect to party walls constructed according to the current UK standard practice. The text regarding party walls in SAP 2005 (BRE 2005) in the section on heat losses states “Losses or gains through party walls to spaces in other dwellings or premises that are normally expected to be heated are assumed to be zero”. Clearly, this statement does not accurately portray the condition where there is a heat bypass mechanism via a party wall cavity into the loft space.

75 The total UK carbon savings up to 2010 that would be realised as a result of the measures introduced for new dwellings as part of the 2006 review of the Building Regulation are predicted to be 0.1 million tonnes of carbon (DEFRA 2004). We have estimated that if the party wall bypass mechanism is present in all new semi-detached and terraced properties built in the 4 years between now and 2010 then those dwellings will have total additional carbon emissions above that predicted by SAP of around 22,000 tonnes of carbon over the four years. (An estimate of the

annual number of terraced and semi-detached dwellings constructed was obtained using data from the NHBC New House Building Statistics (NHBC 2006)). This would mean that the expected total carbon savings due to the 2006 Building Regulations for new dwellings would be compromised by around 22% due to the unaccounted for party wall losses, and this does not include the additional losses from those new apartments which also exhibit the party wall bypass mechanism.

76 It is likely that the party wall-attic bypass mechanism is present in a large proportion of the existing stock of semi-detached and terraced properties in the UK. It is not known for certain when the use of cavity party walls became prevalent in the UK. It is believed that cavity party walls were common in the North of England by 1920, but that solid wall construction persisted in the South East until the mid-1950s (Lowe 2006). Descriptions of various types of party walls dating from the 1950's (Building Research Station, 1959) include both solid party wall constructions and cavity party wall constructions. There is potential for very large carbon savings if a way could be found to easily and cost effectively treat those existing dwellings with cavity party walls.[6]

Recommendations Arising From Co-heating Tests

77 The data gathered from the two co-heating tests provide compelling evidence for heat loss via the party wall. However, before firm conclusions can be made, it would be necessary to conduct further tests to confirm the findings and also to provide more information on the conditions inside the party wall cavity such as vertical temperature profiles and air flows. It would also be useful to investigate the efficacy of various alternative improvement measures that might eliminate the effect. It is therefore recommended that further co-heating tests be carried out at Stamford Brook during the winter of 2006-2007. Ideally, the tests would be conducted using a pair of unoccupied semi-detached houses, subject to availability and agreement with the developers. This would then give the research team control of the conditions in both sides of the party wall and allow us to more easily investigate the effectiveness of retrofitting measures such as the installation of cavity socks or insulation in the cavity wall, including acoustic testing. It may not be possible to conduct these tests within the context of the existing PII project, so it may be necessary to seek additional funding for a new project to investigate the problem. A new project would also give scope to include complex thermal modelling studies of heat flows in party cavity walls.

78 It is suggested that Redrow and Bryant give consideration to changing the design of the party cavity walls at Stamford Brook in order to eliminate the party wall bypass mechanism from all newly constructed properties on the site. Acoustic tests would need to be carried out on any proposed solutions to ensure that any proposed details address the party wall heat bypass mechanism without compromising the requirements of Part E. It may be prudent to submit any proposed solutions to Robust Details Ltd for consideration as a Part E compliant robust detail.

79 It is recommended that BRE be approached to ask them to consider updating the information provided in the SAP documentation to account for the potential for bypass heat losses via party wall cavities.

80 Retrofitting measures to the existing stock of properties with party cavity walls could potentially be carried out relatively easily and cheaply by the installation of flexible insulated cavity socks in the cavity at the level of the ceiling or by insulating the party wall cavity using blown mineral fibre or some other insulant. It is therefore suggested that consideration be given as to how this may be achieved through the Building Regulations for existing buildings. Cavity wall insulation is defined as "Building Works" under Regulation 3 of the Building Regulations (ODPM 2006d), therefore a development of Part L could potentially be used to address this issue.

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[6] Possible remedial measures could include fitting mineral wool insulated cavity socks or some other form of insulation horizontally in the cavity at the line of the ceiling insulation. Alternatively, the party wall cavity could be completely filled with insulation. As well as stopping heat flow vertically up the cavity, any potential solution would also have to comply with the requirements of Approved Document Part E for sound transmission between dwellings.

Airtightness Tests

Airtightness Target

81 The permeability target for Stamford Brook is detailed in the construction specification as 5 m/h at 50Pa pressure difference for all dwellings, subject to a learning period of 20 houses per developer.

Airtightness Design Strategies Adopted at Stamford Brook

82 The strategy for achieving the airtightness target of 5 m/h at Stamford Brook is outlined in Deliverable 2 of the PII project (Roberts et al 2004). The main specific airtightness design measure that was adopted by the developers was the use of a 2mm to 4mm parging layer of plaster that was applied to the internal blockwork of all external walls and party walls, the function of which was to seal the walls and mortar joints. The walls would then be drylined with plasterboard on adhesive dabs as normal. This was proposed as an alternative to a fully wet plastered wall due to concerns about the lengthy drying times of wet plastered walls. The effectiveness of the parging solution still relied to a large extent upon the use of adhesive ribbons at the edge of the plasterboard to prevent air movement between the board and wall.

83 A training package on the specific site requirements and measures for airtightness was developed by Leeds Met for management teams, site operatives and sub-contractors (Roberts et al 2004). The training covered the airtightness design measures for each of the different on-site trades to ensure that all operatives were aware of what was expected and the consequences of poor workmanship and not adhering to the design requirements. As well as this formal training, informal feedback was provided to the developers after each individual pressure test.

Pressure Test Equipment

84 The test equipment used by Leeds Met to measure the air permeability of dwellings at Stamford Brook is summarised in Table 19. The blower door used was an Energy Conservatory Model 3 Minneapolis Blower Door. All tests, with the exception of inter-dwelling pressure tests, were conducted from inside the properties. The blower door is illustrated in Figure 37.

Figure 37 - Minneapolis Blower Door

Table 19 - Pressure Test Equipment Specification

Component	**Equipment Used**	**Comment**
Blower Door	Energy Conservatory Minneapolis Model 3 Blower Door	Flow Range 25 m^3/h to 10704 m^3/h
Pressure/Flow Gauge	Energy Conservatory DG-700 Digital Pressure Gauge	Gauge calibrated annually
Temperature/Humidity	Rotronic Hygropalm 1 with Hygroclip S3 Sensor	
Anemometer & Barometer	Silva ADC Pro	
Electronic Tape Measure	Ryobi Ultrasonic Tape Measure SW-109TL	

Pressure Test Procedure

85 The pressure tests were conducted according to the methodology described in CIBSE Technical Memorandum TM23 (CIBSE 2000) to obtain air permeability in m^3 of air at 50 Pa pressure difference per m^2 of external envelope area. The permeabilities are given in units of m/h at 50Pa pressure difference. Permeabilities and volumetric air change rates were measured for both pressurisation and depressurisation tests, with the values reported being the mean of the two. For each test, air flow measurements were taken at a minimum of six pressures between around 15Pa and 60Pa. A typical pressure test curve of pressure difference versus air flow is illustrated in Figure 38 (Data from depressurisation test on plot 402).

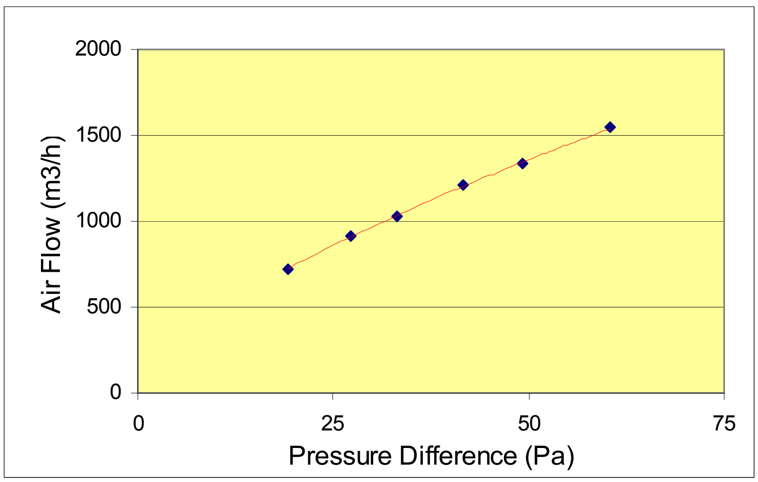


Figure 38 - Typical Plot of Pressure Difference versus Air Flow from Blower Door Test (Plot 402)

86 The dimensions of the test dwellings needed to determine the external envelope area and dwelling volume that were used in the calculation of air permeability and volumetric air change rate were obtained either from the architects CAD drawings, or were measured on site using an electronic tape measure. The pressure and air flow data were entered into the Leeds Met Permeability Data Spreadsheet (Wingfield 2005) to calculate permeability from the raw pressure and flow measurements.

Selection of Dwellings for Airtightness Testing

87 Due to the uncertainties of the developers' build programs, and the expected short window of opportunity for testing between completion of a dwelling and handover to the client, it was not possible to develop a statistically randomised sample for pressure tests. Instead, an ad hoc strategy for airtightness testing was used. Thirteen initial tests were conducted between February 2005 and May 2005. These first tests were focused on dwellings constructed during the very first phase of construction. This first series of pressure tests were intended to establish whether the design strategy and training regime had resulted in dwellings with air permeabilities within the target of 5 m/h and to provide feedback to the developer on their initial performance. Following these initial tests a pseudo-random test selection was adopted based on testing those dwellings that happened to be available during scheduled site visits.

Pressure Test Results

88 A total of 31 dwellings have so far been tested. A summary of the initial pressure tests from these 31 properties is given in Table 20. The permeabilities ranged from 1.8 m/h to 9.7m/h. The volumetric air change rates ranged from 2.3 ach to 9.5 ach. The overall mean permeability for all 31 tests was 4.9 m/h with a standard deviation of 1.8 m/h. The mean permeabilities for the two developers and means for combined categories of dwelling form are summarized in Table 21.

Table 20 - Pressure Test Results (In Test Date Order)

Developer	Test Date	Plot No.	Developer Design Type	Dwelling Form	Permeability (m/h)	Volumetric ACH	R^2 Coefficient	
							Depress	Press
Bryant	23-Feb-05	13	Chatsworth	2-storey Semi	3.32	3.67	0.992	0.998
Bryant	23-Feb-05	14	Chatsworth	2-storey Semi	2.04	2.26	0.988	0.999
Redrow	01-Apr-05	305	Devoke	2-storey End Terrace	3.67	3.82	0.995	0.967
Redrow	01-Apr-05	301	Whittle	Ground Floor Flat	1.75	2.46	0.987	0.992
Redrow	04-Apr-05	309	Derwent	2 ½ -storey Mid Terrace	6.09	5.51	1.000	0.999
Redrow	26-Apr-05	306	Fyne	2-storey Mid Terrace	2.98	2.92	0.995	0.987
Redrow	04-May-05	323	Devoke	2-storey End Terrace	4.64	4.83	0.994	0.990
Redrow	04-May-05	322	Devoke	2-storey End Terrace	4.78	4.87	0.994	0.999
Bryant	04-May-05	16	Doniford	2-storey Semi	4.67	4.73	0.997	1.000
Redrow	12-May-05	311	Derwent	2 ½ -storey Mid Terrace	7.02	6.35	0.987	0.985
Bryant	12-May-05	18	Chatsworth	2-storey Semi	4.66	5.15	0.994	0.998
Bryant	12-May-05	17	Type G	2-storey Detached	3.23	2.80	0.998	0.993
Redrow	20-May-05	320	Devoke	2-storey End Terrace	3.19	3.32	0.988	0.999
Redrow	05-Oct-05	403	Wye	3-storey End Terrace	5.89	5.50	0.998	0.999
Redrow	01-Nov-05	324	Devoke	2-storey Mid Terrace	3.81	3.97	1.000	0.992
Redrow	16-Nov-05	128	Castletown	2-storey Detached	2.91	2.94	0.996	1.000
Redrow	21-Nov-05	406	Wye	3-storey End Terrace	4.64	4.34	1.000	1.000
Redrow	01-Dec-05	127	Cliveden	2-storey Detached	3.46	3.03	0.972	0.989
Redrow	07-Dec-05	101	Mendip	3-storey End Terrace	4.85	4.20	0.999	0.999
Redrow	09-Dec-05	102	Balmoral	3-storey Mid Terrace	4.41	3.75	0.999	0.995
Redrow	09-Jan-06	402	Wye	3-storey Mid Terrace	5.28	4.94	1.000	0.998
Redrow	24-Jan-06	418	Derwent	2 ½ -storey Mid Terrace	7.44	6.44	0.999	0.997
Bryant	25-Jan-06	66	Dunham	2 ½ -storey Mid Terrace	9.70	8.41	0.999	0.981
Redrow	27-Jan-06	419	Derwent	2 ½ -storey Mid Terrace	7.79	7.05	0.996	0.997
Redrow	15-Feb-06	104	Balmoral	3-storey End Terrace	5.75	4.89	0.979	0.986
Redrow	16-Feb-06	513	Whittle	Ground Floor Flat	3.61	5.20	0.990	0.996
Redrow	17-Feb-06	405	Wye	3-storey Mid Terrace	6.30	5.90	0.999	0.998
Redrow	08-Mar-06	512	KE	Top Floor Flat	6.62	9.45	0.999	0.995
Redrow	23-Mar-06	517	Tweed	2 ½ -storey Detached	6.21	4.86	0.998	0.993
Redrow	05-Apr-06	126	Romsey	2-storey Detached	6.08	5.80	0.980	0.994
Redrow	07-Apr-06	518	Tweed	2 ½ -storey Detached	5.97	4.68	0.995	0.994

Table 21 - Mean of Air Permeabilities and ACH by Developer and Dwelling Form

	Number of tests	**Air Permeability at 50Pa**		**Volumetric Air Change Rate at 50 Pa**	
		m/h	**SD**	**ach**	**SD**
Apartment	3	4.0	2.5	5.7	3.5
Detached	6	4.6	1.6	4.0	1.3
2-Storey Terrace/Semi	10	3.8	0.9	4.0	1.0
2½-Storey Terrace/Semi/Detached	7	7.2	1.3	6.2	1.3
3-Storey Terrace/Semi/Detached	7	5.3	0.7	4.8	0.8
Redrow	25	5.0	1.6	4.8	1.5
Bryant	6	4.6	2.7	4.5	2.2
All Tests	31	4.9	1.8	4.8	1.6

89 A bar chart showing the permeability data from Table 21 is illustrated in Figure 39.

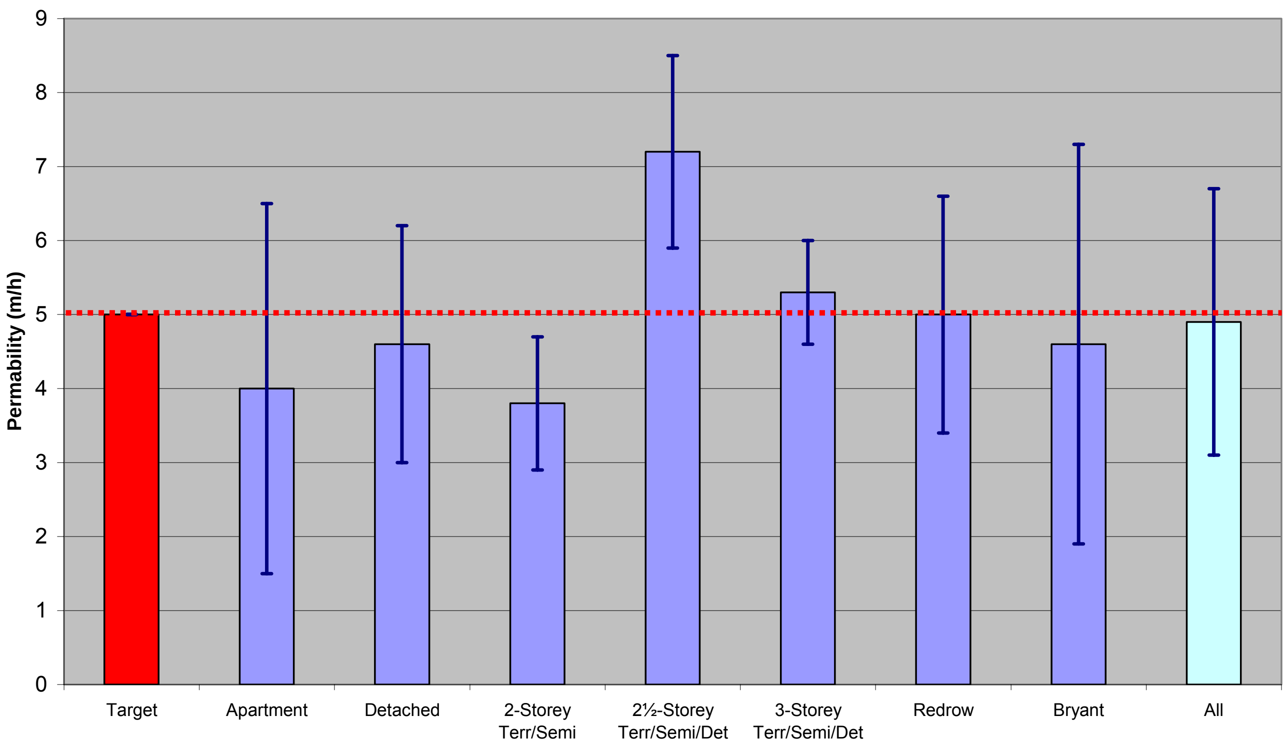


Figure 39 - Bar Chart of Mean Permeabilities (Error Lines Show Standard Deviation on Mean)

90 It can be seen from Figure 39 that although the overall mean from the 31 test dwellings at 4.9 m/h is within the design target of 5 m/h, a significant proportion (42%) of those dwellings tested exceeded the target. There was little difference between the means for the two developers with Redrow at 5.0 m/h and Bryant at 4.6 m/h, although it should be pointed out that significantly more Redrow plots were tested than Bryant. This was due to the fact that a larger number of Redrow properties were available for testing on suitable dates, mainly due to the fact that Redrow had the larger build programme in the first phase of development. Consequently, the standard deviation for the Redrow dataset was significantly smaller then the standard deviation of the Bryant data. In terms of dwelling form, the best performing dwelling types were apartments and the 2-storey

detached, semi-detached and terraced houses with mean permeabilities of around 4 m/h. The highest air permeabilities were measured on the 2 ½ - storey dwellings of room-in-roof type design.

91 The distribution of the permeability data is shown in Figure 40. The overall shape of the distribution curve appears to be a normal distribution centred on the mean of around 5 m/h. However, closer inspection of Figure 40 would suggest that the distribution is actually multimodal and could be formed by several overlapping distributions. It is likely that there is a normal distribution centred on about 3 m/h which is representative of the 2-storey detached, 2-storey semi-detached and 2-storey terraced dwelling types. The also appears to be another distribution centred on around 6 m/h that would be representative of the 2 ½ -storey room-in-roof dwelling forms. The proportion of test dwellings that exceeded the 5 m/h permeability target was 42%.

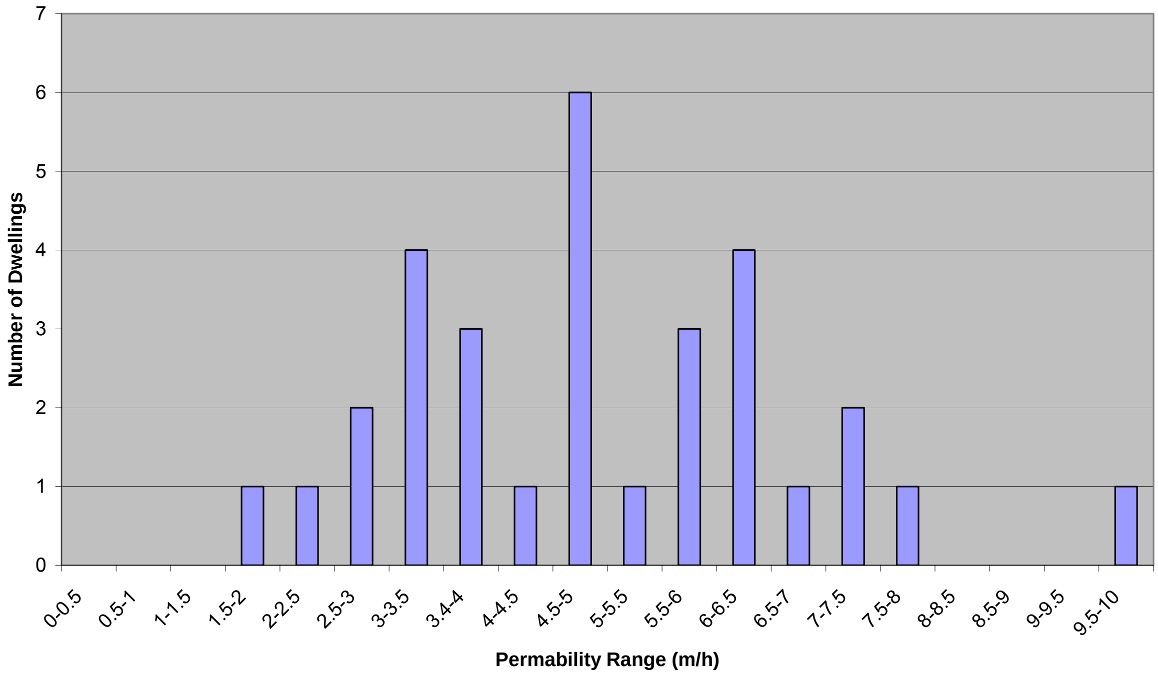


Figure 40 - Permeability Distribution of Stamford Brook Airtightness Tests

92 With 42% of dwellings from the test sample failing to meet the design target, the permeability results indicate that overall the Stamford Brook development will not meet the 5 m/h airtightness performance target stipulated in EPS08. However, the sample set is not representative of the actual distribution of dwelling types on site which will contain a higher number of apartments and 2-storey terraces than in the test sample. A higher proportion of these two dwelling forms in the sample would most likely have resulted in a slightly lower mean.

93 It is perhaps interesting to note that the permeability distribution obtained at Stamford Brook, although not what would be required for a target of 5 m/h, is actually an ideal distribution if the target had been set at the suggested limiting permeability of 10 m/h given in paragraph 37 of Approved Document Part L1A 2006 (ODPM 2006a).

Comparison of Stamford Brook with Other UK Airtightness Datasets

94 The largest dataset of air permeabilities of dwellings in the UK was reported by Stephen (1998, 2000). The database contains the air permeabilities for 384 dwellings representative of the whole UK stock and with a range of dwelling forms and construction techniques. The mean permeability of the whole 384 dwelling BRE database was 11.5 m/h at 50Pa. The Stamford Brook mean of 4.9 m/h is less than half this typical UK mean, showing that the airtightness of dwellings at Stamford Brook is significantly better than normal UK performance. This is clearly illustrated in Figure 41, which shows the probability distribution of the 31 dwelling Stamford Brook permeability data compared to the probability distribution of the 384 dwelling BRE database.

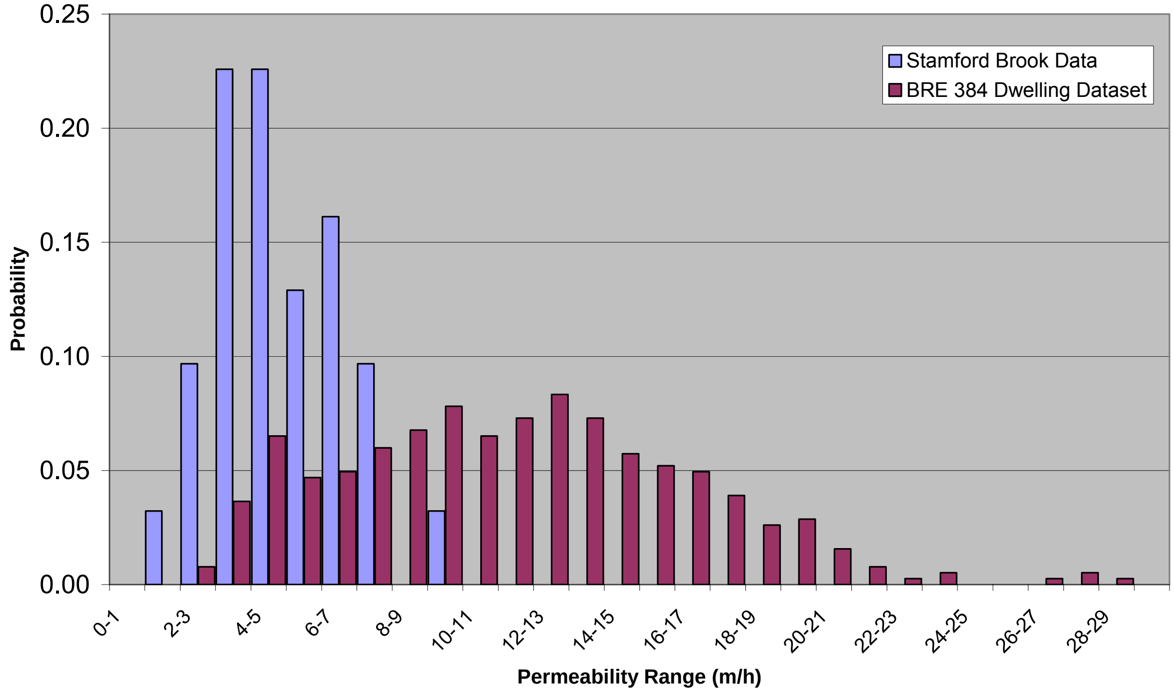


Figure 41 - Probability Distribution of Stamford Brook Data and BRE 384 Dwelling Dataset

95 A more recent study of airtightness for the Energy Savings Trust (EST) by Grigg (2004), reported the air permeabilities of 99 UK dwellings built to the requirements of ADL1 2002. The mean of this dataset was 9.2 m/h at 50Pa, and the values ranged from 3.2 m/h to 16.9 m/h. This indicates that the airtightness of dwellings at Stamford Brook is significantly better than dwellings built to meet the requirements of ADL1 2002. The probability distribution of the 31 dwelling Stamford Brook permeability data is compared to the probability distribution of the 99 dwelling EST database in Figure 42. The proportion of apartments in the 99 dwelling data set was 36% compared to only 10% for the Stamford Brook data.

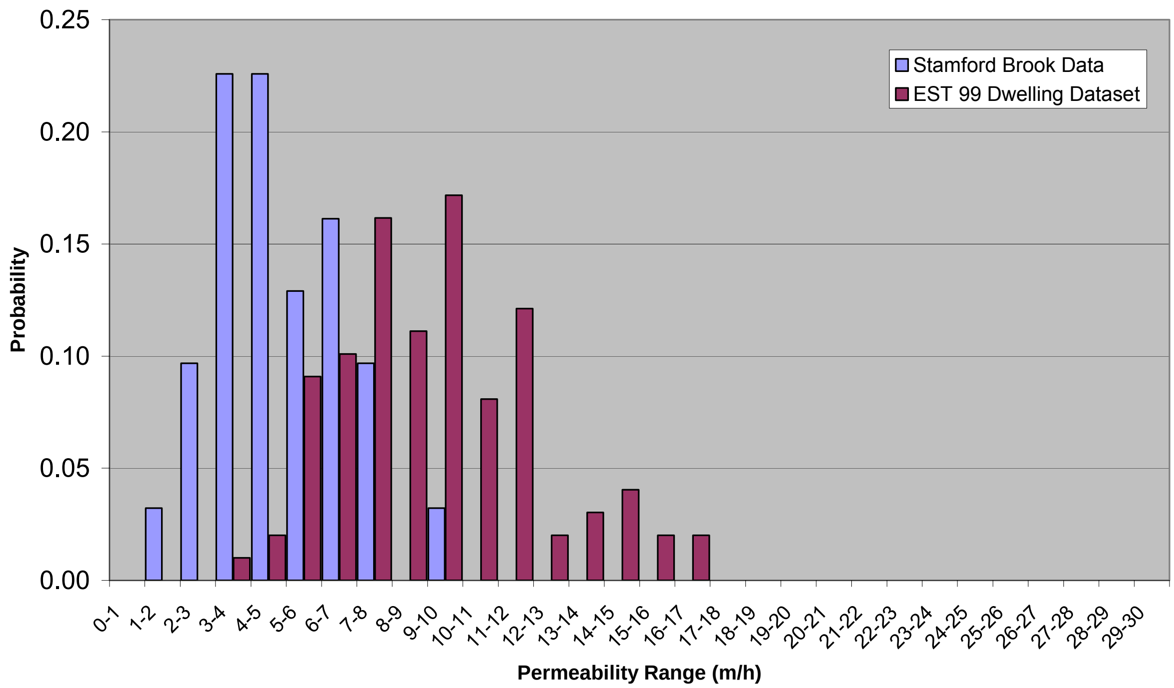


Figure 42 - Probability Distribution of Stamford Brook Data and EST 99 Dwelling Dataset

96 Another recent study of the airtightness of UK dwellings constructed to meet the requirements of ADL1 2002 was carried out by Leeds Met under the Building Operational Performance Framework (Project L2) (Johnston, Miles-Shenton & Bell 2006). This project investigated the airtightness of dwellings constructed by 5 different developers using Part L Robust Construction Details (DEFRA 2001) as the chosen method of compliance with the requirements of Part L. The dwellings were all constructed between 2004 and 2005. Four of the developers used masonry cavity construction, whilst the fifth used steel frame construction. During the first phase of the study, 26 dwellings were tested. The construction forms included apartments (24% of total), detached, semi-detached and terraced properties. The permeabilities ranged from 4.0 m/h to 16.5 m/h, with a mean of 11.1 m/h. The probability distribution of the 31 dwelling Stamford Brook permeability data is compared to the probability distribution of the 26 dwelling Leeds Met L2 first phase database in Figure 43. This is further evidence of the high levels of airtightness being achieved at Stamford Brook compared to that being achieved by dwellings constructed using ADL1 2002 Robust Details.

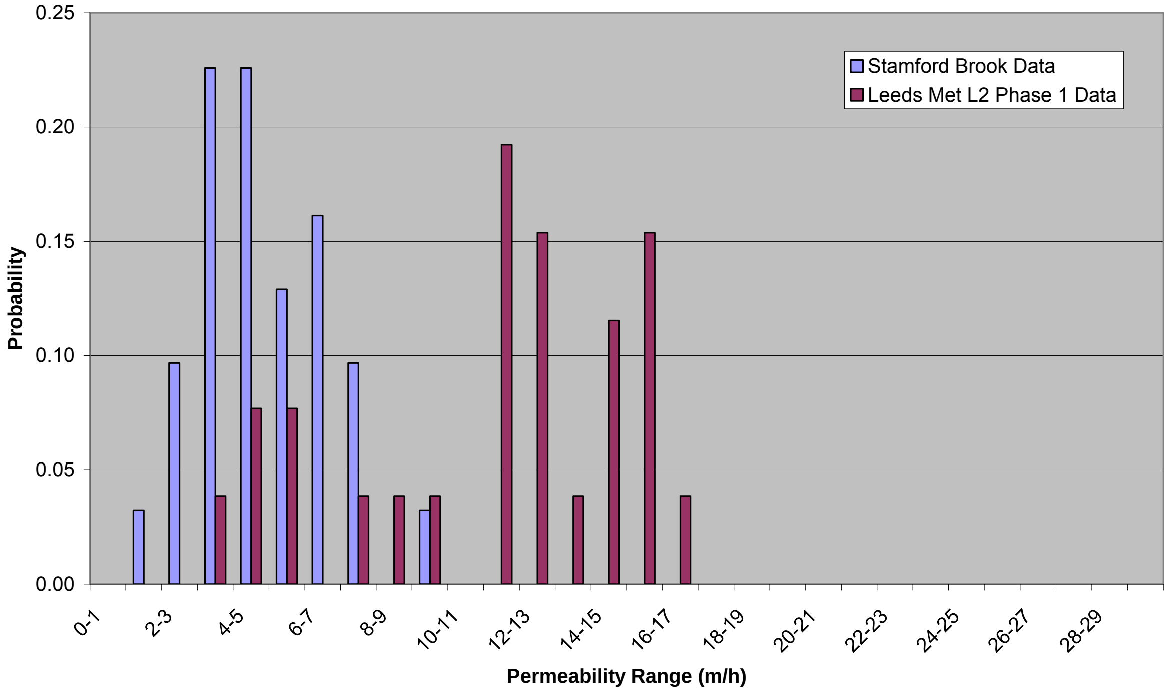


Figure 43 - Probability Distribution of Stamford Brook Data and Leeds Met L2 Phase 1 Data

Variability in Airtightness as a Function of Test Date

97 A time plot of the Stamford Brook pressure test results for the 31 dwellings is shown in Figure 44.

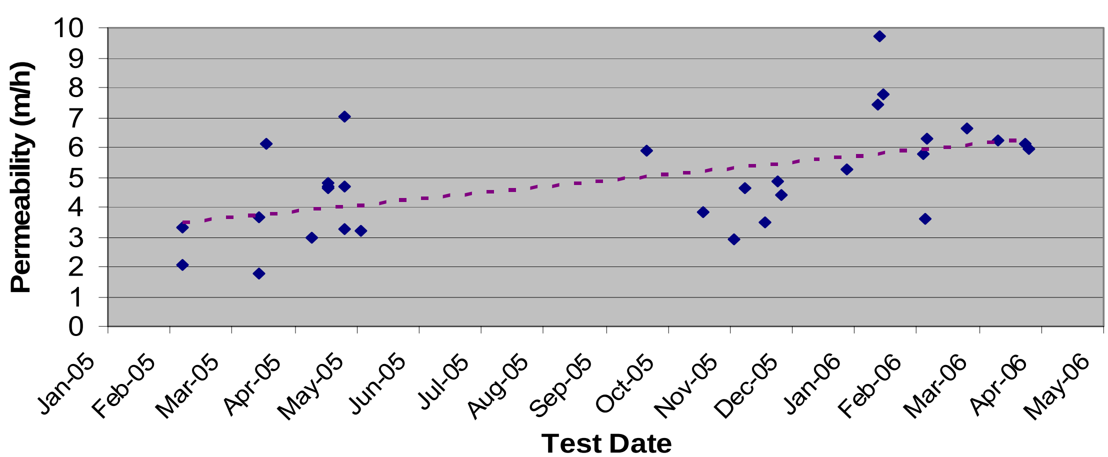


Figure 44 - Time Plot of Stamford Brook Permeability Data by Test Date

98 The test date time plot in Figure 44 suggests a trend of deteriorating airtightness performance at Stamford Brook over time. There was a gap in the pressure testing program between June 2005 and October 2005. The data from before this period ranged from 1.8 m/h to 7 m/h with a mean of 4 m/h. The permeabilities from pressure tests since October 2005 ranged from 2.9 m/h to 9.7 m/h with a mean of 5.6 m/h. There could be several reasons for this apparent reduction in performance. These could include the following factors:

a) A shift in focus away from controlling airtightness due to other technical problems.

b) Lack of quality control due to financial constraints and time pressures as developers approach their year end.

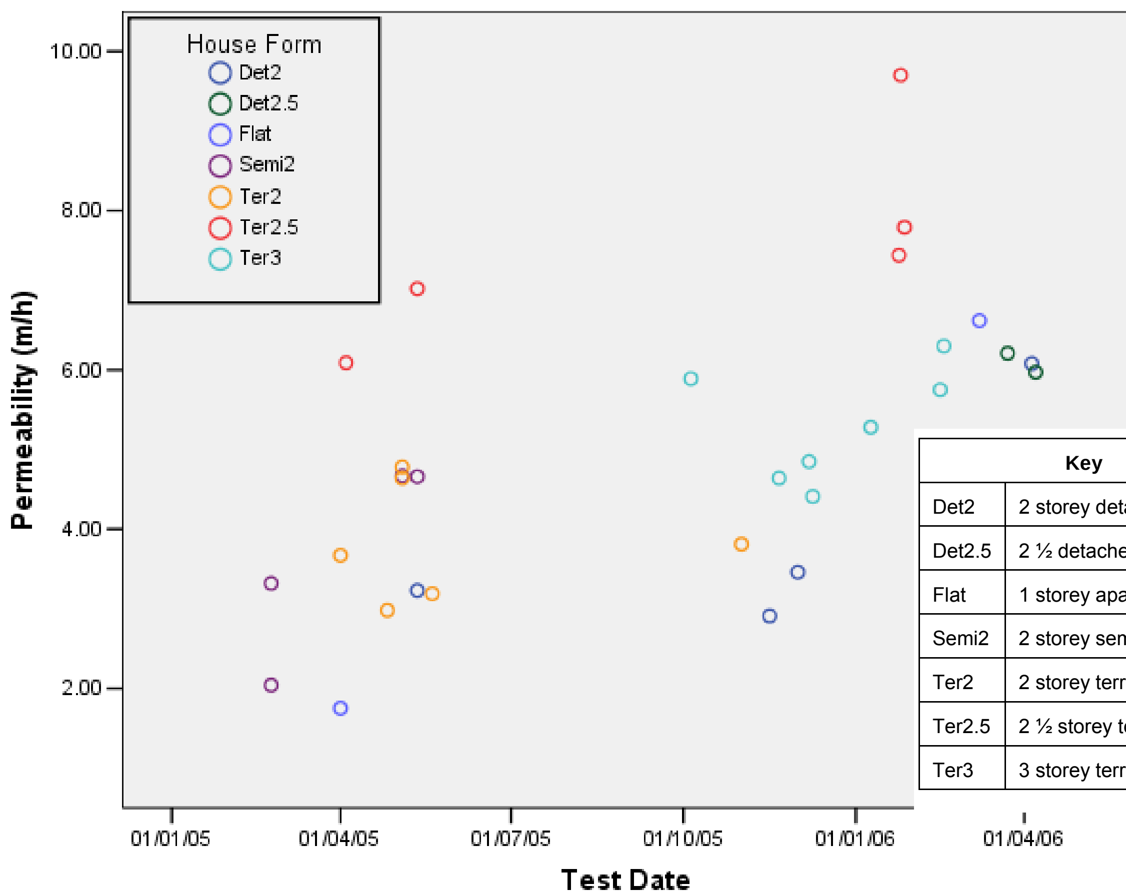
c) Changes in site personnel and subcontractors.

d) Reduced presence of Leeds Met researchers on site advising on airtightness issues.

e) Reduced level of training on airtightness measures and control procedures.

f) Material and product substitutions.

99 The trend for reduced performance does not appear to be related to a shift in the mix of dwelling type being constructed. The time plot is shown in Figure 45 with the data sorted and plotted according to dwelling form. These data indicate that, for most dwelling types, dwellings constructed at later dates have higher permeabilities than those constructed at the start of the development. For example, the lowest permeability measured at Stamford Brook was from apartment plot 301 tested at the start of April 2005, which had a permeability of 1.8 m/h. In contrast, apartment plots 513 and 512, which were tested in February/March 2006, had permeabilities of 3.6 m/h and 6.6 m/h respectively.



Key	
Det2	2 storey detached
Det2.5	2 ½ detached
Flat	1 storey apartment
Semi2	2 storey semi-detached
Ter2	2 storey terraced
Ter2.5	2 ½ storey terraced
Ter3	3 storey terraced

Figure 45 - Time Plot of Stamford Brook Permeability Data by Test Date and Sorted by Dwelling Form

Deterioration in Airtightness of a Dwelling over Time

100 The airtightness of the Bryant semi-detached show home plot 13 has been measured on three different occasions over the period of a year since it was constructed. The permeabilities from these tests are given in Table 22. The permeability has increased from 3.3 m/h post-construction, to 4.9 m/h a year later. Such changes in airtightness over time for occupied properties have been reported in the literature and are discussed in the literature review for the Leeds Met L2 airtightness project (Johnston Wingfield & Bell 2004). Increases of around 80% during the first year of occupation have been reported in the literature, which is similar to the increase of 50% that we have observed for plot 13. The literature indicates that such increases may be due to a combination of shrinkage, settlement and occupier interventions. Plot 13 has not yet been occupied but has been used for one of the co-heating tests. The observed continuing increase in permeability is therefore most likely due to settlement and shrinkage cracks in the materials forming the air tight barrier, and also potentially the failure of seals around service penetrations. It is intended that further pressure tests will be conducted on plot 13 whilst it remains a show home.

Table 22 - Changes to Airtightness of Plot 13 since Construction

Test Date	Air Permeability (m/h)	Volumetric Air Leakage Rate (ach)
23 February 2005	3.3	3.7
14 December 2005	4.2	4.6
22 March 2006	4.9	5.4

Inter-dwelling Leakage Test

101 The balanced fan pressure test technique (Reardon & Shaw 1988) was used to measure the inter-dwelling leakage rate between the adjacent semi-detached Bryant plots 13 and 14. The results are shown in Table 23. The test involved first measuring the air permeability of plot 13 using one blower door. A second blower was then installed in plot 14. The pressure test was then repeated with the internal pressures in both plots matched during the test. In order to make it easier to coordinate the test pressures in both dwellings, the test was conducted from the outside. A photograph of the test in progress is illustrated in Figure 46. The inter-dwelling leakage can be calculated from the difference between the two test results. It can be seen from the results in Table 23 that there was no difference between the two tests with both results at 4.9 m/h. This indicates that there was no air leakage from plot 13 to the inside of plot 14. This result is perhaps not surprising given the parging layer on the party walls and the careful attention to sealing around the built in I-beam joists using sealant and filler pieces between web and flange. Also, as these properties were amongst the first to be constructed they would have been more subject to more stringent quality control checks and observations of critical stages of the construction process.

Table 23 - Inter-dwelling Leakage Test Results

Test Description	Air Permeability (m/h)	Volumetric Leakage Rate (ach)
Permeability of Plot 13 - Pressure test conducted from outside	4.86	5.38
Inter-dwelling test - Permeability of Plot 13 measured from outside - Test pressure in Plot 14 matched to pressure in Plot 13	4.84	5.35
Permeability of Plot 13 - Pressure test conducted from inside	4.92	5.44

102 A third test was conducted on plot 13, this time from the inside of the dwelling. The measured permeability was again 4.9 m/h. We therefore have three measurements on one day from one dwelling, all giving the same air permeability result of 4.9 m/h. This gives a degree of confidence in the repeatability of pressure test data from the Energy Conservatory Minneapolis blower door in conjunction with the TM23 pressure test procedure.

Figure 46 - Photograph of Inter-dwelling Pressure Test using Two Blower Doors

Identification of Leakage Paths

103 Some of the dwellings at Stamford Brook that were pressure tested also underwent extensive leakage detection immediately after the pressure test in order to identify the main infiltration pathways through the building envelope. The entry points of major leakage paths into the internal envelope were located using handheld smoke generators whilst the dwellings were pressurised to around 75 Pa. It was not possible to determine the complete infiltration paths to outside as the majority of the path was always hidden behind walls and boxing-in. However, it was possible to make a judgement as to the most likely route given knowledge of the actual construction and using experience gained from the Leeds Met L2 airtightness project.

Windows

104 The Danish Rationel windows were found to perform very well in terms of air infiltration, with no indications of any significant air movement at any point around the window seals. Some leakage had been noted on early dwellings at the junction between the framing elements of bay windows which had not been sealed correctly, but this was rectified on later dwellings. The Rationel window trickle vents (Figure 47) were found to have virtually no leakage in the closed position.

Figure 47 - Trickle Vent on Rationel Window showing Foam Seal

105 The good performance of the Rationel trickle vents is in direct contrast to observations of significant leakage around various types of closed trickle vents on UK-sourced windows during airtightness tests undertaken on other developments during the L2 project (Johnston et al 2006). The Rationel trickle vents are supplied fitted with a compressible foam seal as shown in Figure 47. In comparison, trickle vents on typical new UK windows are usually closed using a simple plastic flap or some form of sliding mechanism without any proper seal (see example in Figure 48).

Figure 48 - Leakage around Typical UK-sourced Trickle Vent (picture from Leeds Met L2 project)

Doors and Patio Doors

106 The Rationel back doors were in general free from any significant air leakage around the seal between frame and door. It was not possible to test the seal around any of the front doors or through the letterbox, as the blower door was always located in the front door frame during the pressure test.

107 Patio doors were found to be a common source of significant leakage on many of the dwellings tested at Stamford Brook. Leakage was found to occur at several different locations including under unsealed door thresholds, at the bottom corners at the junction of the threshold with the wall and also on several occasions where the door closing mechanism was faulty such that the door seals were not fully compressed giving rise to leakage between the frame and patio door. Some examples of leakage around patio doors are illustrated in Figures 49 to 52.

Figure 49 Patio Door Leak at Unsealed Threshold

Figure 50 Patio Door Leak at Threshold Corner

Figure 51 - Leak between Patio Doors

Figure 52 - Leakage under Threshold

Rooflights

108 The rooflights used by both developers (Redrow rooflights were supplied by Keylite, Bryant rooflights were supplied by Velux) were found to be associated with significant leakage around the trickle vents, between window and frame, and at the joint between the frame and ceiling plasterboard. Examples of leakage around rooflights are illustrated in Figures 53 to 56.

Figure 53 - Leakage around Rooflight Frame

Figure 54 - Leakage around Rooflight Frame

Figure 55 - Leakage at Rooflight Seal

Figure 56 - Leakage at Rooflight Seal

Loft Hatch

109 The moulded polypropylene loft hatches installed at Stamford Brook were mostly manufactured by Glidevale. There were two main alternative designs as described in the Glidevale brochure (Glidevale 2002). One design (type LA1) was a push-up hatch and the other (type LA2) was a hinged pull-down hatch. The gap between polypropylene frame and plaster board was sealed using a foam strip. In the case of type LA1, the seal between hatch and frame was achieved using a foam strip located on the top edge of the frame, whereas in type LA2 the foam seal was positioned on the top edge of the hatch (see Figure 57). For both types, air leakage was observed between the frame and ceiling (see example in Figure 58), and also between the hatch and frame (see example in Figure 59).

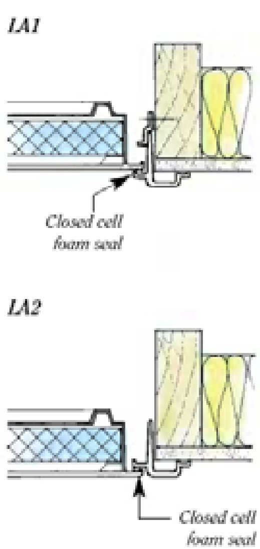


Figure 57 - Location of Hatch Seals (Glidevale 2002)

Figure 58 - Leakage between Hatch Frame and Ceiling

110 It is likely that the air leakage around loft hatches was related to poor installation practice. This poor practice is exemplified by the apparent confusion on site between the two types of hatch. Several examples were observed of hatch installations of the pull-down hatch type LA2 which had actually been installed as a push-up hatch. Consequently, as there was no foam strip on the inside top lip of the frame, there was no air seal between frame and hatch. During one pressure test, the push-up hatch had been fitted without the anti-uplift mechanism and had become dislodged during the test (Figure 60).

Figure 59 - Leakage between Loft Hatch and Frame

Figure 60 - Hatch Dislodged during Test

Soil Stack

111 Perhaps the biggest contributor to overall air leakage in nearly all tested dwellings was due to air movement via the soil stacks. The importance of this leakage path was apparent from both the number of times it was observed and also from the apparent speed and volume of airflow relative to other leakage paths. Leakage due to soil stacks could usually be detected at the ground floor termination of the stack either in the kitchen or in a ground floor bathroom. The other main route into the soil stack was in upper floor bath or shower rooms, where the soil pipes penetrate the boxing in around the stack. The actual path into soil stack was generally hidden behind kitchen cabinets, bath, and bath panel or shower tray. However, smoke could still be observed going behind bath panels, shower tray panels and kitchen units as illustrated in Figures 61 to 64. In the case of both developers, the soil stacks were all internal and terminated in the loft space or roof. The stacks thus provide a direct infiltration route from the inside of a dwelling to the attic. The fact that such high levels of leakage were observed indicates that little or no effort had been taken to seal the air barrier where the stack penetrated the ceiling.

Figure 61 - Leak around Bath Panel

Figure 62 - Leak at Shower Tray

Figure 63 - Leak behind Kitchen Cabinets

Figure 64 - Leak behind Kitchen Cabinets

Service Penetrations and Consumer Units

112 In general, service penetrations were found to be well sealed. The main exception to this was the boiler flue outlet, which was found to be leaky in some dwellings (see example in Figure 65). Attempts had usually been made to seal the joint but were in some cases this had been unsuccessful, apparently due to difficulties in access to the rear of the joint closest the wall. A more common leakage point was behind the consumer unit as shown in Figure 66.

Figure 65 - Leak at Boiler flue

Figure 66 - Leak behind Consumer Unit

Boxed-in Service Voids

113 Significant leaks were found at the joints of the boxed-in services and where pipe runs leading into the boxed void had not been sealed. In general, the pipe runs would have ultimately led to a soil stack. Examples of leaks at pipe penetrations into boxed-in service voids are illustrated in Figure 67 (cut-out for sink trap) and 68 (toilet soil pipe entry into boxed-in void).

Figure 67 - Leak at Cut-out for Sink Trap

Figure 68 - Leak where Toilet Soil Pipe enters Boxed Service Void

Cylinder Cupboard

114 A sometimes forgotten area of air leakage is the cylinder cupboard. Due to the large number of pipe penetrations both into the floor void and through the ceiling, it is common to find service penetrations that have not been properly sealed, and this was indeed the case at Stamford Brook (see Figure 69). In addition, less care was generally taken in finishing off the wall-ceiling junctions and wall-floor junctions inside the cupboard as they are not in view. These junctions were often found to be very leaky (see Figure 70).

Figure 69 Leak through Unsealed Hole

Figure 70 Leak at Wall-Floor Junction in Cupboard

115 The Ventaxia fan unit for the MEV system was also located in the cylinder cupboard. This meant that the flexible and solid ducting for the ventilation system was routed through the cupboard ceiling. In many tested dwellings the penetrations for the ducts through the ceiling had not been properly sealed, if at all. An example is shown (Figure 71) where two of the duct penetrations had been sealed but one had been forgotten. In the worst cases, inappropriately large, sometimes

square holes had been made to route the ducting through. These large holes were often left unsealed (Figure 72).

Figure 71 - Unsealed Duct Penetration

Figure 72 - Oversize Hole

External Wall to Floor Junction

116 On some dwellings, leakage was found to occur at the junction between the blockwork wall and floor under the skirting board, usually on the first and second floors (Figures 73 and 74). Leakage at this point would indicate air movement up behind the plasterboard. It is likely that such air movement would be caused either by the presence of unfilled gaps between floor joists and blockwork allowing infiltration into the wall cavity or alternatively by incomplete sealing at critical junctions, allowing air movement either into the floor void or loft space.

Figure 73 - Leakage at Floor-Wall Junction

Figure 74 - Leakage at Floor-Wall Junction

Partition Walls

117 Leaks at the bottom edge of top floor partition walls were observed in nearly all dwellings with the exception of plots 13 and 14. These leaks were most easily seen at the bottom edges of the partition wall at junctions with door frames as illustrated in Figures 75, 76 and 77. It is likely that the air movement is directly into the attic via the cavity formed by the light steel framed partitioning system used by both developers.



Figure 75 - Leak at Partition Wall **Figure 76** - Leak at Partition Wall **Figure 77** - Leak at Partition Wall

Ceiling Light Fittings and MEV Extract Vents

118 Some minor leaks were identified on a few properties around light fitting in ceilings and between MEV extract vents and ceilings as shown in the example in Figures 78 and 79. Discussions with Ventaxia indicate that normal procedure for installation of the vents is to use silicone sealant to seal around the vent. Clearly this had not been done on a number of properties.

Figure 78 - Leak around Light Fitting

Figure 79 - Leak around MEV Extract Vent

Response of Developers to Feedback on Airtightness

119 The developers have received extensive feedback on airtightness performance from Leeds Met in several ways during the course of the project as follows:

a) An email summary was sent to both developers and the National Trust immediately after each pressure test. This included the test result, descriptions of any critical leakage paths that were identified and an update on the overall mean for all tests.

b) Verbal feedback after each test was given by the Leeds Met testing team on site to the site manager from the appropriate developer. This included brief information on the test result and relevant technical advice.

c) A summary of the airtightness results has been given at several of the quarterly steering group meetings and discussions were held at these meetings as to the impact of the result trends and site observations.

d) Formal sessions with the developers and National Trust on airtightness have included a focus group held in March 2005 and a seminar held in March 2006.

e) Training sessions have been held on site with teams from both developers on the operation of the blower door and pressure test procedures[7]. The sessions included general advice on airtightness issues.

f) Several repeat pressure tests were undertaken by Leeds Met on dwellings that had failed to meet the 5 m/h target. Before the retests, attempts were made by the developers to improve the airtightness using secondary sealing techniques and by rectifying any obvious faults. Site managers were always present during the retests so feedback could be given to them directly on the performance of secondary sealing measures.

120 As well as the feedback from Leeds Met, the developers have also received weekly reports from the National Trust's site quantity surveyor, who included comments on issues relating to airtightness in the reports.

Sequencing of Ceiling and Partition Erection

121 It is likely that the reason why plots 13 and 14 did not exhibit air loss via the partition walls, is due to the different construction method employed on these two dwellings, which were the first two properties constructed by Bryant. For plots 13 and 14, the top floor ceiling was erected before the partitioning (Figure 80). This meant that the ceiling air barrier formed by the plasterboard was continuous. All subsequent dwellings constructed by both Bryant and Redrow had the partitions erected before the ceiling as seen in Figure 81. This resulted in gaps in the plasterboard air barrier where the partitions were located. Air could easily move through the partition and into the loft via the cut-out holes in the steel frame that are provided for routing services.

Figure 81 - Partitioning Erected before Ceiling

Figure 80 - Plot 13 Ceiling Erected before Partitions

[7] Both developers have purchased identical blower doors to the type used by Leeds Met. These are currently stored on site at Stamford Brook to enable the developers to conduct their own pressure tests.

122 Initial discussions were held with the developers in early 2005 with regard to the potential for air leakage up the steel frame partitioning into the loft. The developers were unwilling to change the build sequence of the top floor so that the ceiling was erected first. This was due to safety concerns for operatives working in the loft. Instead, it was agreed to use timber head plates and sole plates to try to seal the top and bottom of the steel partition as shown in Figure 82. It was also agreed that the any holes made through the timber to route wiring or pipework would be filled with sealant. However, it is apparent from the leakage detection results that this method has not prevented air flow up the partition. It is probable that air is still able to move in the gap between the side of the timber stud and the plasterboard. There will also be gaps at the joints between lengths of timber.

Figure 82 - Timber Studs at Top and Bottom of Steel Frame Partitioning

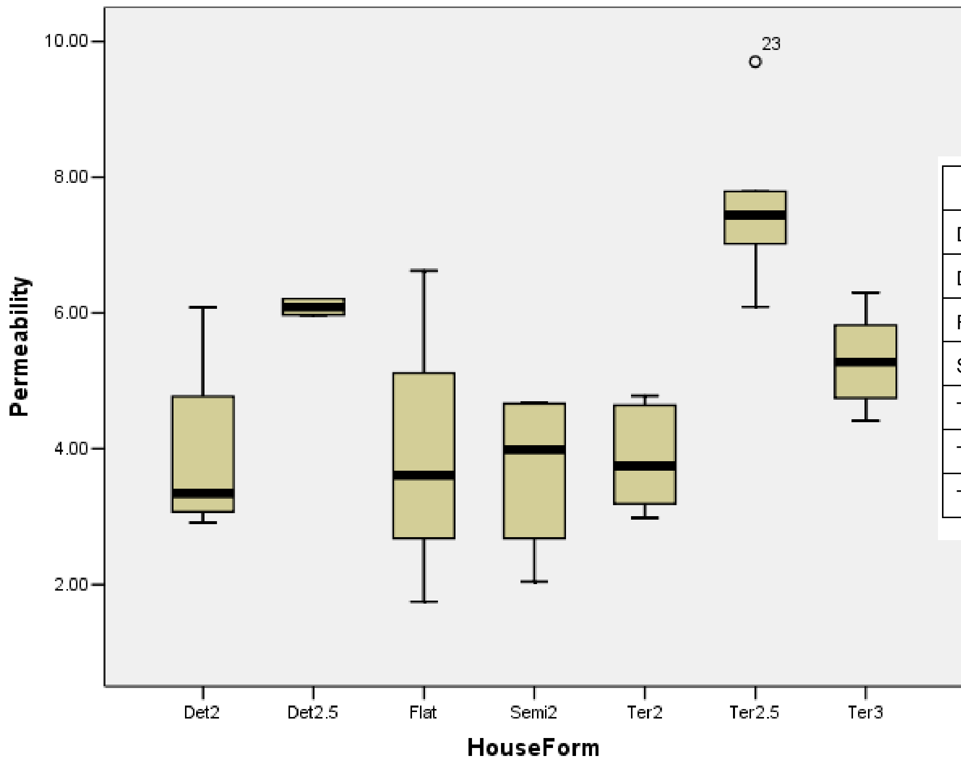
123 It has been recommended to the developers that an alternative solution needs to be found to minimise air leakage via the steel frame partitioning. One potential solution for example, could involve the use of a plastic sheet laid over the top of the partitions and sealed to the top of the plasterboard. However, the method preferred by Leeds Met is to revert to the build sequence used on plot 13 and 14 where that the plasterboard ceiling is constructed before the partitions, assuming some way could be found to resolve the developer's safety concerns.

Continuous Air Barrier Design for Room-in-roof Dwellings

124 One of the biggest concerns of the research team has been the poor performance of the room-in-roof 2 ½-storey house designs. The permeability of this dwelling type has consistently exceeded 5 m/h for both developers. The relative poor performance of 2 ½-storey dwellings can be seen in the box plot of permeabilities sorted by house form shown in Figure 83.

125 The research team have retested several 2 ½-storey properties that have undergone extensive remedial action such as secondary sealing of floor-wall junctions. However, this did not result in any significant improvement in permeability. For example, Bryant plot 66 had a permeability of 9.7 m/h on its first test. Site operatives then sealed secondary leakage points in plot 66 using silicone sealant and expanding polyurethane foam. The dwelling was then pressure tested a second time. In order to eliminate the influence of large gaps in the cylinder cupboard at the MEV duct penetrations, these holes were temporarily sealed using tape and plastic film for the retest. The permeability of the second test on plot 66 was only slightly lower than the first test at 8.9 m/h, even with the gaps in the cylinder cupboard sealed. This illustrates the difficulty in achieving significant improvements in airtightness with remedial measures. Several similar attempts were made to improve the air permeability of Redrow 2 ½-storey terraced plot 309 and these also achieved little success.

126 The high air permeability results obtained for Redrow 2 ½-storey plots 309 and 311 in April and May 2005 gave the developers an early indication of the potential airtightness issues with room-in-roof designs. This enabled Redrow to initiate some site-led design changes to try and improve airtightness on similar properties. An analysis of the drawings showed that one of the main difficulties with the 2 ½ storey designs was related to the detailing at the junction between the wall, plasterboard and roof joists. It was apparent that there were major discontinuities in the air barrier at this point, as can be seen on the roof section drawing illustrated in Figure 84. The main problem was how to link the air barrier at the top of the wall (the parging layer) with the bottom of the plasterboard forming the air barrier on the knee wall of the room-in-roof.



Key	
Det2	2 storey detached
Det2.5	2 ½ detached
Flat	1 storey apartment
Semi2	2 storey semi-detached
Ter2	2 storey terraced
Ter2.5	2 ½ storey terraced
Ter3	3 storey terraced

Figure 83 - Box Plot of Air Permeability sorted by Dwelling Form

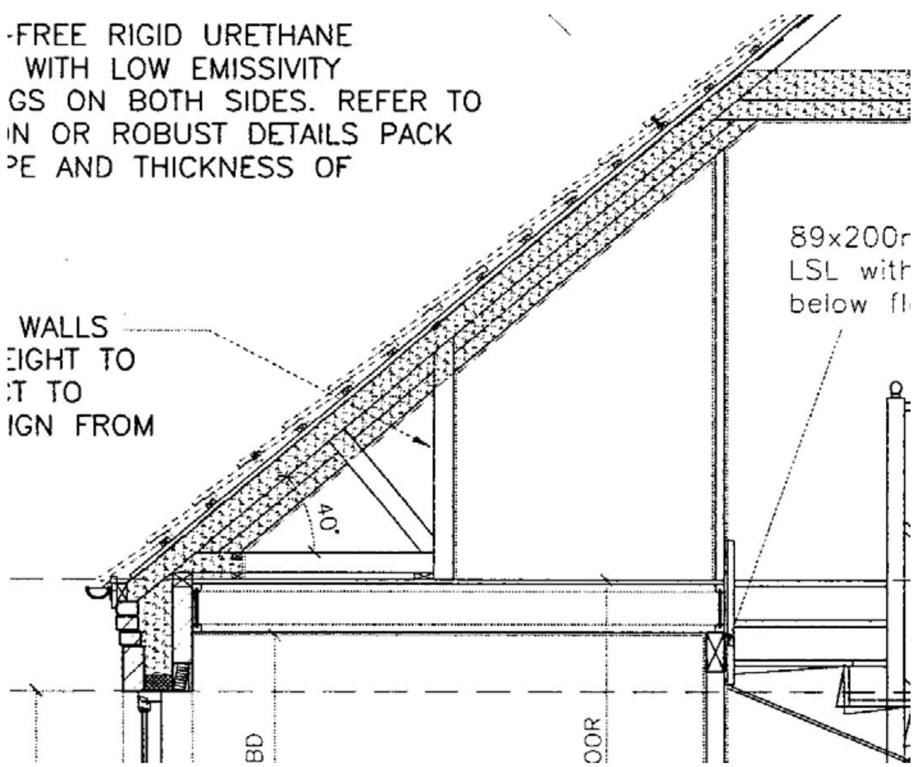


Figure 84 - Wall-Roof Junction for Redrow Room-in-roof Derwent Design

127 The solution proposed and adopted by the Redrow site team was to lay a sheet of polythene damp proof membrane under the roof trusses and above the chipboard flooring as shown in Figure 85, with the aim being to use the polythene to provide the link in the air barrier between parging and plasterboard.

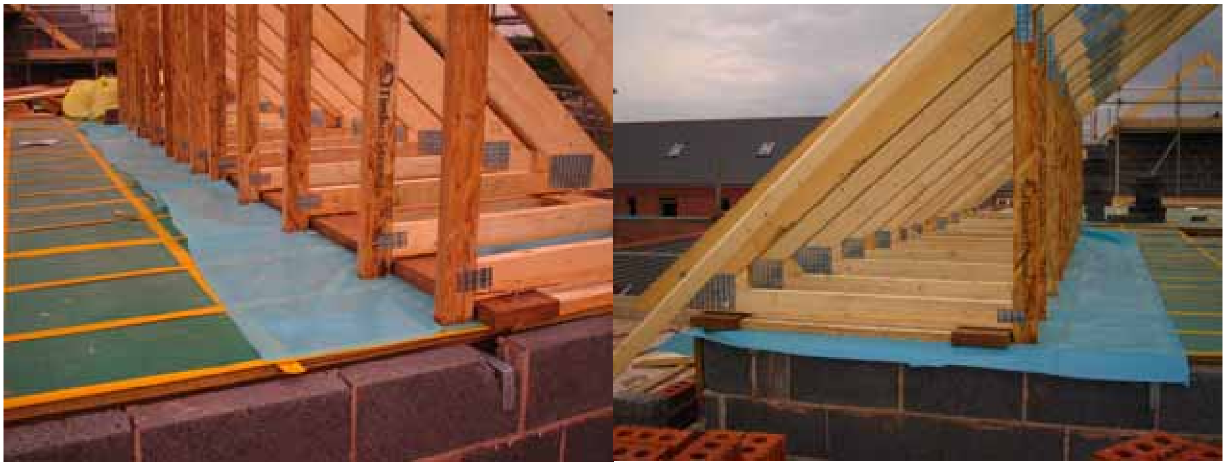


Figure 85 - Polythene Sheet Air Barrier under Roof Truss in Redrow Room-in-Roof Property

128 The pressure test results for Redrow roof-in-the-roof designs that were constructed using the polythene sheet method shown in Figure 85 do not however shown any significant improvement in air permeability. The permeabilities of the two Derwent type dwellings plots 418 and 419 that were constructed using the plastic sheet method were 7.4 m/h and 7.8 m/h respectively. This is actually higher that the permeabilities for the two Derwent type dwellings (plots 309 and 311) constructed before the design change took place which came in at 6.1 m/h and 7.0 m/h. One of the reasons why this method was not successful is likely due to the fact the polythene sheet was not properly linked to either the parging or plasterboard. This can be seen in Figure 86 which shows that the bottom edge of the polythene is cut short and nailed to the end board and does not actually link with the parging layer. It can also be seen that the side of the polythene sheet also finishes short of the edge of the flooring. There is clearly more work to be done here in the fine detailing of this solution to make it airtight, though it should be possible to achieve a very tight roof.

Figure 86 - Polythene Sheet Air Barrier in Room-in-Roof Dwelling

129 A change in direction taken by Redrow will mean a complete rethink of how they tackle the room-in-roof airtightness issue. Redrow decided that, in order to improve buildability and reduce construction time, they would alter the way that they construct room-in-roof dwellings by introducing full room-in-roof attic trusses instead of the TrusJoist “Spatial Roof” raised tie truss system

(TrusJoist 2006) used in earlier dwellings on the development. For example, attic trusses are being installed on Redrow Tweed type dwellings at Stamford Brook as illustrated in Figures 87 and 88.

Figure 87 - Attic Truss at Stamford Brook

Figure 88 - Attic Truss Viewed from Below

130 It would not be possible to use the same technique for attic trusses of laying a polythene sheet between the floor and truss, as the attic truss is designed as a single piece as can be seen in Figures 87 and 88. The Redrow design team submitted the proposed attic truss detail to the Leeds Met team for comment and the weaknesses of the design in terms of airtightness were pointed out to them. Nonetheless, Redrow decided to go ahead with the change, without incorporating any special measures for airtightness at the room-in-roof junction save a polythene layer at the knee wall. The permeabilities of the first two Tweed properties that were pressure tested both exceeded the 5 m/h target at 6.2 m/h for plot 517 and 6.0 m/h for plot 518. This is around twice the mean permeability for standard 2-storey detached houses at Stamford Brook of a similar size. Clearly, more thought must be given by the developers to the design of a continuous air barrier for room-in-roof houses with attic trusses.

131 It has also been pointed out to the developers that, where there are steel frame partition walls in the attic room formed by the room-in-roof design, then these can provide a direct leakage path into the cavity behind the stud work knee wall. A steel frame partition in an attic room can be seen in Figure 89.

Figure 89 - Steel Frame Partition in Room-in-roof

132 Again, this is an issue of sequencing as the partitioning is normally erected before the plasterboard on the knee wall. This leaves a potential infiltration path via the partition, through the holes in the steel frame and directly into the cavity.

Linking of Soil Stack with Attic Space

133 The problem of air leakage via boxed in soil stacks into the attic should be a relatively simple one to solve. The ideal solution would be to ensure that the primary air barrier at the ceiling is continuous and properly sealed where the soil pipe penetrates the barrier. This is clearly shown in the drawing detail as illustrated in Figure 90. What is probably the most likely build sequence is that the boxed-in sections for the soil stacks are erected first and the soil pipes installed before the ceiling goes up. This will mean that there is no plasterboard at the top of the boxed-in void and this will give rise to a major discontinuity in the air barrier.

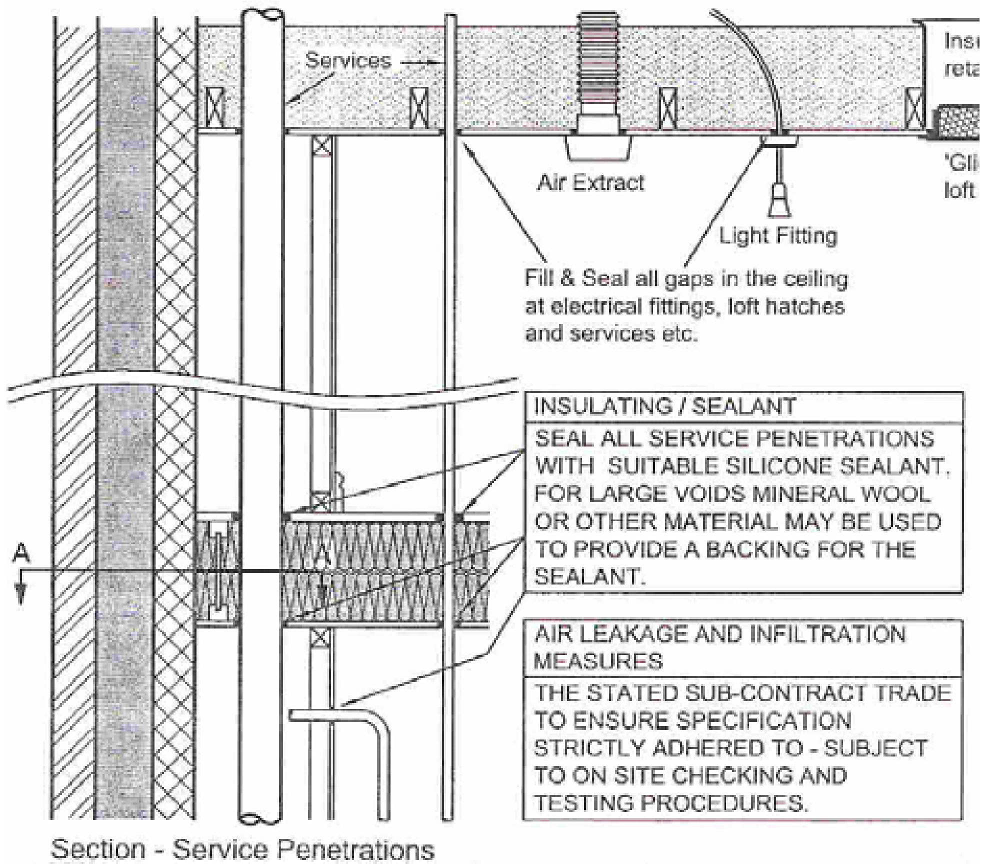


Figure 90 - Drawing Detail for Service Void and Service Penetrations

134 Following a series of pressure tests on Redrow properties which gave a poor results and where there was significant leakage via the soil stacks, the initial response from the site manager was to send out a team to remove all bath panels and kitchen units and to try and seal the stack at the bottom. Following consultation with the research team, the developer is now giving much more thought to a design solution that deals with the primary air barrier. The first concept they came up with was to use a sheet of polythene film fitted tightly around the soil pipe to seal around the top of the stack. They have now moved away from this idea and are now considering using plywood cut-outs sized to suit the soil pipes and which would be easier to seal to the plasterboard than a plastic sheet.

135 An alternative solution to the problem of soil stacks would be to make the soil pipes an external feature of the dwelling. This would solve the issue of having to deal with the penetration of the ceiling air barrier and would instead make it necessary to seal the soil pipe penetrations through the external wall. This approach would increase the total number of penetrations of the air barrier. This solution would of course change the external aesthetics of the dwellings. Whatever solution is

adopted, the indications from leakage detection are that significant improvements in airtightness could be achieved if the sealing of soil stacks were to be improved.

Built-in Joists

136 The intermediate floor I-beam joists used at Stamford Brook were built in to the blockwork walls, with the exception of some Redrow properties in area 3 that used joist hangers on both external and party walls. To make it easier to seal around the joints between the blockwork and I-beam, timber filler pieces were attached to the webs before installation as shown in Figure 91. It was also emphasised to the masonry subcontractors about the importance of ensuring that the gap between the end joist and wall was completely filled. Initial observations showed that this was indeed taking place (Figure 92).

Figure 91 Filler End Pieces on I-beam Web

Figure 92 Gap Filled between End Beam and Wall

137 During discussions between the researchers and the developers in 2004 (Roberts at al 2005), it was originally proposed that for party walls, the I-beam joists would be supported with joist hangers as opposed to being built-in, and that to allay safety fears the Simpson Safety Fast system (Simpson Strong Tie 2006) would be used to support the joists. This system uses a joist hanger with restraint at the joist junction with a party wall. For external walls the joist would be built in using a plastic joist end cap to minimise air leakage. It is believed that this system was never actually used due to developers' concerns about additional complexity (Roberts et al 2005), and no examples of its use were observed.

138 One of the expected long term problems with built-in joists as opposed to the use of joist hangers is that in the case of built-in joists there may be deterioration in the seal between the timber and blockwork due to differential expansion and contraction, which in time could lead to an increase in air permeability. It is also very difficult to properly fill the gap between the end joist and wall corner, especially where the gap is very small. For these reasons, joist hangers remain the approach most likely to produce a robust solution. The timber intermediate floor will always remain a weak point in the air barrier. Concrete floors, particularly in-situ, would remove this weak point completely, probably improve acoustic performance and simplify the structure (by for example by removing the need for wall ties in party walls).

139 The fact that Redrow successfully used joist hangers on area 3 at Stamford Brook indicates that any technical or safety issues associated with their use must be resolvable. Photographs of intermediate floors being installed using joist hangers are shown in Figures 93 and 94.

Figure 93 - Intermediate Floor on Joist Hangers with Parged Wall

Figure 94 - Intermediate Floor Being Installed on Joist Hangers

140 The developers have shown some initiative in trying out new ideas. An example of this if the use of foam inserts for I-beam joist ends as an alternative to the timber filler pieces. A foam insert is illustrated in Figure 95 and a foam insert in situ is shown in Figure 96. Since no tests on this approach have been conducted, it is not possible to comment on its effectiveness.

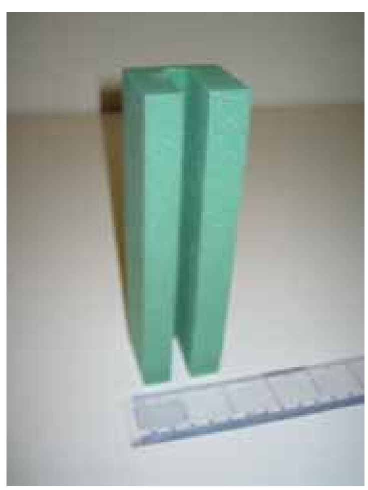


Figure 95 - Foam Insert for End of I-Beam

Figure 96 - Built in I-Beam with Foam Insert

Wet Plastering as an Alternative to Parging and Plasterboard

141 Although the primary air barrier for the walls was the parging layer, it was decided by the developers to retain the requirement for continuous perimeter ribbons of adhesive as illustrated in the drawing detail in Figure 97. Observations from pressure test leakage detection show that, in most cases, there is significant air movement between the plasterboard and wall. This indicates that a complete perimeter seal is not being achieved and that the gap between the plasterboard and wall is forming a plenum that links up all the air leakage paths in the dwelling. This is not surprising, as the research team have concluded from observations on many other developments that it is actually very difficult, if not impossible, to achieve a complete perimeter seal around the edge of a plasterboard wall due to the many practical constraints.

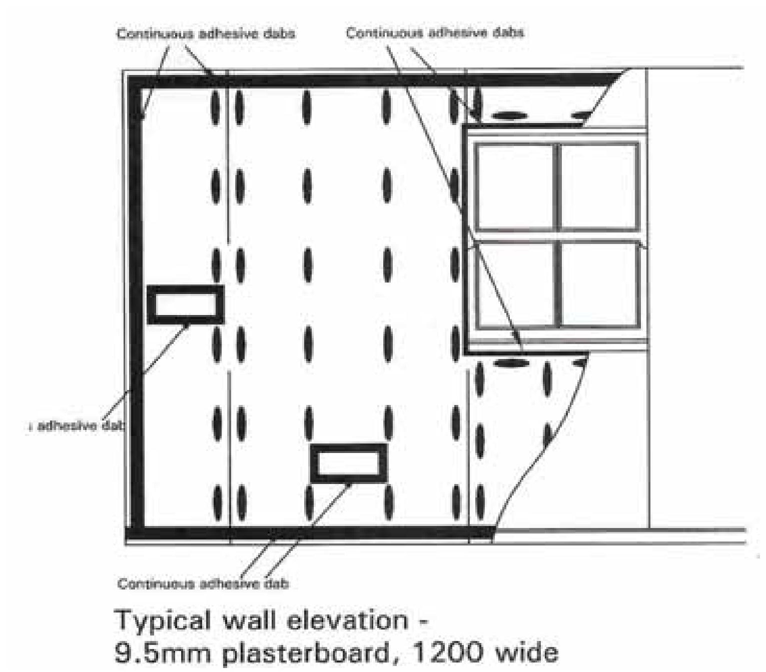


Figure 97 - Drawing Detail for Plasterboard Adhesive Dabs

142 It was originally believed by the research team that wet plastering is a much more robust solution in terms of airtightness than plasterboard on dabs. Research carried out by Leeds Met on thirteen other sites as part of the ODPM L2 project (Johnston et al 2006) and ODPM C1 project (Bell Smith & Miles-Shenton 2005) concluded that it is extremely difficult to achieve continuous adhesive

ribbons in practice and that there are nearly always gaps in the perimeter seal. It was also concluded that wet plastered cavity masonry dwellings are intrinsically airtight.

143 The original Stamford Brook development plan called for a proportion of the first phase of dwellings to be finished using wet plastering so that a comparison with the parging solution and plasterboard on dabs could be made. This did not take place, as the developers were greatly concerned about the extended drying times needed for wet plastering and the perceived nationwide lack of skilled plasterers. An alternative approach to traditional wet plastering of mechanically applied wet plastering was considered, but no trials have yet been undertaken.

144 There may be other solutions that could be used in conjunction with the plasterboard-parging method to make the technique more robust. For example, it might be advantageous to fit some form of angled moulding or plastic sheet along the top edge of the parged wall to link the parging layer with the ceiling plasterboard. The difficulty would be in finding a suitable compatible sealing material.

Sealing under Door Thresholds

145 Air leakage under door thresholds to outside and at threshold corners into the cavity has been identified during numerous pressure tests and the cause and remedy has been fed back by the research team to the site teams several times. Nonetheless the same fault persists despite the fact that it is relatively simple infiltration path to deal with.

146 Discussions with some of the site management team revealed that they have misunderstood how the air barrier at Stamford Brook is constructed. There appeared to be a lack of understanding of the air barrier concept and how air moves around a dwelling, even though the site teams had taken part in the airtightness training sessions earlier in the project. For example, some of the site team were of the belief that sealing the outside of the door threshold would maintain the air barrier. This suggests that the airtightness training package may need to be reassessed so that it emphasises the location of the primary air barrier. It may also be prudent to introduce refresher courses to key members of the site team and contractors.

Secondary Sealing versus Design Solutions

147 It was clear from discussions with both site management teams that they believe that secondary and remedial sealing is a viable method for achieving the airtightness targets despite evidence to the contrary. It is likely that there is considerable pressure on the site managers to meet the airtightness requirements and that they will use any method at their disposal to try and meet the target. However, for there to be viable long term solutions to improving airtightness these must be design led. The Leeds Met L2 project concluded that approaches to airtightness that involve no changes to design but instead concentrate efforts on basic workmanship coupled with secondary and remedial sealing measures during construction are likely to be much less robust than those approaches that are based on an explicit attempt at the design stage to concentrate on ensuring that there is an effective and continuous primary air barrier (Johnston et al 2006).

Discussion of Airtightness Test Results

148 The results of airtightness testing at Stamford Brook have shown that the dwellings constructed are very airtight compared to typical current UK practice, especially for such a large development being built by high volume developers. The mean permeability of 4.9 m/h at 50 Pa is just below the 5 m/h EPS08 target, significantly below the 10 m/h limit set in ADL1A 2006 and better than the UK mean from the BRE 384 dwelling database of 11.5 m/h. All dwellings tested have been below the 10 m/h limit set in Part L 2006. These results show that it is possible to build cavity masonry dwellings on a large scale to a consistently high level of airtightness. However, it should be remembered that an air permeability of around 5 m/h is still much higher than that typically achieved in countries such as Sweden and Canada where permeabilities of less than 2 m/h for new dwellings are the norm and where best practice is of the order 0.3 m/h (Johnston et al 2004).

149 Of the 31 properties tested 13 (42%) did not meet the 5 m/h target. The majority of those dwellings which failed to meet the target were 2-½ storey room-in-roof and 3-storey dwelling types. The failure of these house types to meet the target is believed to be an intrinsic design issue that cannot be adequately resolved by on-site measures. The developers have agreed to try to develop design solutions for these dwelling types and will be setting up a team to consider the alternatives.

150 It is possible that the reduced airtightness seen for the Redrow Derwent 2 ½ storey terraced dwellings with polythene sheet detail below the truss is due to the better performance of joist

hangers versus built-in joists. The two Derwent properties tested with the polythene sheet were on area 4, by which time Redrow had switched to using built-in joists. This highlights the problems of comparing performance between dwellings on a real site where multiple changes take place.

151 The excellent airtightness performance of dwellings at Stamford Brook in comparison with the airtightness of typical new UK dwellings is likely due to several factors as follows:

a) The requirements for airtightness were discussed and considered at the design stage and specific airtightness measures such as parging were adopted.

b) The design drawings contained explicit details and instructions for all airtightness measures.

c) An airtightness training package was implemented for all groups involved in the development including client, senior management, design team, site management, site operatives and subcontractors.

d) A comprehensive pressure testing regime was adopted that provided real data on actual airtightness which could be used to monitor performance.

e) Continuous feedback on airtightness performance and leakage paths and recommendations for improvement measures were provided by the Leeds Met team.

f) There was some degree of competition between the site teams for the two developers in terms of who was achieving and maintaining the better airtightness figures.

152 The fact that the airtightness values have generally been getting higher as the development has progressed suggests that the developers have shifted their focus away from airtightness, perhaps due to the very good results that were achieved early on. Some of this reduction in performance may be related to staff turnover and changes in subcontractors. However, it is just as likely that financial and time pressures have resulted in a reduction in quality. It is suggested that improvements in the quality control and monitoring systems used by the developers might reverse the upward trend in airtightness. There are also indications that some of the knowledge imparted to the site teams during the initial airtightness training sessions has been lost and perhaps the training needs to be reinforced by refresher courses. Another possible explanation is that more subtle design changes and product substitutions have been made that have not been notified to the research team as they were though unimportant. However, even very small changes if not considered carefully could have a significant effect on airtightness.

153 There is an apparent conflict in some cases between buildability and airtightness as illustrated by Redrow's decision to change from the TrusJoist "Spatial Roof" roof truss system to a normal room-in-roof attic truss for 2 ½-storey designs. This decision was taken despite the knowledge that it may impair airtightness, as was indeed found to be the case.

154 It is clear that there are many untapped opportunities to improve airtightness at Stamford Brook still further. In particular, design measures that address the issues of the soil stack, steel frame partitioning and door thresholds would be expected to achieve improvements.

155 The observation that there are significant infiltration losses in the main wet rooms via the soil stacks suggests the possibility of short-circuiting of the whole ventilation system. It is possible that the air feeding the extract vents will come not from the window trickle vents and across the living areas but instead via the soil stack infiltration routes. This could give rise to under-ventilation of the main living areas which have no extract vents.

Implications of Airtightness Test Results

156 The two developers have proved that they can achieve air permeabilities of 5 m/h. However, in order to achieve the required standard consistently, the developers need to address the issues discussed above so that subsequent test results are in line with the airtightness values that were achieved in the early stages of the project.

157 In terms of Part L, the data from Stamford Brook have shown that it is possible for a volume house builder to construct a large development of cavity masonry dwellings and meet the 10 m/h permeability target set in ADL1 2006. This should give the ODPM confidence that, as long as developers have adopted a design and construction approach that properly considers airtightness, then 10 m/h is a viable target. A concern would be for those developers that choose to adopt a regulatory compliance approach for airtightness that uses the new accredited details rather than pressure testing. These developers may not adopt a holistic design and construction methodology for airtightness and hence may not consider all the interrelated factors that influence airtightness

that are not covered in the accredited details. Consequently they may have some difficulty in achieving the target.

158 The data suggest that with better attention to the design of the air barrier for dwellings with complex detailing such as room-in-roof designs, it should be possible to consistently achieve permeabilities of less than 5 m/h. The airtightness levels achieved at Stamford Brook could therefore be used as evidence to support the setting of a more stringent airtightness target for dwellings under the 2010 review of Part L of the order of 7 m/h or lower, though there is a strong argument for leaving the limit to design freedom for air permeability at 10 m/h and simply reducing the Target CO_2 Emission Rate. Designers could then decide for themselves what the best strategy for CO_2 should be.

159 It is apparent that in order to maintain consistently good levels of airtightness over the lifetime of a development, it will be necessary to maintain a robust quality control system and training package for the duration of the project. The quality system must be able to react to changes in design, changes in materials and product substitutions, changes in key personnel and changes in subcontractors. The compliance testing procedure in ADL1A 2006 includes the requirement for the test sample for each dwelling type to be skewed towards the start of the development to enable lessons to be learned and any necessary design changes implemented in the early stages. It may be prudent to require that the remaining pressure tests are spread across the duration of the project to pick up any drift in performance. In the case of developers that use accredited construction details, the requirement in ADL1A 2006 is that only one dwelling need be tested for each dwelling type. Consequently, if these are all tested in the first stages of the development and there is no further requirement for testing, then any drift in performance would not be picked up.

160 The observed deterioration in airtightness over time for plot 13 could have implications for the way that air permeability values are used in SAP, for the setting of airtightness targets in Part L and also for the size of the predicted carbon savings resulting from the new building regulations. The current SAP methodology uses the air permeability from a pressure test conducted soon after completion of a dwelling. Our results suggest that airtightness of masonry cavity dwellings is actually a moving target which will degrade over time in response to shrinkage and settlement. In the case of plot 13 for example, the increase in permeability from 3.3 m/h immediately post construction to 4.9 m/h a year later would have only a small effect on thermal performance, increasing the ventilation heat loss coefficient from 33.3 W/K to 35.3 W/K and the dwelling carbon emission rate from 21.1 $kgCO_2/m^2$ to 21.4 $kgCO_2/m^2$. However, the differences would be much larger for bigger increases in permeability. Further pressure tests on plot 13 later in 2006 will hopefully give an indication as to whether permeability will continue to increase over time. One concern is that deterioration due to settlement and shrinkage may be relatively higher in percentage terms on airtight dwellings compared to similar changes on less airtight properties.

Recommendations on Airtightness

161 One of the difficulties that the research team encountered when analysing the pressure test data was that assumptions had to be made about the route of hidden leakage paths based on general site observations and CAD drawings, as data were not available on the construction of the dwellings actually tested. This means that there may have been specific construction faults or material omissions that were not accounted for in the analysis. A more precise investigation of the leakage paths would be possible if the dwellings had been observed during construction and a photographic record taken of the critical stages before being pressure tested. This was the approach adopted by the Leeds Met L2 project (Johnston et al 2006). It is therefore suggested that a similar approach is taken on a limited number of dwellings at Stamford Brook.

162 It is critical that the developers take a lead in developing design solutions for those 2 ½-storey and 3-storey dwelling types that have been found to exceed the airtightness target of 5 m/h. The developers have already agreed that they will set up a working party to look at the problem, with Leeds Met contributing to the group discussions.

163 It is important that the developers put in place an airtightness quality system for their design process for new dwelling types and also major design changes. The quality system should specify the location of the primary air barrier, identify any potential discontinuities in the air barrier and provide information on what measures need to be adopted on site to ensure the continuity of the air barrier during construction.

164 It is suggested that the developers consider the appointment of a senior quality manager at either regional or national level. The remit of such a role would be to develop robust quality systems to monitor and control the performance of new dwellings not just in terms of airtightness but also other

important measurable performance indicators such as continuity of insulation and acoustics. It is envisaged that the developers would want to develop their own testing expertise and to monitor a set of key performance indicators using a statistically based process control system (SPC). The quality system would ideally link with the product development, design and group purchasing functions. It is recommended that the developers consider a process improvement system based on the use of Six-Sigma analytical tools and methods invented by Motorola and widely used in the manufacturing industries (Motorola 2006).

165 It is recommended that the research team continue to conduct occasional pressure tests on Bryant plot 13 over the next year whilst it remains a show home. This will give further data on the deterioration in airtightness over time.

166 The developers' site teams at Stamford Brook would probably find it useful to develop their own pressure testing programme to provide feedback on airtightness performance relative to the 5 m/h target, especially for the time when the PII project has ceased and Leeds Met are no longer providing any new pressure test data.

Ventilation System Testing

Ventilation Flow Measurement Test Equipment

167 Flow rates from the MEV systems extract vents were measured using an Energy Conservatory Exhaust Fan Flow Meter in conjunction with an Energy Conservatory DG-700 digital pressure gauge. The test procedure is described in the operation manual (Energy Conservatory 2003). A photograph of the test equipment in operation is shown in Figure 98. The Fan Flow Meter has an effective flow measurement range of 13 m^3/h (3.6 l/s) to 210 m^3/h (58.5 l/s) with an accuracy of $\pm$10%. This range would be expected to be sufficient for all MEV vents at Stamford Brook which would be expected to have flows in the range 18 m^3/h (5 l/s) to around 54 m^3/h (15 l/s).

Figure 98 - Exhaust Fan Flow Meter in Operation (Energy Conservatory 2003)

Ventaxia MEV System

168 The MEV fans installed at Stamford Brook were Ventaxia Multivent systems. Those MEV systems installed during the first phase of construction were fitted with a simple two speed switch with a “normal” setting and “boost” setting. Later dwellings were fitted with an updated fan unit and a new five position control unit (“II”, “IIII”, “max”, “night-time” & “unoccupied” settings). The “normal” mode and “II” setting for the two alternative switch types were set to be 50% of the maximum flow and the installed system was to be balanced such that the normal mode would provide an extract rate equivalent to the normal design flow rate. A programme is in place to gradually upgrade the original fan units from the first phase of construction with a new control board and to replace the old 2-position switch with the new 5-position switch. The number of extract vents installed in each dwelling depended upon the size of the dwelling and the number of wet rooms. The total design extract flow was calculated according to the Leeds Met ventilation flow spreadsheet (Lowe & Roberts 2004).

Mechanical Extract Ventilation System Flow Rates

169 The total extract flow rates in “normal” or “II” mode depending upon the type of speed switch installed) for nine tested dwellings are shown in Table 24. It can be seen that in all but one case, the MEV systems failed to achieve their design flow rates, in some cases by as much as 63%. It can also be seen from Table 24 that in seven out of the nine dwellings, at least one of the individual extract vents failed to achieve a flow rate greater than 12 m^3/h and hence were below the minimum measurable flow of the fan flow meter. In these cases the total flow rate shown in Table 24 is an estimate of the maximum possible flow. There does not appear to be any difference in performance between the two types of fan and fan control unit.

Table 24 - Dwelling Total Extract Flow Rates

Developer	Plot No	MEV system type	Measured normal mode flow [8] (m^3/h)	Design flow in normal mode (m^3/h)
Redrow	403	2-position	104	101
Redrow	324	2-position	< 55	101
Redrow	309	2-position	< 56	130
Redrow	402	2-position	63	101
Redrow	405	5-position	< 37	101
Redrow	406	5-position	< 64	101
Bryant	13	2-position	< 59	86
Bryant	14	5-position	< 68	86
Bryant	69	5-position	< 91	144

170 An investigation was undertaken to determine the cause of the underperformance of the ventilation systems. The results of this investigation are described in Appendix 3. The conclusions of this study were as follows:

a) The test data indicated that the poor performance was likely due to a combination of pressure loss between the fan unit and roof vent and a pressure loss in ductwork in the dwelling.

b) The MEV systems had not been adequately commissioned.

c) There was a potential problem with the roof terminal vents which appeared to differ from the approved design and consequently may have a pressure drop that is too high for the system.

d) It was likely that some of the 2-position switches had been wired up incorrectly.

[8] In most cases the total measured flow could not be accurately measured as the flow from some of the vents was below the 13 m^3/h measurement threshold of the fan flow meter. In these cases each vent for which a measurement could not be obtained was assigned a value of 12 m^3/h and the total flow is shown as a figure with a less than sign (<).

e) There were indications that the upgraded fan was performing differently to the originally installed system.

171 The developers and Ventaxia are currently working together to resolve the problems identified in the ventilation tests. This will include tests of various types of Glidevale ridge and tile terminal vents to determine their suitability for use at Stamford Brook. A procedure is also being put in place to commission all MEV systems on new dwellings and also to check and if necessary rectify the MEV systems in dwellings that have already been occupied.

Effect on MEV Extract Flows of Opening Trickle Vent and Interior Doors

172 A series of flow measurements were conducted in plot 309 to determine the effect on ventilation extract flows of air input flow from the trickle vents and also the effect of whether the interior doors were open or closed. The total flow rates were measured in normal and boost mode in three different conditions, firstly with all trickle vents open and all interior doors wedged open, secondly with all trickle vents open and all interior doors closed and thirdly with all trickle vents closed and all interior doors open. The results are shown in Table 25.

Table 25 - Effect of Trickle Vents and Interior Door Opening on Ventilation Flow Rates (m^3/h)

Extract Vent Location	**Trickle Vents Open Interior Doors Open**		**Trickle Vents Open Interior Doors Closed**		**Trickle Vents Closed Interior Doors Open**	
	Normal	Boost	Normal	Boost	Normal	Boost
Toilet	≤ 12	17	≤ 12	19	≤ 12	20
Kitchen	≤ 12	15	≤ 12	16	≤ 12	17
En-suite	18	46	18	46	19	47
Bathroom	13	31	14	31	13	32
Total	< 55	109	< 56	112	< 56	116

173 It can be seen from Table 25 that opening or closing the trickle vents of interior doors makes little difference to the measured MEV system extract flow rate. The permeability of plot 309 was 6.1 m/h. Therefore, with an infiltration rate at this level, there is sufficient flow of air through the external fabric to supply the mechanical ventilation system without the need for air flow from the trickle vents. We do not know what would happen in a much tighter dwelling.

Background Ventilation Rate using Carbon Dioxide Concentration Decay Rate

174 The measurement of carbon dioxide decay rates as a cheap and simple method of determining background ventilation has been reported in the literature (Roulet & Foradini 2002). It was decided to use the data from one of the occupied dwellings at Stamford Brook taking part in the extensive monitoring program (Dwelling Code C). The sensor installation in Dwelling C included a CO_2 sensor centrally located the house in the main bedroom. The CO_2 data was assessed to identify a point in time when the occupants went on holiday for several days to allow a sufficient time series of data for the decay. The occupants were then asked to confirm the precise time when they left the house and also to confirm that the MEV system had been switched to the minimum "unoccupied house" speed setting.

175 A plot of the CO_2 decay versus time obtained and a first order exponential fit are shown in Figure 99. The R^2 coefficient for the fit of the exponential curve was 0.99, showing an excellent match to the data. The 1/e constant was 12624 seconds (3.5 hours) giving a half life of 2.4 hours. The background ventilation rate is calculated from the 1/e value and gives a ventilation rate of 0.29 air changes per hour. This compares to the n/20 ventilation rate for this dwelling of 0.23 air changes per hour showing very good agreement with the ventilation rate obtained from the CO_2 decay rate.

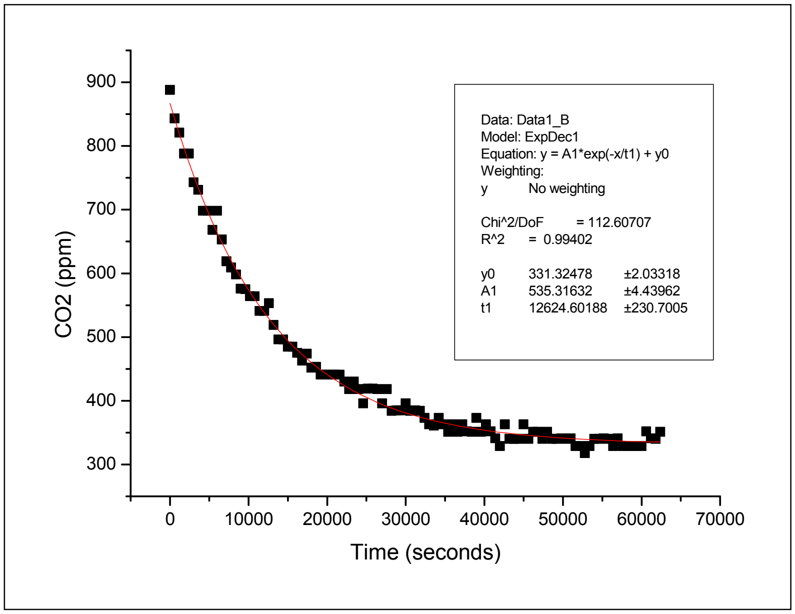


Figure 99 - CO_2 Decay and First Order Exponential Fit for Dwelling C

Discussion of Ventilation System Performance

176 The identification of commissioning problems with a large number of MEV systems and subsequent underperformance is of some concern, particularly so since most of these properties are now occupied and could potentially have MEV systems that are underperforming their design flow rates by as much as 50%. In the worse case scenario, in a very airtight house with an air permeability of 3 m/h less, this could give rise to air quality problems. Although the very positive response by the developers and manufacturer will, undoubtedly, ensure that significant air quality problems are unlikely, the findings raise a number of questions about commissioning processes and the impact of component substitution.

177 The new part L approved documents are unclear when it comes to the commissioning of ventilation systems for dwellings. There is no specific requirement in Part F1 2006 for a commissioning certificate for ventilation systems for dwellings (ODPM 2006b). Approved document part L2A 2006 for new non-domestic buildings (ODPM 2006c) specifically states that all building services including ventilation systems are commissioned and that a notice detailing the test results is provided to building control. Approved document L1A (ODPM 2006a) for dwellings details explicit requirements for commissioning heating and hot water systems but not mechanical extract ventilation systems. However, Regulation 20c of the building regulations (ODPM 2006d) contains the requirement that the local authority should be given a notice confirming that the fixed building services have been commissioned in accordance with a procedure approved by the Secretary of State. The definition of fixed building services in Regulation 2 (ODPM 2006d) includes mechanical ventilation systems. It would be clearer if the advice in Approved Document Part L1A or Part F1 included specific information on the commissioning of mechanical ventilation systems for dwellings and non-mechanical systems of roughly equivalent complexity (for example passive stack ventilation).

178 There appears to have been a breakdown in communication between the developers and ventilation system supplier (Ventaxia) which has resulted in a product substitution of the approved roof terminal vents that is potentially detrimental to the overall performance of the MEV system. It is believed that the changes were made on the grounds of aesthetics, with there being a preference for low profile tiles vents over ridge vents as they were less visible on the roof. It is clear that a more rigorous product approval system is needed that would check and verify any proposed product or material substitutions.

179 The good correlation between the background ventilation rate predicted from the air permeability test result and that measured directly from the carbon dioxide decay rate suggests that the n/20 rule is a good approximation for a dwelling with a form factor similar to that of the dwelling tested. The form factor (ratio of dwelling volume to external envelope area) for dwelling C was 1.07. It would be useful to have the same comparison of background ventilation rates for dwellings with a wide range of form factors, but unfortunately all the houses that have so far agreed to take part in

the long term monitoring program have similar form factors to dwelling C. Nonetheless it may be a useful exercise to check the CO_2 data for the other monitored dwellings.

Recommendations from MEV System Testing

180 It is suggested that the developers review their processes for product approval and substitution. It is important that there are systems in place that will prevent materials and products being used on site that do not meet performance requirements, as would appear to have been the case for the low profile tile terminal vents that were substituted for the approved ridge terminal vents.

181 It would be useful to repeat the ventilation flow test with trickle vents open & closed in a dwelling with a very high level of airtightness of the order 3 m/h or less.

182 The ODPM should consider including a specific requirement in Approved Document L1A for commissioning certificates for all dwellings with whole house mechanical ventilation systems.

Thermal Imaging

183 Infra-red thermal imaging was carried out on a limited number of dwellings at Stamford Brook. This included internal images and external of the two co-heating test dwellings and internal images of three dwellings from households that had signed up to the extensive monitoring program. The infrared camera used was a FLIR Systems Thermacam P65 model.

184 In order to avoid misinterpretation, the conditions and procedures needed for infra-red thermography of buildings are very limiting and are described in a BRE information paper on infra-red thermography for building surveys (Hart 1990). The ideal conditions for a survey are when there is a large temperature difference between outside and inside, when all surfaces are very dry and when there is very little solar radiation. These conditions limit the occasions when infra-red thermography can be undertaken.

185 With the exception of the infra-red images taken in the loft of plot 13, limited information was obtained from thermal imaging.

186 Infrared images of the internal walls of plot 13 during the co-heating test showed that it was possible with this technique to distinguish the pattern of adhesive used to attach the plasterboard drylining to the walls. It can be seen in Figure 100 of the internal party wall in the hallway of plot 13 that the plasterboard adhesive dabs are readily identifiable as cold spots in blue. By contrast, in Figure 101, one can identify ribbons of plasterboard adhesive, again as colder areas in blue. What is interesting about Figure 101 is that there appear to be gaps in the perimeter adhesive ribbons. This provides further evidence of the difficulty of ensuring that complete perimeter ribbons are achieved reliably in practice.

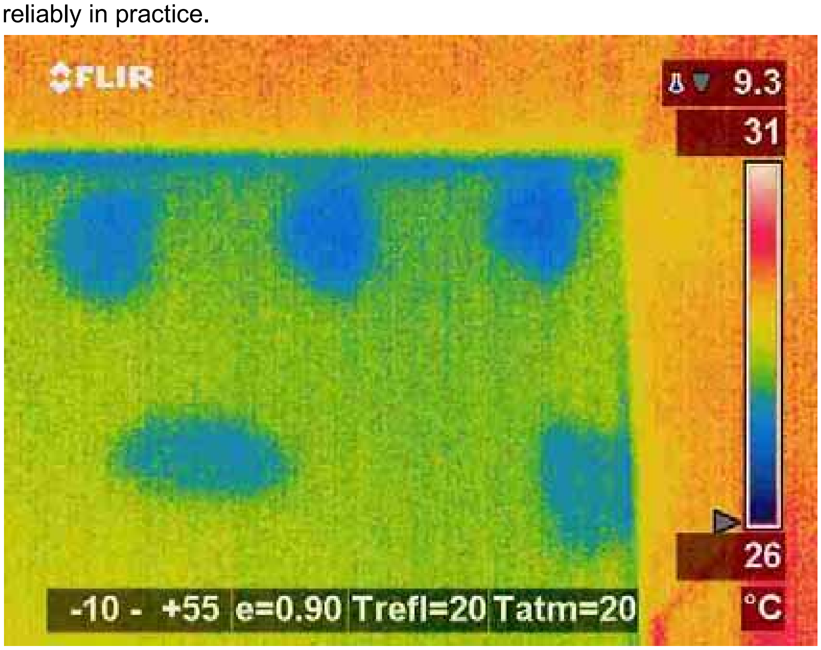


Figure 100 - Thermal Image Plasterboard Adhesive Dabs

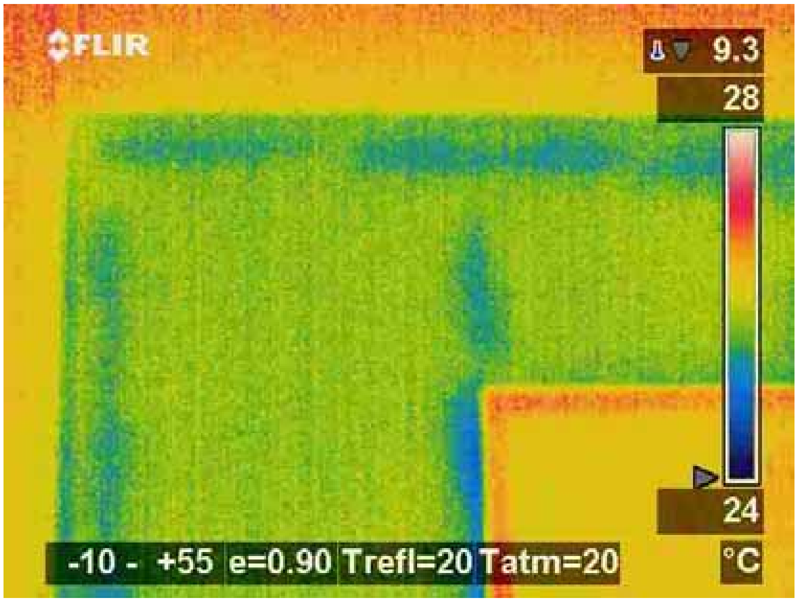


Figure 101 - Thermal Image Plasterboard Adhesive Ribbons

187 There was some indication in the first floor study of plot 13 of a cooler area by 1 to 2 degrees in the top right corner of the external wall as shown in Figure 102 in blue. It is possible there was less dense filling of the cavity with blown insulation in this area, which is adjacent to the plastic sheet used as a cavity tray above the window lintel. It is however more likely that the observed cold spot was an artefact caused by the movement of cooler air from behind the adjacent curtain. The cold area is unusual in that the coolest zone is towards the middle, whereas if the effect was due to reduced insulation the coolest area would be expected to be in the top corner. It was not possible to drill any inspection holes in the wall to check the cavity. It was not thought that this small area would have had a significant impact on the measured heat loss for plot 13 as the temperature difference observed was very small. The cool area was not repeated in the adjacent room where the external wall continued. Also, when the same area of wall from plot 13 was thermally imaged from outside the dwelling, there was no indication of significant heat loss as shown in Figure 103. No other external or internal wall areas were found to show any significant variation in temperature patterns (other than those from the plasterboard dabs) in either plot 13 or plot 402.

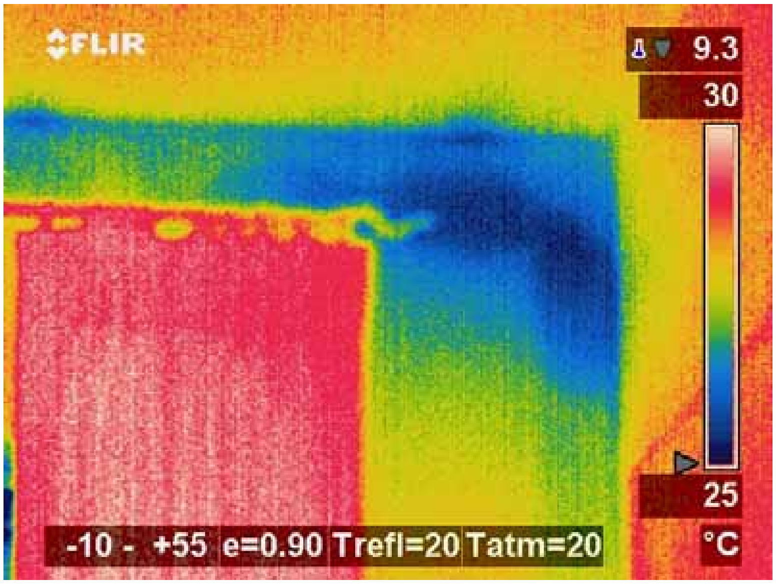


Figure 102 - Thermal Image of Cooler Area of External Wall in Study of Plot 13

Figure 103 - External Thermal Image of Plot 13 Showing Study in Top Right Corner

188 The external thermal image of plot 406 illustrated in Figure 104 indicates higher heat loss through the trickle vents of the Rationel windows which are located along the sides of the window frame.

Figure 104- Thermal Image Showing Heat Loss through Window Trickle Vents

189 Figure 105 shows heat loss via the roof tile terminal vent of the mechanical extract system of plot 406. The vent shows as a white area to the top left hand side of the image.

Figure 105 - Thermal Image Showing Heat Loss at MEV System Roof Terminal Vent

190 Figure 106 illustrates the higher heat loss from the front door of plot 13 which has a surface temperature of around 10°C to 11°C relative to the heat loss from the walls which have a surface temperature of 7°C to 8°C.

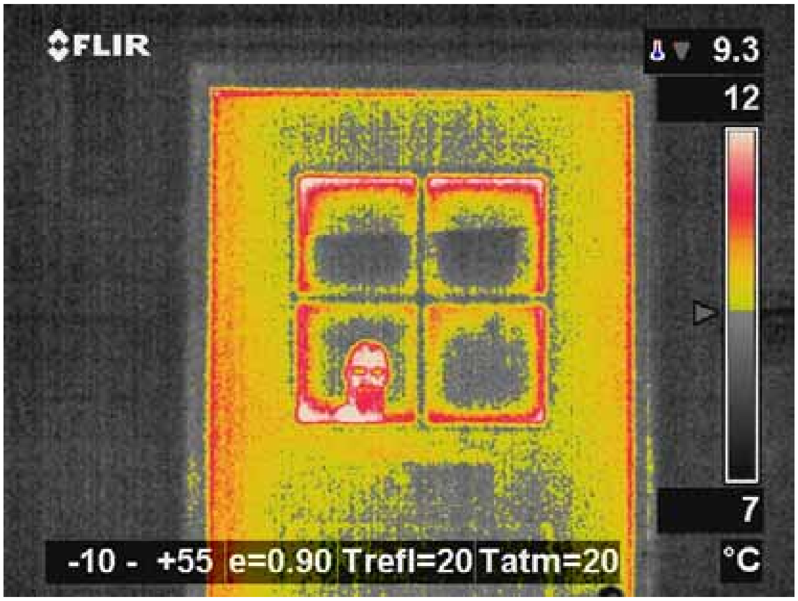


Figure 106 - Thermal Image of External ace of Front Door of Plot 13

Discussion of Thermal Imaging Results

191 Due to the many limitations of the technique, and the difficulties in interpretation, thermal imaging was found to be of restricted usefulness. However, there were occasions where infra-red images have given additional information that would not have otherwise been available. The two notable example of this at Stamford Brook were the thermal images of the attic party wall and the thermal images showing the shape and location of plasterboard adhesive. On others sites as part of the ODPM L2 project, Leeds Met have successfully identified a range of quality issues using thermal

imaging, so we have little doubt that if there were major problems with the performance of the building fabric we would have observed them. An example of this is shown in Figure 107, which shows a thermal image from the ODPM L2 project of an external wall with missing insulation at a site in Manchester.

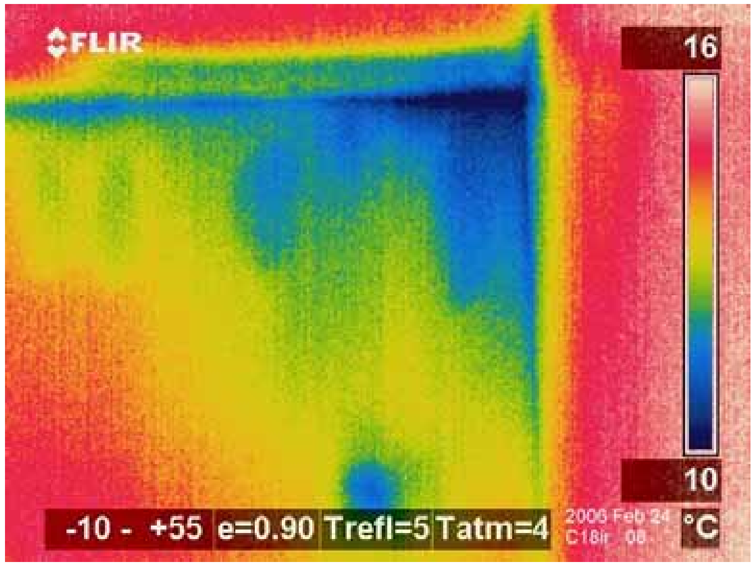


Figure 107 - Thermal Image of External Wall with Missing Insulation on Site in Manchester

Recommendations on the use of Thermal Imaging

192 There is potential to use a high resolution thermal imaging camera as a quality control tool. It has been shown that the technique can detect the presence of plasterboard dabs and perimeter ribbons non-destructively. The developers might consider purchasing a thermal imaging camera. However, the cost may be prohibitive with suitable thermal cameras priced at around £30,000.

General Comments and Conclusions

193 The Stamford Brook development is a text book example of the benefits of partnering. It is unlikely that the high build quality and fabric performance that we have observed on site would have been possible without the close cooperation between the National Trust, developers, suppliers, subcontractors and the Leeds Met research team. Perhaps the best example of partnering in action was the reaction of the partners to the underperformance of installed MEV systems. The traditional response in the construction industry would have been to seek to apportion blame and to resort to some form of legal action. What actually happened was that all the partners sat round a table, discussed the problem and identified a course of action that would resolve the situation in the interests of all parties including the home owners.

194 There is no doubt that the frequent presence of the research team on site and the constant monitoring of key performance factors such as airtightness, ventilation and build quality will be in part be responsible for the results achieved at Stamford Brook. The true test will come once the research team has left site and the developers will have to maintain the same performance levels using their own resources whilst still achieving the financial and sales targets for the development.

195 The results of the co-heating tests have highlighted some of the limitations of the BREDEM/SAP domestic energy model. It would obviously be impractical to require that all carbon emission calculations are carried out using a full thermal simulation model. However, it would seem prudent for either the BRE or the FMNectar consortium to conduct a more thorough series of extended co-heating tests and annual energy audits over a range of dwelling types and construction methods to identify if there are other heat loss mechanisms that may have been overlooked in SAP. As overall fabric performance improves in response to the CO_2 targets set in Part L, hidden heat loss mechanisms could potentially become major factors in overall heat loss, as we have demonstrated is the case with the party wall cavity heat loss path for terraced and semi-detached cavity masonry dwellings. Note that most if not all of the factors omitted from SAP would also be omitted from more complex thermal simulations. The crucial factor in ensuring the comprehensiveness of any model is

a vigorous programme of field enquiry and measurement, capable of revealing and quantifying previously poorly understood aspects of energy use and heat loss. This project has demonstrated the value of undertaking such work in cooperation with industry and other stakeholders.

196 Stamford Brook is a clear demonstration that it is possible for large volume house builders to meet tough performance targets such as those for airtightness. It has also been shown that given the right support and training, new technologies, techniques and ways of working can become embedded in the site culture. The successes achieved at Stamford Brook can be used as an example to other developers that it is possible to build a sustainable development on a large scale. It will be interesting to see whether Bryant and Redrow can effectively disseminate and retain what they have learnt from Stamford Brook throughout their respective organisations.

197 Despite the low air permeabilities achieved at Stamford Brook relative to the UK norm for masonry cavity dwellings, the research team believe that even better performance could have been achieved.[9] The developers made several design compromises over what the research team believe would have been more robust design choices that would have maximised the potential airtightness of a brick-block cavity masonry dwelling with timber intermediate floors built using common UK construction practices and techniques. The compromises were made by the developers on the grounds of buildability, cost, saleability, visual appearance, and for perceived safety reasons. The proposed robust design details are detailed in Table 26.

Table 26 - Proposed Robust Airtightness Details for Cavity-Masonry Dwelling

Detail	Robust Design Solution	Stamford Brook Design Solution
Intermediate floor-wall junction	Joist hangers	Built-in joists
Wall finish	Wet plastering	Parging and plasterboard on dabs
Windows	High performance window seals	High performance window seals
Trickle vents	High performance trickle vent seals	High performance trickle vent seals
Soil vent pipe stack	External soil stack	Internal boxed-in soil stack
Ceiling	Ceiling erected before partitions	Partitions erected before ceiling
Dwelling form	Simple rectilinear forms with minimum complex detailing	Range of dwelling forms, some with complex details such as room-in-roof

198 The background ventilation measured by carbon dioxide concentration decay shows good agreement with that calculated from the n/20 rule using the air permeability value from a dwelling with a form factor (ratio of volume to envelope area) close to 1. Stephen (1998) notes that the n/20 rule of thumb was originally conceived as a relationship between background ventilation rate and the volumetric air change rate measured at 50 Pa. However, SAP 2005 has extended the relationship to apply the rule to air permeability at 50 Pa. Our data indicate that this relationship is still true and gives a good approximation where dwelling volume and envelope area have similar numerical values. However, the relationship may not hold quite so well for all dwelling types. The numerical values for the mean air permeability and mean volumetric air change rate at Stamford Brook are very similar at 4.9 m/h and 4.8 ach respectively (see Table 21). This would mean that the n/20 rule would likely hold true for the mean of the development as a whole, irrespective of whether air permeability or volumetric air change rate were used. However, the values for individual dwellings would vary significantly depending upon their shape, especially for dwelling types where the numerical volumes of volume and envelope area differ significantly. This is demonstrated by the box plot of volumetric leakage rates by dwelling form shown in Figure 108, which illustrates a completely different pattern of results from the box plot of air permeability shown in Figure 83. The form factors of the tested dwellings at Stamford Brook varied from 0.7 for apartments to 1.3 for large 2 ½ and 3-storey houses. With the national trend in the mix of dwelling types over the last few years showing an ever increasing proportion of apartments (NHBC 2006), it may be prudent to review the ongoing validity of the n/20 rule for all dwelling types. For example, it may be possible to apply a simple correction factor based on dwelling form. Stephen (1998) proposed correction factors for dwelling height and wind shielding to account for the influence of wind effects on actual

[9] Footnote: This goes a long way to explaining the apparent churlishness of the research team for whom it appears that nothing is ever good enough.

ventilation rates. Air permeability remains the most useful indicator of ventilation rates due to its ease of measurement and consistency. However, the whole issue of how background ventilation rates are obtained from pressure test data for use in SAP perhaps needs much more careful consideration by taking into account the influence of other variables such as house form and wind effects.

Key	
Det2	2 storey detached
Det2.5	2 ½ detached
Flat	1 storey apartment
Semi2	2 storey semi-detached
Ter2	2 storey terraced
Ter2.5	2 ½ storey terraced
Ter3	3 storey terraced

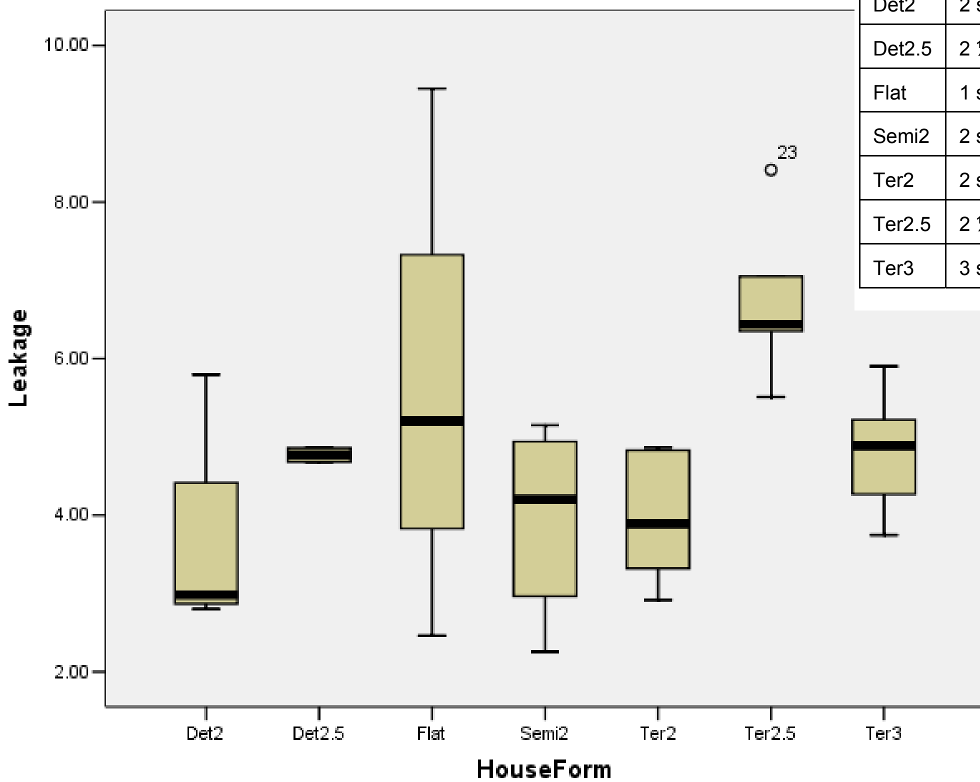


Figure 108 - Box Plot of Volumetric Air Change Leakage Rates (ach) Sorted by Dwelling Form

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Appendix 1 - Parametric SAP Spreadsheets for Co-heating Tests

Parametric SAP Spreadsheet for Plot 13

Parametric domestic energy model

Version 13.94 **R Lowe, D Roberts, M Bell & J Wingfield, based on Draft version 9.80 (2) April 2005.**

leeds metropolitan university

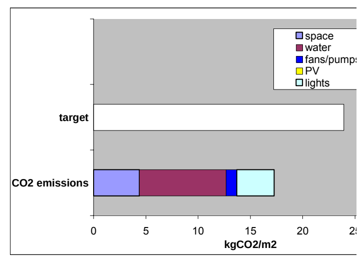
gross floor area	73	m2	
occupants	2.35		
storeys	2		
terrace level	0.5	(0=detached, 0.5 =semi, 1=mid terrace)	
dwelling type selector	house		semi detached house
integral garage		m2	
average room height	2.50	m	
plan aspect ratio	1.64	ratio of plan depth to width	
width	4.72	m	
depth	7.74	m	
glazing ratio	0.17	window area / gross floor area	
glazing asymmetry	0.5	proportion of glazing on main façade	
orientation	0	of main façade with respect to due South (0, 45, 90, 135, 180 degrees)	
target	2005		
rough standard	2005		user defined
U value multiplier	1.00	raises or lowers all U values by this proportion	
thermal bridge method	full calculation		full calculation

Climate Change		
no change	0	K
Summary of results:		
Mean U value	0.31	W/m2K
Fabric heat loss, cf	50.6	W/K
Ventilation heat loss, cv	13.2	W/K
HLP	0.9	W/K
solar hot water fraction	0.00	

	t/year	kg/m2a	
Space heating	0.32	4.4	
Water heating	0.61	8.3	
Fans & pumps	0.07	1.0	
Solar hot water output	0.00	0.0	
PV & others saving	0.00	0.0	
Lighting	0.26	3.6	
CO2 emissions	1.260	17.3	complies wit
target CO2 emissions	1.747	**23.9**	
target reduction against ADL2002		20.0%	

Areas and Nominal U values

	U W/m2K	A m2	AU W/K	user defined
roof	0.14	36.5	5.2	0.14
wall	0.23	76.9	17.7	0.23
ground floor	0.17	36.5	6.3	0.17
doors & windows	1.30	12.4	15.5	1.30
roof windows	1.30		0.0	
thermal bridging	0.04		6.0	
Aexposed		162.3		
Atotal		202.5		
Aexposed/GFA		2.22		



design ach	0.5	ac/h	
volume	190	m3	
ventilation type	natural	('natural', 'mev' or 'mvhr')	
ventilation performance category	medium		
leakage rate	4.28	ac/h at 50 Pa	
pressurisation test result	5.0	m/h at 50 Pa	5.0
effective ventilation rate	0.21	ac/h	
heating type	central	(central, point)	
primary fuel	gas	('gas', 'lpg', 'oil', 'electricity')	
secondary fuel	electricity	('gas', 'lpg', 'oil', 'electricity','none')	
primary heat source	boiler	('boiler', 'ground source heat pump', 'air source heat pump', 'microCHP')	
space heating efficiency	91	%	91
water heating efficiency	91	%	
secondary space heating efficiency	100	% (defaults to primary heating efficiency)	
secondary water heating efficiency	100	% (electric immersion heater)	
living area fraction	0.3		
solar water heating panel area	0	m2	
solar water heating tank volume	100	litres	
solar panel type	flat plate	('flat plate' or 'evacuated tube')	
solar panel direction	south	('north', 'south' or E/W')	
solar panel pitch	30º	('horizontal', '30 deg' or '45 deg')	
peak power of PV installation		kWp	
ratio of low energy bulbs over total bulbs	0.3		

Parametric SAP Spreadsheet for Plot 402

Parametric domestic energy model

Version 13.94 **R Lowe, D Roberts, M Bell & J Wingfield, based on Draft version 9.80 (2) April 2005.**

leeds metropolitan university

gross floor area	105.5	m2	
occupants	3.27		
storeys	3		
terrace level	1	(0=detached, 0.5 =semi, 1=mid terrace)	
dwelling type selector	house		terraced house
integral garage		m2	
average room height	2.40	m	
plan aspect ratio	1.37	ratio of plan depth to width	
width	5.07	m	
depth	6.94	m	
glazing ratio	0.19	window area / gross floor area	
glazing asymmetry	0.4	proportion of glazing on main façade	
orientation	90	of main façade with respect to due South (0, 45, 90, 135, 180 degrees)	

			user defined
target	2005		
rough standard	2005		
U value multiplier	1.00	raises or lowers all U values by this proportion	
thermal bridge method	full calculation		full calculation

Climate Change

no change	0	K

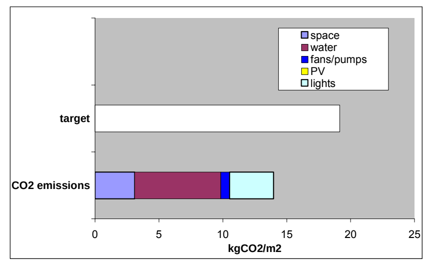
Summary of results:

Mean U value	0.37	W/m2K
Fabric heat loss, cf	54.9	W/K
Ventilation heat loss, cv	20.3	W/K
HLP	0.7	W/K
solar hot water fraction	0.00	

	t/year	kg/m2a	
Space heating	0.33	3.1	
Water heating	0.71	6.7	
Fans & pumps	0.07	0.7	
Solar hot water output	0.00	0.0	
PV & others saving	0.00	0.0	
Lighting	0.36	3.4	
CO2 emissions	1.474	14.0	complies with ADL05
target CO2 emissions	2.019	**19.1**	
target reduction against ADL2002		20.0%	

Areas and Nominal U values

	U W/m2K	A m2	AU W/K	user defined
roof	0.14	35.2	5.0	0.14
wall	0.23	57.0	13.1	0.23
ground floor	0.17	35.2	6.0	0.17
doors & windows	1.30	20.0	24.9	1.30
roof windows	1.30		0.0	
thermal bridging	0.04		5.8	
Aexposed		147.3		
Atotal		252.8		
Aexposed/GFA		1.40		



design ach	0.5	ac/h	
volume	267	m3	
ventilation type	natural	('natural', 'mev' or 'mvhr')	
ventilation performance category	low	SAP 2005 default	
leakage rate	2.92	ac/h at 50 Pa	
pressurisation test result	5.3	m/h at 50 Pa	5.3
effective ventilation rate	0.23	ac/h	
heating type	central	(central, point)	
primary fuel	gas	('gas', 'lpg', 'oil', 'electricity')	
secondary fuel	electricity	('gas', 'lpg', 'oil', 'electricity','none')	
primary heat source	boiler	('boiler', 'ground source heat pump', 'air source heat pump', 'microCHP')	
space heating efficiency	91	%	91
water heating efficiency	91	%	
secondary space heating efficiency	100	% (defaults to primary heating efficiency)	
secondary water heating efficiency	100	% (electric immersion heater)	
living area fraction	0.3		
solar water heating panel area	0	m2	
solar water heating tank volume	100	litres	
solar panel type	flat plate	('flat plate' or 'evacuated tube')	
solar panel direction	E/W	('north', 'south' or E/W')	
solar panel pitch	30º	('horizontal', '30 deg' or '45 deg')	
peak power of PV installation		kWp	
ratio of low energy bulbs over total bulbs	0.3		

Appendix 2 - Alternative Method of Correcting Co-heating Data for Solar Gain

From SAP 2005, the heat gain through windows and glazed doors is calculated as:

$$G_{solar} = 0.9 \times A_w \times S \times g \times FF \times Z \quad (W)$$

where:

0.9 is a factor representing the ratio of typical average transmittance to that at normal incidence

A_w is the area of an opening (a window or a glazed door), m²

S is the solar flux on a surface, W/m²

g is the total solar energy transmittance factor of the glazing at normal incidence

FF is the frame factor for windows and doors (fraction of opening that is glazed)

Z is the solar access factor

We can therefore correct the daily co-heating data with the equations:

Total Daily Solar Gain (W) = Mean Daily Insolation (W/m^2) x Solar Factor

Corrected Daily Heat Input (W) = Measured Daily Heat Input (W) + Total Daily Solar Gain (W)

Table 1 - Solar Factors for Plot 13

South facing window area	6.20	m^2
North facing window area	6.20	m^2
Total window area (Aw)	12.40	m^2
Orientation factor for S versus N	0.40	from SAP table 6a
Solar access factor	1.00	from SAP table 6d
Frame factor (FF)	0.70	from SAP table 6c
Glazing solar transmittance (g)	0.66	from SAP table 6b
Average incidence factor	0.90	from SAP 2005 p17
TOTAL SOLAR FACTOR	3.61	
Corrected Heat Loss Coefficient	108.5	W/K

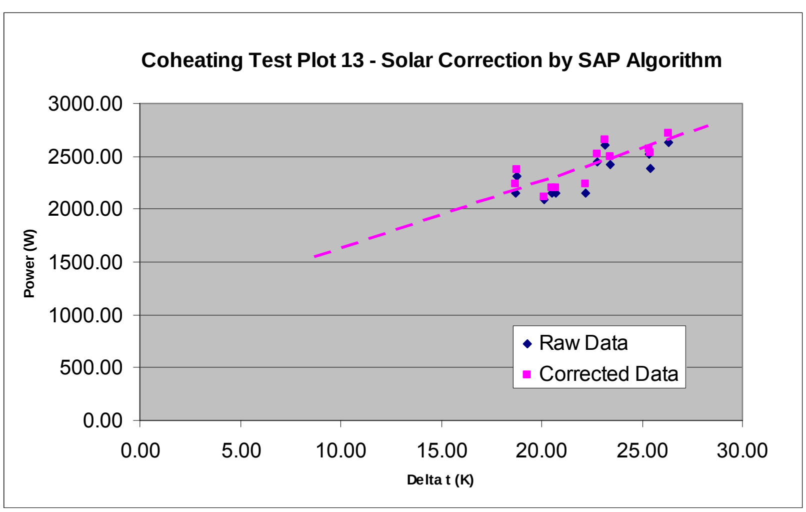
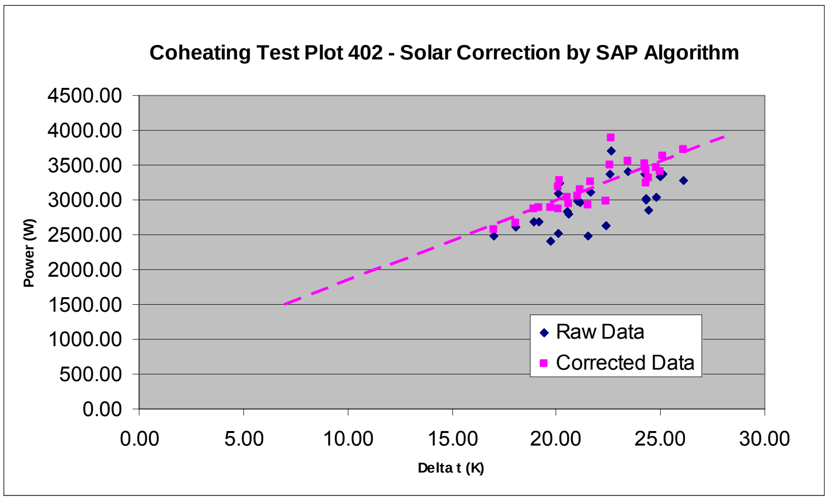


Table 2 - Solar Factors for Plot 402

East facing window area	8.02	m^2
West facing window area	12.03	m^2
Total window area (Aw)	20.05	m^2
Orientation factor for E/W versus N	0.67	from SAP table 6a
Solar access factor	1.00	from SAP table 6d
Frame factor (FF)	0.70	from SAP table 6c
Glazing solar transmittance (g)	0.66	from SAP table 6b
Average incidence factor	0.90	from SAP 2005 p17
TOTAL SOLAR FACTOR	5.61	
Corrected Heat Loss Coefficient	146.7	W/K



Appendix 3 - Technical Note on Performance of MEV Systems

Technical Note

Stamford Brook – MEV System Flow Measurements

Dr Jez Wingfield, Leeds Metropolitan University, 18 February 2006

1. Introduction

Previous measurements of ventilation system flows in several Redrow properties at Stamford Brook indicated lower than expected performance and inconsistencies between plots for some MEV installations. To investigate this further, additional flow tests were arranged to be carried out at Stamford Brook on the 17th February 2006. These tests were supported and witnessed by technical representatives from Ventaxia.

2. Test Dwelling

Redrow plot 405 was selected for test. This is a 3-bedroom 3-storey mid-terraced property (Wye dwelling type). The volume of the dwelling was calculated to be 275m^3. A picture of the dwelling type is illustrated in Figure 1.

Figure 1 – Wye Dwelling Type at Stamford Brook

The MEV Multivent fan was located on the top floor in the cylinder cupboard at the front of the house. There were four MEV extract vents in the dwelling, one each in the kitchen and toilet on the ground floor and one each in the bathroom and ensuite on the top floor. The Ventaxia fan control unit had been upgraded from the old 2 position control unit (normal & boost settings) to the five position control unit (II, IIII, max, night-time & unoccupied settings). The new control unit is illustrated in Figure 2.

Figure 2 – New 5-position Ventaxia Control Unit

The MEV system has been designed by Ventaxia to give 0.5 ach in normal/"II" mode and at least a 40% increase from this to 0.7ach in boost/max mode. According to the spreadsheet developed by Leeds Met, the requirement of 0.5 ach for this dwelling is equivalent to an extract flow requirement of 102 m^3/h. This figure is in agreement with that calculated by Ventaxia.

3. Test Equipment

Ventilation flows were measured using an Energy Conservatory Exhaust Fan Flow Meter in conjunction with an Energy Conservatory DG-700 pressure/flow gauge. The quoted accuracy of this equipment is ±10% of the measured flow. The minimum flow rate that can be measured with this device is 13 m^3/h. Under normal circumstances this minimum flow would be sufficient to measure the expected flow rates from the MEV system extract vents installed at Stamford Brook.

4. Results and Discussion

The control unit in plot 405 was opened up to check the position of the dip switches inside that determine the fan power curve used. The dip switches were set for dwelling type 6. There are seven possible settings of the dip switches ranging from type 1 to type 7 – see Figure 3. The factory default setting is for dwelling type 5. Looking at the Ventaxia Multivent fan performance curve for house type 6, and assuming a typical pressure loss of 100Pa through the system, gives an estimated air volume capability of around 280m^3 which should give sufficient fan capacity for this dwelling which has a volume of 275m^3. The fan performance curve for the Multivent MEV unit is shown in Figure 4. According to the Ventaxia service manual, with the dip switches set in this configuration means that the normal/"II" setting gives 50% of available power and the "Max" setting gives 100% of available fan power.

Figure 3 – MEV Control Unit Dip Switch Settings

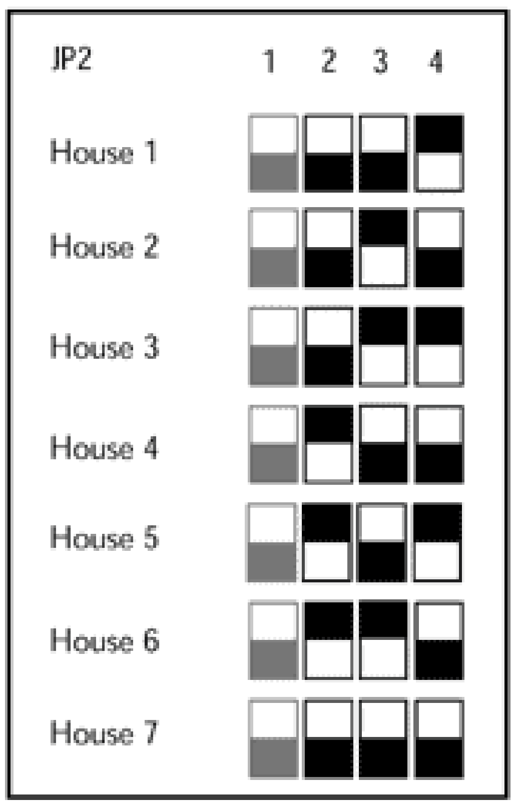
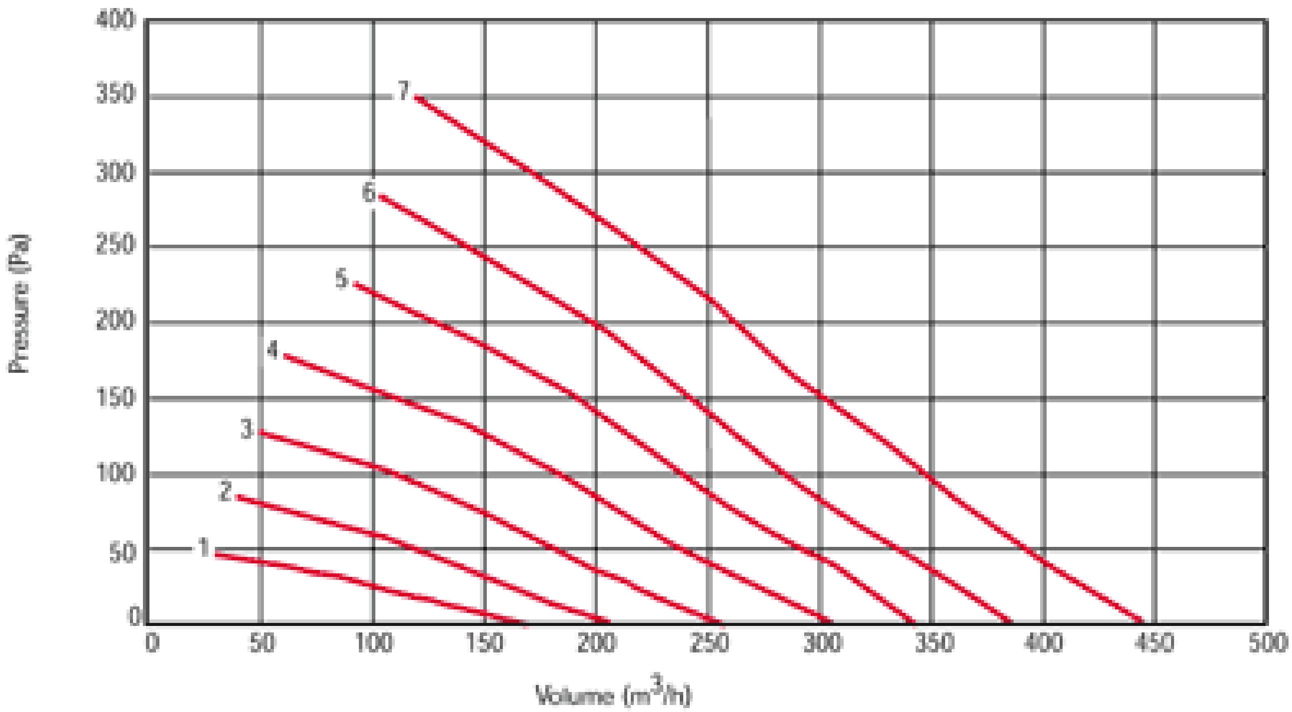


Figure 4 – Multivent Performance Curve



The vents were tested initially in the condition in which they were first found. The results of this test are shown in Table 1. It can be seen from this data that in normal ("II") mode it was only possible to obtain a flow measurement from the bathroom vent. Even in Max mode, flow could only be measured in the bathroom and ensuite. Clearly in normal mode the total flow is significantly below the required 102 m^3/h.

Table 1 - TEST 1 – Vents, Ducts and Fan Left in As-Found Condition

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	≤ 12
Downstairs Toilet	≤ 12	≤ 12
Bathroom	13	29
Ensuite	≤ 12	15
TOTAL	**< 37**	**< 68**

For test 2, all four extract vents were adjusted to their fully open position. The results are illustrated in Table 2. Opening the vents improved the flows in normal mode for the bathroom and ensuite but still no reading could be obtained for the downstairs vents in the kitchen and toilet. The total flow in normal mode is still well below the required 102 m^3/h and still below 102 m^3/h even at the Max setting.

Table 2 - TEST 2 – All Four Extract Vents Fully Opened – Fan and Ducts Left in As-Found Condition

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	≤ 12
Downstairs Toilet	≤ 12	≤ 12
Bathroom	20	38
Ensuite	18	32
TOTAL	**< 62**	**< 94**

In test 3, the four extract vents were left in the fully open position and the duct that connects the outlet flow from the top of the Multivent fan unit to the terminal vent on the roof was disconnected. This is shown in Figure 4.

Figure 4 – Disconnecting Outlet Duct

The reason for disconnecting the terminal duct was to determine if there was any pressure loss between the fan and roof terminal. It can be seen from the results of this test (shown in Table 3) that disconnecting the extract duct had a dramatic effect on the measured flow rates. The flow rates from the bathroom and ensuite in normal mode nearly doubled from 20 to 36 m^3/h and 18 to 30 m^3/h respectively. However, the flow from the downstairs vents still remained below the measurement limit of 13 m^3/h. These results suggests that there is some fault either in the ductwork between the fan unit and roof vent or at the roof terminal vent itself and are also indicative of some pressure loss in the ductwork between the upstairs and downstairs of the dwelling.

Table 3 - TEST 3 – All Four Extract Vents Fully Opened – Duct to Roof Vent Disconnected from Fan Unit – Other Ducts Left in As-Found Condition

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	13
Downstairs Toilet	≤ 12	≤ 12
Bathroom	36	62
Ensuite	30	55
TOTAL	**< 90**	**< 142**

It was also noticed during inspection of the fan unit that the pipe connections to the spigots on the unit and all the connections between the ductwork that were visible in the cylinder cupboard were all loose and had not been properly sealed with tape or sealant. Escaping air flows could be felt with ones hand held close to any of the connections. An example of one of the loose spigot connections is illustrated in Figure 5.

Figure 5 – Loose Spigot Connection

Black duct tape was used to seal all the visible connections and the extract flows measured again. All other parameters were the same as for test 3. The results are given in Table 4. It can be seen that there was only a very small improvement in the measured flows which would be within the experimental error. This indicates that, although leakage was observed at these locations they were not significant enough to result in a major pressure drop.

Table 4 - TEST 4 – All Four Extract Vents Fully Opened – Duct to Roof Vent Disconnected from Fan Unit – All Other Connections to Fan Sealed with Tape

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	13
Downstairs Toilet	≤ 12	≤ 12
Bathroom	35	63
Ensuite	32	55
TOTAL	**< 91**	**< 143**

For test 5 the outlet fan was reconnected to the fan unit. The other duct connections were left sealed with black tape. The results are similar to those observed in Test 2 and confirm that no improvement had resulted from sealing the ductwork around the fan unit.

Table 5 - TEST 5 – All Four Extract Vents Fully Opened – Duct to Roof Vent Reconnected to Fan Unit – All Other Connections to Fan Sealed with Tape

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	13
Downstairs Toilet	≤ 12	≤ 12
Bathroom	19	36
Ensuite	17	32
TOTAL	**< 60**	**< 93**

For the final test it was decided to partially balance the system by adjusting the flow at the vents in the upstairs bathroom and ensuite to a nominal 20 m^3/h each in normal running mode. In theory, this would make more fan power available to the two downstairs vents. This test was conducted with the duct to the roof vent disconnected from the fan unit so as to give maximum potential air flow. The downstairs vents in the kitchen and toilet were left fully open. It can be seen from the results in Table 6 that this test did not result in any measurable increase in flow in the kitchen and toilet in normal mode, as the flow rate remained below the measurement threshold. There was a very small increase in the flow in Max mode for the kitchen and toilet of around 3 m^3/h. However, this increase is much less than the estimated extra flow in Max mode of around 40 m^3/h that would now be available to the downstairs vents as a result of reducing the flow from the upstairs vents (108 m^3/h minus 68 m^3/h). This result is further supporting evidence for some kind of flow restriction in the duct between the upstairs and downstairs. In Table 7 an estimate is given for the air flows in the kitchen and toilet vents in normal mode for Test 6. This was done using the ratio of normal flow to maximum flow observed for the bathroom and ensuite (ratio = 0.55).

Table 6 - TEST 6 – Kitchen and Downstairs Toilet Extract Vents Fully Opened – Bathroom and Ensuite Vents Adjusted to Give 20 m^3/h each - Duct to Roof Vent Disconnected from Fan Unit – All Other Connections to Fan Sealed with Tape

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	≤ 12	16
Downstairs Toilet	≤ 12	15
Bathroom	20	36
Ensuite	20	37
TOTAL	**< 64**	**104**

Table 7 - TEST 6 (B) – Data as per Test 6 above but the results for Normal flow at kitchen and toilet extract vents have been estimated by multiplying the results for these 2 vents in Max mode by the mean ratio of Normal mode flow to Max mode flow obtained for the bathroom and ensuite vents (ratio = 0.55)

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	9 (estimated)	16
Downstairs Toilet	8 (estimated)	15
Bathroom	20	36
Ensuite	20	37
TOTAL	**57**	**104**

5. Other Comments

Observation from the ground of the roof of plot 405 by a Ventaxia representative was indicative to him that the type of terminal vents that could be seen could potentially be contributing to the pressure drop between the fan unit and roof vent as measured in the tests. His feeling was that this type of vent would be unsuitable for the required air flows. The vents are shown in Figure 6. The same low profile roof tile vents are used across the whole of the Redrow site.

Figure 6 – Low Profile Roof Tile Vents on Plots 405 and 406

The roof vents in use on Bryant dwellings are of a different ridge vent design as illustrated in Figure 7.

Figure 7 – Ridge Vent on Bryant Property

A quick inspection of the ductwork in the attic of plot 405 indicated that the joints were sealed properly. However, due to access problems and the fact that the ducts were covered with Warmcell insulation, it was not possible to do a thorough inspection.

Discussions with the Ventaxia representative on site following telephone conversations that he had with personnel at Ventaxia head office indicate that none of the installed MEV systems on Redrow properties at Stamford Brook have been commissioned and no new systems are being commissioned. He said that this was due to continuing commercial disagreements between Redrow and Ventaxia. Somewhat bizarrely, this is reassuring in terms of what we have observed on plot 405 as it means the system is unlikely to have been commissioned properly. If the MEV system had been commissioned then this would have called into question the technical abilities of the Ventaxia commissioning engineers. However, in terms of what this means on site, this finding will cause great difficulties. It means that there are many MEV installations in occupied Redrow properties at Stamford Brook that have not been properly checked or commissioned and could potentially be faulty. All these householders will now have to be contacted to arrange to commission the systems. In cases where faults are found such as those observed in plot 405, this may necessitate remedial action such as inspection and repair of ductwork. In the worse case scenario, this could involve removal of floor boards and boxed in vertical risers to access the ducts, causing great inconvenience to the home owners. It is not know what the position is with respect to Bryant properties.

It should be noted that in both Approved Document Part F1 2000 and the new draft Part F1 2005 it is a requirement that, in order to demonstrate compliance with the building regulations, any ventilation system should be “designed, installed and **commissioned** to perform in a way which is not detrimental to the health of the people in the building” (see guidance section paragraph f in Part F1 2000 and section 0.2e in Draft Part F1 2005). Clearly, as commissioning has not been carried out in a large number of properties at Stamford Brook, this could be interpreted by Building Control that the properties in question would fail to meet the requirements of Approved Document Part F1. This is potentially a very serious issue.

Some concern was expressed by the Ventaxia representative as to the location of the fan unit which was positioned on the partition wall between the cylinder cupboard and small bedroom. His concern was about noise transmission through the partition wall at high fan speeds to what is likely to be used in many cases as a children’s bedroom.

Previous test results from plot 406 next door to 405 which is of the same Wye type dwelling as 405, and which also had the new 5-mode fan controller installed, are given in Table 8 (this test was carried out in December 2005). These data, which were measured in the as-found vent opening condition, show a different pattern from plot 405 in that the maximum flow in plot 406 was from the kitchen vent. This may be due to the settings and balance of the four vents. The data also showed that plot 406 had a total flow in normal mode of less than 55 m^3/h which would fail to meet the 102 m^3/h flow requirement in normal mode to give the designed 0.5 ach. It is not known whether any adjustments to the vent openings in 406 would give an increase in the flow rates. Nor is it know how the dip switches inside the control unit are set. Plot 406 is now occupied, so permission would be needed from the householder to check any of these issues or make any adjustments.

Table 8 – Extract Vent Results from Plot 406 (Note that results for the bathroom and ensuite in normal mode were estimated using the normal/max ratio in the kitchen as the flows were below 13m3/h. It was not possible to do this for the kitchen as the kitchen vent was also less than 13m3/h in max mode)

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Max Mode (m3/h)
Kitchen	28	50
Downstairs Toilet	≤ 12	≤ 12
Bathroom	8 (estimated)	15
Ensuite	7 (estimated)	13
TOTAL	**< 55**	**< 90**

By contrast the previous results from plot 403 (also a Wye type property) as illustrated in Table 9 showed a much higher total flow than either plot 405 or 406 in normal mode. In this case the total extract flow in normal setting was 104 m^3/h which meets the performance requirement for a Wye type property of 102 m^3/h. In maximum (boost) mode the total flow rate increased to 129 m^3/h which does not quite reach the 40% increase expected for the boost setting. It should be noted that plot 403 was tested in October 2005 and had the old style 2 position normal/boost control switch fitted at the time. It is not known whether the control unit has now been upgraded, which in turn may change the performance of the system depending upon how it was set up. Plot 403 is also occupied, so any further checks could only be carried out with the permission of the householder.

It should be pointed out that plot 403 has the same type of roof vent as both plot 405 and 406. It is therefore unlikely that the use of this type of extract terminal vent is the sole cause of the poor performance of 405 and 406. This obviously requires more detailed investigation. For example, it may have something to do with differences between the two types of fan controller.

Table 9 – Extract Vent Results from Plot 403

Extract Vent Location	Flow – Normal Mode (m3/h)	Flow – Boost Mode (m3/h)
Kitchen	14	18
Downstairs Toilet	35	43
Bathroom	23	29
Ensuite	32	39
TOTAL	**104**	**129**

6. Conclusions

- The results of the flow measurement tests carried out on plot 405 show that the MEV system as installed does not meet the design requirement for 0.5 ach in normal running mode. Even with all extract vents fully open the system as installed would only give a ventilation rate of around 0.25 ach in normal mode.

- The test data from plot 405 indicate that the poor performance is due to a combination of pressure loss between the fan unit and roof vent and a pressure loss in ductwork between the upstairs and downstairs. Further work would be required to confirm these findings and the exact cause.
- If the pattern of poor performance of the MEV system measured in 405 is repeated in other properties at Stamford Brook which also happen to have very low fabric air permeabilities, then this could have serious implications for the air quality in some dwellings.
- The lack of commissioning of the MEV systems is a very serious issue that needs to be resolved as quickly as possible as it raises important concerns about compliance with building regulations and the ventilation performance of occupied dwellings.

7. Recommendations

- All existing MEV installations should be fully commissioned as a matter of urgency. The systems in any dwellings which fail to meet the performance criteria will need to have rectification measures carried out on them.
- Any commercial disagreements between Ventaxia and Redrow should be resolved as soon as possible so that all MEV systems are commissioned.
- An attempt should be made to locate and rectify the cause of the pressure loss in ducting between the upstairs and downstairs in plot 405.
- The performance specification of the roof vents in use by both Redrow and Bryant should be checked to ensure compatibility with the MEV systems being used at Stamford Brook. If it is found that any tile vents do not meet the performance requirement then this will necessitate replacement of existing roof vents across the site with ones that do comply. In any case, further investigation will be needed to determine the exact cause of the pressure drop between fan unit and terminal roof vent as measured in plot 405 and the reason for the difference in performance between 403, 405 and 406 despite them having the same roof vent.
- Further tests should be carried out on both Redrow and Bryant properties to understand the frequency of the problems identified in plot 405.
- The installation procedures used on already installed MEV systems and systems currently being installed at Stamford Brook should be checked to verify whether they comply with the Ventaxia protocols.

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18 February 2006