Report to EURISOL

Investigations of the Party Wall Thermal Bypass in Timber Frame Dwellings

Final Report

Dr. Jez Wingfield, Centre for the Built Environment, Leeds Metropolitan University

Prof. Malcolm Bell, Centre for the Built Environment, Leeds Metropolitan University

Dominic Miles-Shenton, Centre for the Built Environment, Leeds Metropolitan University

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Executive Summary

1 This report details the findings of a project designed to investigate the mechanisms of the party wall thermal bypass in timber framed dwellings. The work was carried out by the Centre of the Built Environment at Leeds Metropolitan University on behalf of Eurisol.

2 A series of coheating tests and other measurements were carried out on a pair of semi-detached timber framed dwellings built near Darlington. The tests were designed to investigate the thermal and acoustic performance of a typical timber frame party wall detail. The results demonstrated that cavity party walls constructed to the requirements of Robust Detail E-WT-2 in timber frame dwellings can exhibit a significant thermal bypass. The magnitude of the party thermal bypass in the houses at Darlington was found to be equivalent to an effective U-value of the order 0.5 W/m^2K. The work also demonstrated that the thermal bypass could be reduced to close to zero by filling the cavity with mineral wool insulation. Acoustic tests indicate that the airborne sound insulation performance was reduced after the cavity had been filled with insulation, but would nonetheless still easily meet the airborne sound insulation requirements of Part E of the Building Regulations.

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Introduction

3 Research carried out by the School of the Built Environment at Leeds Metropolitan University between 2005 and 2007 as part of the Stamford Brook Field Trial identified significant heat losses via a thermal bypass operating in the party wall cavities of terraced and semi-detached masonry houses. Measurements showed that the magnitude of the party wall thermal bypass was equivalent to the party wall having an effective U-value of the order 0.5 to 0.7 W/m^{2}K. (Wingfield, Bell, Bell & Lowe 2006 and Wingfield, Bell Miles-Shenton, Lowe & South 2007, Lowe, Wingfield, Bell & Bell 2007). An initial investigation was also carried out at Stamford Brook to investigate the use of an insulated cavity sock positioned horizontally at the top of the party wall cavity, the aim of which was to reduce vertical air flows in the party wall and thus mitigate the bypass. The effect of this horizontal cavity sock was to reduce the effective U-value of the party wall to around 0.2 W/m^{2}K. Further work carried out by the Leeds Met research team on a timber frame development at Elm Tree Mews in York showed that the thermal bypass effect was also present in cavity party walls in timber frame construction (Wingfield, Bell & Miles-Shenton 2008). These findings on bypassing via party wall cavities are important because modelling conventions used in domestic energy models such as SAP2005 (BRE 2005) and in other heat loss calculations methodologies such as PHPP (Passive House Planning Package) (Passivhaus Institut 2007) assume that there is no heat loss due to a party wall between dwellings. This was because the fundamental heat loss mechanisms due to this form of thermal bypass were not fully understood at the time these protocols were written. These issues have been recognised in the latest version of the Standard Assessment Procedure for dwellings (SAP2009) which now requires that the potential for thermal bypassing is taken into account in the calculation of fabric heat losses (BRE 2010). SAP2009 proposed that by fully filling a party wall cavity with insulation and with effective edge sealing of the cavity, then the bypass can be assumed to be negligible. However, there is little field data on the actual thermal and acoustic performance of insulated party wall cavities. Work carried out by Leeds Met on two cavity masonry terraced houses in Bradford during the winter of 2008/2009, showed that by filling the party wall cavity with mineral wool, the U-value of E-WM-2 masonry party walls could be reduced from around 0.6 W/m^{2}K to effectively zero, with no significant impact on acoustic performance (Wingfield, Miles-Shenton, Bell & South, 2009). This latest project extends this work to cavity party walls in timber frame dwellings.

Description of Test Dwellings

4 The test dwellings at Darlington comprised of a pair of new unoccupied semi-detached timber framed dwellings in a T-shaped configuration. A photograph of the test houses is shown in Figure 1, and front elevation and ground floor plan drawings are illustrated in Figure 2 and Figure 3 respectively. The two test houses formed part of an estate of 16 homes on a speculative housing development built by a local developer between 2008 and 2009. The houses were built to comply with Part L1a 2006 of the Building Regulations. House No15 (brick façade) was designated as the access house and House No.16 (rendered block façade) was designated as the test house for the purposes of testing.

Figure 1 – Photograph of Test Houses at Darlington

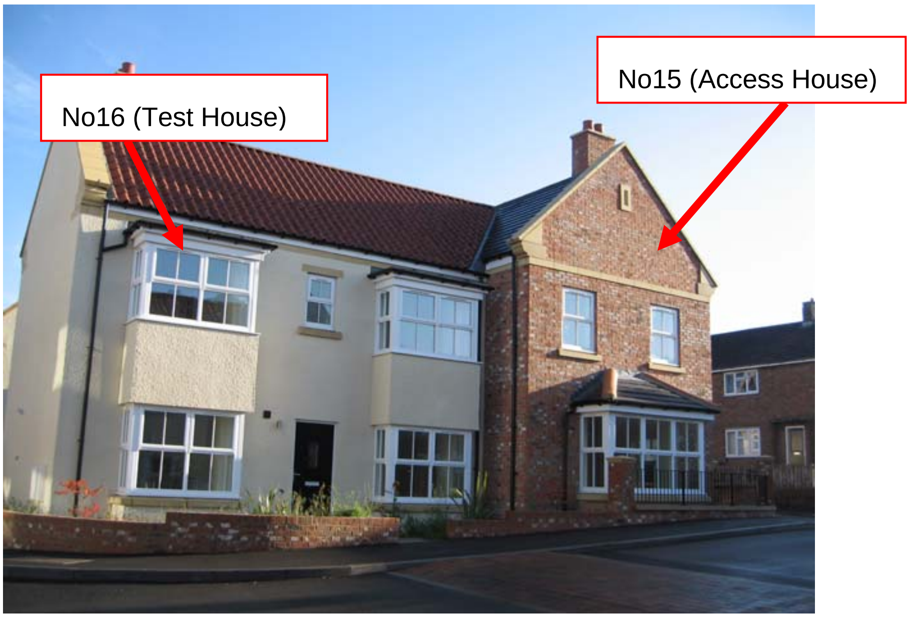
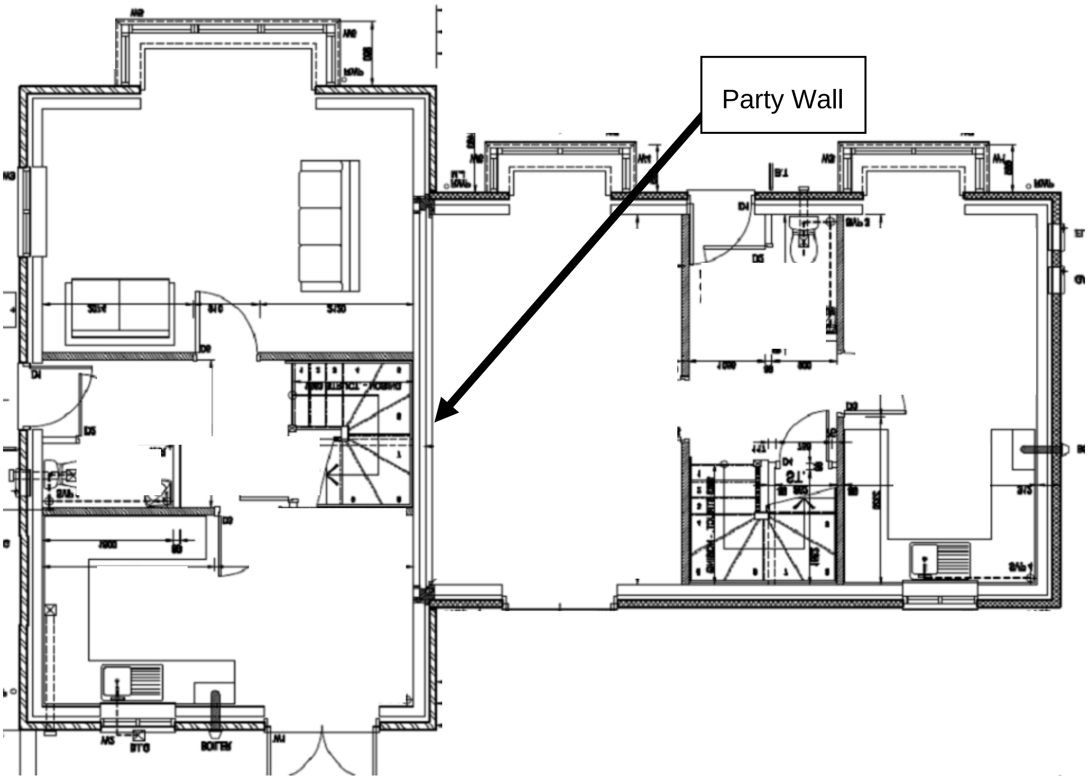


Figure 2 – Drawing of Front Elevation of Test Houses at Darlington

Figure 3 – Drawing of Ground Floor Plan of Test Houses at Darlington



5 The dimensions of the test houses are given in Table 1. Due to the high width to depth ratio and T-shaped configuration, the area of party wall of the Darlington houses was relatively small (25.8 m^2), comprising only 11% of overall external envelope area This means the effect on overall heat loss of any thermal bypass due to the party wall cavity is also likely to be small. In comparison, the party wall area (64.6 m^2) of the end terrace test house studied for the Eurisol testing carried out at Bradford comprised 24% of the overall external envelope area (264.9 m^2) (Wingfield, Miles-Shenton, Bell & South, 2009). There was also a small stagger (~500mm) between the two dwellings, with the floor level of No.15 being around 300mm higher than that of No16.

Table 1 – Dimensions of Test Dwellings

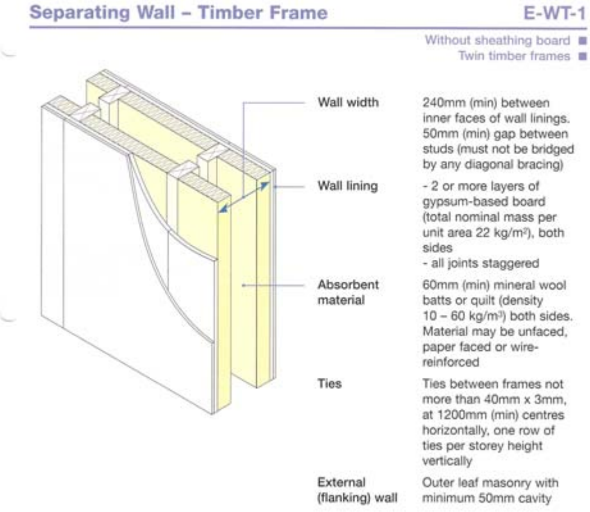
Dimension	House No.16 (Test House)	House No.15 (Access House)
Nominal Internal Width (m)	5.1	5.1
Nominal Internal Depth (m)	8.3	8.3
Nominal Internal Height (m)	5.0	5.0
Gross Floor Area (m^2)	86.7	86.4
External Surface Area (m^2)	236.9	227.4
Exposed External Surface Area (m^2)	211.1	201.6
Internal Party Wall Area (m^2)	25.8	25.8
Internal Volume (m^3)	223.3	217.5

6 Descriptions of the main elements of the Darlington houses are given in Table 2. It should be noted that the design data provided by the developer states that the party wall detail was constructed according to the requirements of Robust Detail E-WT-1 (Robust Details 2009). This separating wall detail for E-WT-1 comprises a double timber frame with a minimum of 50mm between the studs and a clear cavity with no sheathing on the inside of the studs as shown in Figure 4. The test houses were selected on the basis that the party wall detail conformed to E-WM-1, as this would make the process of filling the cavity wall with insulation easier than if there were any inner sheathing layers, and also make it easier to insert sensors into the cavity during the coheating test. However, subsequent investigations on site showed that the party wall was actually constructed to the requirements of Robust Detail E-WT-2. This detail is similar to E-WT-1 in most respects, with the exception that the inner faces of the two sides of the timber frame walls are both sheathed with OSB (see Figure 5). This means that the process of filling the party wall cavity is made much more difficult. The house was tested in the as-built condition with no changes to the fabric other than to add some insulation to the loft in areas that were found to be uninsulated.

Table 2 – Description of Fabric Elements of Darlington Test Houses

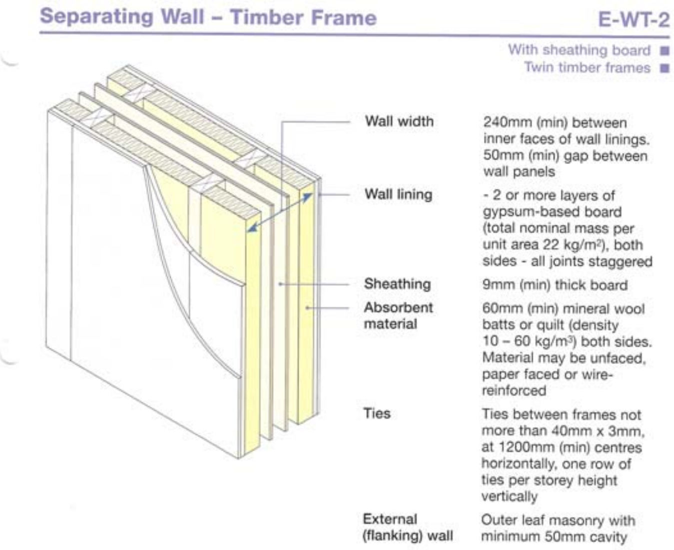
Element	General Description
Walls	Stick built timber frame, 140mm stud, mineral wool insulation, OSB sheeting with bubble wrap breather foil membrane on outside of frame, plastic vapour control layer on inside of frame with plasterboard finish. House No16 clad in rendered block, house No15 clad in brick. U-values 0.29 W/m^2K.
Windows	Double glazed units with timber frame. Nominal whole window U-value 1.8 W/m^2K.
Ceiling	Mineral wool insulation in between and above ceiling joist to give nominal U-value of 0.15 W/m^2K.
Ground Floor	Beam and block construction with insulation and chipboard above to give nominal U-value 0.23 W/m^2K.
Party Wall	Design shows E-WT-1 acoustic robust detail. Party wall as constructed was E-WT-2 acoustic robust detail.
Thermal Bridging	Design assumed to conform to the requirements of accredited construction details. (y-value =0.08 W/m^2K)

Figure 4 – E-WT-1 Separating Wall Robust Detail (Robust Details Ltd 2009)



Wall width	240mm (min) between inner faces of wall linings. 50mm (min) gap between studs (must not be bridged by any diagonal bracing)
Wall lining	- 2 or more layers of gypsum-based board (total nominal mass per unit area 22 kg/m^2), both sides - all joints staggered
Absorbent material	60mm (min) mineral wool batts or quilt (density 10 – 60 kg/m^3) both sides. Material may be unfaced, paper faced or wire-reinforced
Ties	Ties between frames not more than 40mm x 3mm, at 1200mm (min) centres horizontally, one row of ties per storey height vertically
External (flanking) wall	Outer leaf masonry with minimum 50mm cavity

Figure 5 – E-WT-2 Separating Wall Robust Detail (Robust Details Ltd 2009)



7 The nominal designed fabric heat loss data are shown in Table 3 (House No.16) and Table 4 (House No.15). These data are based on U-value information from the SAP datasheets.

Table 3 – Design Fabric Heat Loss No.16 Darlington (Test House)

Fabric Element	Area (m^2)	U-Value (W/m^2K)	Heat Loss (W/K)
Windows/Doors	27.02	1.80	48.63
Floor	44.29	0.23	10.19
Ceiling	44.29	0.15	6.64
External Wall	95.48	0.29	27.69
Party Wall	25.76	0.00	0.00
Thermal Bridging (y-value)	211.09	0.08	16.89
		TOTAL HEAT LOSS	**110.04**

Table 4 – Design Fabric Heat Loss No.15 Darlington (Access House)

Fabric Element	Area (m^2)	U-Value (W/m^2K)	Heat Loss (W/K)
Windows/Doors	20.53	1.80	36.95
Floor	44.27	0.23	10.18
Ceiling	44.27	0.15	6.64
External Wall	92.57	0.29	26.85
Party Wall	25.76	0.00	0.00
Thermal Bridging (y-value)	201.63	0.08	16.13
		TOTAL HEAT LOSS	**96.75**

Observations of Dwellings as Constructed

8 Prior to commencement of testing, the dwellings were surveyed for any construction issues that might affect the testing processes and also to check consistency with the as-built design drawings. The first issue identified was the condition of the loft insulation. There were found to be large areas of missing loft insulation, especially adjacent to the party wall as illustrated by the photographs of the loft in House No.15 (Figure 6) and in House No.16 (Figure 7). The presence of boarding in the loft indicates that the insulation was left out to enable work to take place on the party wall, but was not put back later. The developer was asked to remove the boarding and replace the loft insulation.

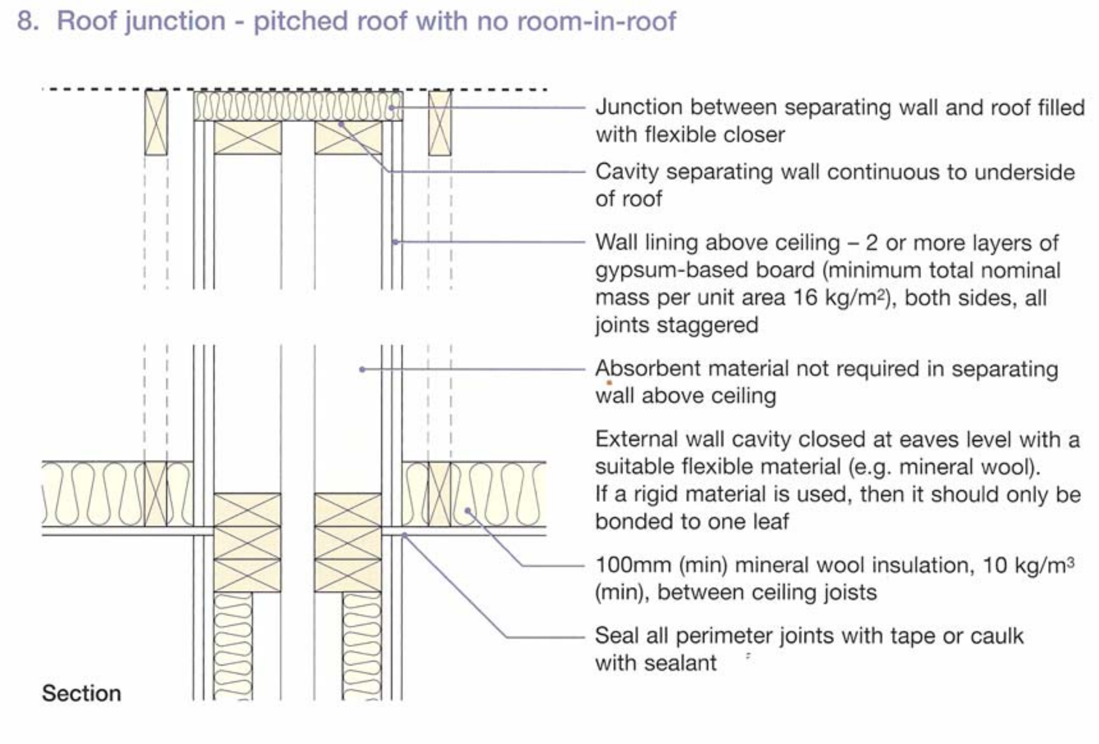
Figure 6 – Loft in House No.15 as Found

Figure 7 – Loft in House No.16 as Found

9 A gap was observed between the wall plate at the top on the internal party wall and the loft party wall. This gap continued across the whole width of the party wall on both sides. The drawings for the junction in both E-WT-1 and E-WT-2 Robust Details show the party wall as being continuous up to the roof line with no gap (see Figure 9). It was not possible to do anything to change this detail in the two test dwellings, so the gap remained as found for the duration of the testing.

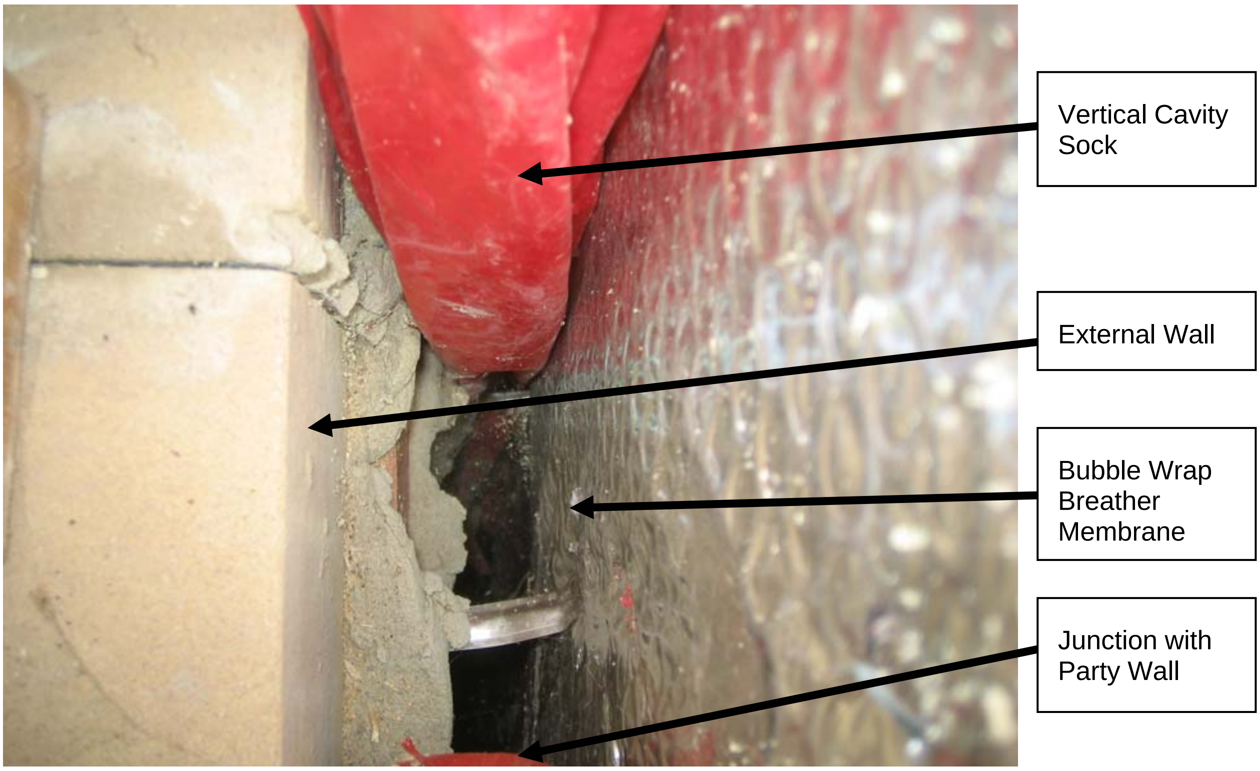
Figure 8 – Gap between Top of Internal Party Wall and Party Wall in Loft

Figure 9 – Schematic of Separating Wall Roof Junction from Robust Detail E-WT-1 (Robust Details 2009)



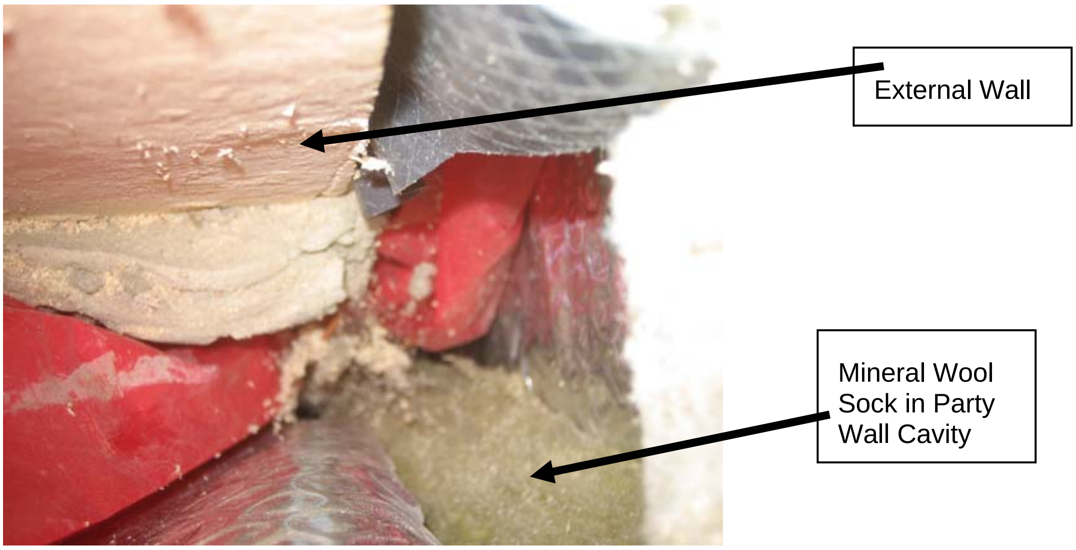
10 It was possible to observe the condition of the vertical cavity socks at the edges of the party wall by pointing a camera down into the junction from the loft. These photographs show that there were in fact two vertical socks at each vertical edge of the cavity, with each sock being slightly to the side of the party wall cavity, as shown by the example photograph in Figure 10.

Figure 10 – Vertical Cavity Sock in External Cavity at Junction of Party Wall (House No.16)



11 In addition to the vertical cavity socks in the external walls, it was found that a mineral wool batt had been inserted part way into both vertical edges of the party wall cavity (see Figure 11).

Figure 11 – Junction between External Wall and Party Wall Cavity (Viewed from Above)



12 The top of the party wall in the loft at the junction with the roof had been fitted with a mineral wool batt restrained in a wire mesh, as shown in Figure 12. The same wire mesh/mineral wool batt had also been used in the inner cavity of the party wall in the loft, although this does not appear to be a requirement of Robust Details.

Figure 12 – Top of Party Wall in Loft

Test Procedure

13 The main objective of the test programme on the houses at Darlington was to measure the magnitude of the heat loss associated with any party wall bypass and to determine the level of reduction in heat loss that could be achieved by filling the party wall cavity with mineral wool fibre. The primary test procedure that would be used to assess any change in heat loss would be a coheating test. The experimental procedures used for the coheating test are were the same as for the tests carried by Leeds Met to investigate party wall bypasses in masonry houses (Wingfield, Miles-Shenton, Bell & South 2009). The test protocols were designed around two consecutive coheating tests, the first one carried out with the party wall in the as-built condition and the second one taking place immediately after the party wall cavity had been filled with mineral wool fibre. Two values for whole house heat loss will therefore be obtained, one in the as-built condition and one with a filled party wall cavity. In addition to the coheating tests, the airtightness of the test dwellings was measured at the start and end of each of the two phases of the coheating test in order to measure the ventilation component of the heat loss. After allowing for any observable changes

such as changes in background ventilation rate, the difference between the before and after heat loss coefficients can therefore be ascribed to the physical changes in the party wall, and the effect such changes may have on both heat flows and air flows. Acoustic measurements were taken at the start and end of the test to assess the effect of any changes on the acoustic properties of the party wall.

14 The test programme for the houses at Darlington is shown in Table 5. The overall test programme ran from the 13th November 2009 (initial site observations) until the 26th January 2010 (final acoustic tests). The coheating test before filling the party wall ran from the 19th November to the 7th December, and gave 17 days of useable data that could be analysed to obtain a heat loss coefficient. The coheating test after filling the party wall ran from the 16th December to the 24th January, and gave 32 days of useable data that could be analysed to obtain a heat loss coefficient. The large datasets were required in order to reduce the error associated with the measured heat loss coefficients so as to give the best possible chance of identifying any differences in performance that might be due to any party wall thermal bypass.

Table 5 – Darlington Test Programme

Test Activity	**Date(s)**
Site Observations	13th November 2009
Initial Airtightness Pressure Tests	17th November 2009
Initial Acoustic Tests	18th November 2009
Phase 1 Coheating Test	19th November 2009 to 7th December 2009
Intermediate Airtightness Pressure Tests	8th December 2009
Filling Party Wall Cavity with Insulation	10th to 11th December 2009
Reinstate Party Wall	12th to 15th December 2009
Phase 2 Coheating Test	16th December 2009 to 24th January 2010
Final Airtightness Pressure Tests	25th January 2010
Final Acoustic Tests	26th January 2010

Observations of Filling of Party Wall

15 The party wall was filled by a CIGA approved contractor using blown Knauf Supafil 40 glass fibre insulation. In order to access the inner layer of OSB sheathing, the plasterboard and insulation batts were first removed from one side of the party wall. This was done from House No.16 as there was only one partition wall and one radiator on that side of the party wall. It was interesting to note that, on the ground floor, the 90mm cavity between the plasterboard and OSB sheathing was fully filled using 100mm glass fibre quilt. By contrast, on the first floor, the 90mm cavity was only partially filled using ~50mm glass fibre batts. A photograph showing the exposed sheathing layer and studwork in the party wall in the living room of No.16 is illustrated in Figure 13.

16 Measurements taken of the width of the cavity between the two OSB sheathing layers showed that the depth was quite variable, ranging from a low around 35 mm towards the middle of the party wall and increasing to a high of around 80 mm towards the edges of the party wall. This compares to a minimum requirement in Robust Detail E-WT-2 of 50 mm between the inner faces of the sheathing. The nominal cavity width according to the design drawings is 66 mm.

17 Deconstruction of the facing of the party wall showed that it comprised of two layers of plasterboard, the inner board being of 19 mm thickness and the outer board being of 12.5 mm thickness, giving a total of 31.5 mm. The plasterboard had no foil facing. The inner layer of OSB sheathing was 9 mm thick.

Figure 13 – Exposed OSB Sheathing and Timber Studwork in Party Wall (Living Room No.16)

18 Filling of the party wall cavity was achieved by drilling holes through the OSB. The pattern of the holes was set initially at a spacing that would be normal for a conventional masonry wall. However, the installation technicians had difficulty maintaining consistent flow. They believed that this was party due to the variable cavity depth and possibly due to the difference in wall friction of the OSB compared to masonry. To alleviate this problem the technicians drilled additional holes and also adjusted the insulation injection settings. The fill density was nominally set at 20 kg/m^3 for the initial settings. The installers used 2 ½ bags of insulation, with each bag containing 17.6 kg, giving a total of 44 kg of insulation. The area of the party wall is 25.8 m^2, plus approximately 5 m^2 for the area due to the terrace step, giving a total fill area of 30.8 m^2. With a nominal 50 mm cavity width, the volume of the party wall cavity filled with insulation would be 1.54 m^3. So the mean fill density based on these data is 44/1.54 = 28.6 kg/m^3. This assumes that the estimate of the number of bags of insulation used is correct and also that there was no loss of insulation to the sides of the cavity. A photograph of the technician filling the party wall cavity is shown in Figure 14.

Figure 14 – Cavity Wall Technician Filling Party Wall at Darlington

Airtightness Test Results

19 The pressure test results are given in Table 6 for House No.16 and in Table 7 for House No. 15. There were relatively modest increases in air permeability during both coheating tests. The mean air permeabilities for the period of the coheating tests before and after filling the party wall cavity are given in Table 8. The mean air permeability in the second coheating test compared to the first coheating test increased by 1.34 $m^3/h.m^2$@50Pa for House No.16 and by 0.85 $m^3/h.m^2$@50Pa for House No.15. These changes will likely be due to drying shrinkage caused by the high temperature conditions of the coheating test rather than any effect caused by the filling of the party wall with insulation.

Table 6 – Darlington House 16 (Test House) Pressure Test Results

Date	Air Permeability $m^3/h.m^2$@50Pa			Comment
	Depressurisation	Pressurisation	Mean	
17/11/2009	9.07	9.60	9.33	Pre coheating test
08/12/2009	10.29	10.98	10.63	Post 1st coheating test, Before fill
25/01/2010	11.39	12.61	12.00	Post 2nd coheating test

Table 7 – Darlington House 15 (Access House) Pressure Test Results

Date	Air Permeability $m^3/h.m^2$@50Pa			Comment
	Depressurisation	Pressurisation	Mean	
17/11/2009	8.18	8.39	8.28	Pre coheating test
08/12/2009	8.71	9.23	8.97	Post 1st coheating test, Before fill
25/01/2010	9.64	10.32	9.98	Post 2nd coheating test

Table 8 – Mean Air Permeabilities during Coheating Tests

Test Dwelling	Mean Air Permeability Coheating Test Before Filling Party Wall Cavity ($m^3/h.m^2$@50Pa)	Mean Air Permeability Coheating Test After Filling Party Wall Cavity ($m^3/h.m^2$@50Pa)	Difference in Air Permeability ($m^3/h.m^2$@50Pa)
No.16 (Test House)	9.98	11.32	+1.34
No.15 (Access House)	8.63	9.48	+0.85

Predicted Heat Loss Coefficients

20 The nominal predicted whole house heat loss coefficients are given in Table 9. The fabric heat loss data are based on the fabric U-values and areas given in Table 3 and Table 4, and assume that the party wall U-value is zero. The ventilation heat loss is calculated from the mean air permeabilities for the two coheating tests as shown in Table 8. The ventilation heat loss coefficient is calculated from the product of the dwelling volume and effective background ventilation rate (air permeability/20), multiplied by the ventilation allowance for air at 20°C (0.33 W/m^3K). A sheltering factor of 1 was assumed due to the exposed site at Darlington.

Table 9 – Predicted Whole House Heat Loss Coefficients

Test House	Ventilation Heat Loss (W/K)	Fabric Heat Loss (W/K)	Total Heat Loss (W/K)
House No.15 (Access House) – First Coheating Test	30.97	96.75	127.72
House No.16 (Test house) – First Coheating Test	36.76	110.04	146.80
House No.15 (Access House) – Second Coheating Test	34.02	96.75	130.77
House No.16 (Test house) – Second Coheating Test	41.70	110.04	151.74

Acoustic Test Results

21 Airborne sound insulation acoustic tests were carried out before and after filling the party wall cavity. The tests were carried out by a Robust Details registered tester according to the requirements of BS EN ISO 140-4 (BSI 1998). The results for the initial tests with the unfilled party wall cavity are given in Table 10 and Table 11 for the final tests with the filled party wall cavity in . The changes in acoustic performance are summarised in Table 12. In all cases, the data show a decrease in airborne sound insulation after filling. For example, the mean value for $D_{n,Tw} + C_{tr}$ is 3.7 dB lower after filling. The effect on mean R'_w is not as noticeable, only falling by 1.4 dB. The decrease in performance is highest for the measurements taken between the living room in House No.16 and the kitchen in House No.15. The results indicate that the mineral wool in the party wall cavity is having a small detrimental effect on airborne sound insulation. Despite the reduction in acoustic performance, the party wall when filled with insulation still comfortably exceeds the minimum 45 dB limit given in Part E of the Building Regulations for airborne sound insulation of separating wall elements (Part E refers to the $D_{n,Tw} + C_{tr}$ parameter).

Table 10 – Acoustic Test Results Darlington – Before Filling Party Wall (Test Date 18/11/09)

Source Room	**Receiving Room**	**$D_{n,Tw}$ (dB)**	**$D_{n,Tw} + C_{tr}$ (dB)**	**R'_w (dB)**
No15 Living Room	No16 Living Room	67	61	60
No16 Living Room	No15 Kitchen	70	63	64
No16 Bedroom 2	No15 Bedroom 3	66	55	64
	Mean Result	**67.7**	**59.7**	**62.7**

Table 11 – Acoustic Test Results Darlington – After Filling Party Wall (Test Date 26/01/10)

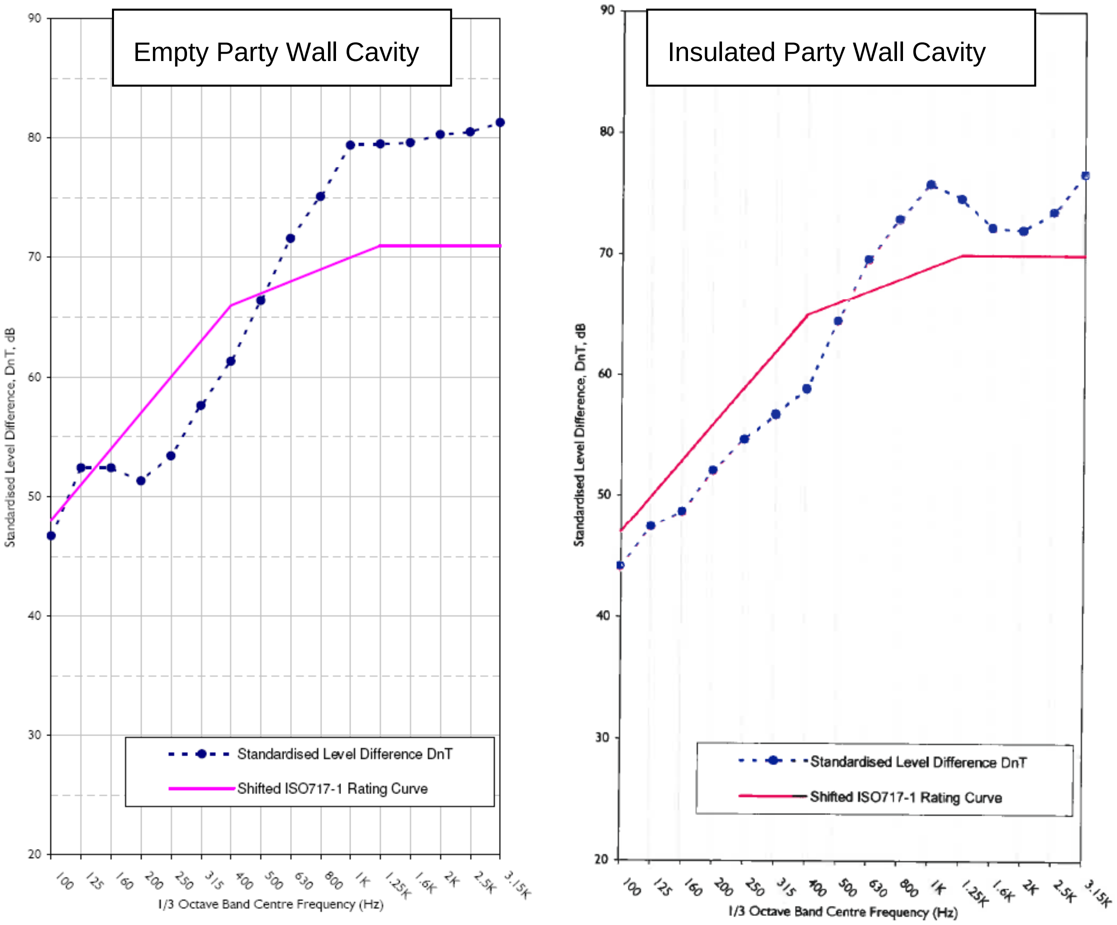
Source Room	**Receiving Room**	**$D_{n,Tw}$ (dB)**	**$D_{n,Tw} + C_{tr}$ (dB)**	**R'_w (dB)**
No15 Living Room	No16 Living Room	66	59	61
No16 Living Room	No15 Kitchen	65	57	59
No16 Bedroom 2	No15 Bedroom 3	66	52	64
	Mean Result	**65.7**	**56.0**	**61.3**

Table 12 – Changes in Acoustic Performance

Acoustic Measurement	**Before Filling Party Wall Cavity**	**After Filling Party Wall Cavity**	**Difference**
Mean $D_{n,Tw}$ (dB)	67.7	65.7	-2.0
Mean $D_{n,Tw} + C_{tr}$ (dB)	59.7	56.0	-3.7
Mean R'_w (dB)	62.7	61.3	-1.4

22 Example of graphs of test frequency versus standardised level difference (D_{nT}) are shown in Figure 15 for the tests between the living room in No. 15 to the living room in No. 16, both before and after filling the party wall cavity with mineral wool insulation.

Figure 15 – Plots of Acoustic Frequency versus Standardised Level Difference – Measurements from Living Room in No. 15 to Living Room in No. 16 before and after Cavity Fill.



Coheating Test Results

23 The results from the coheating tests in both test houses, before and after filling the party wall cavity are summarised in Table 13 (raw data) and Table 14 (solar corrected). The raw data show a reduction in the heat loss coefficient of between 5 to 8 W/K after filling the party wall cavity. The solar corrected data show a reduction in the whole house heat loss coefficient of around 9 to 10 W/K after filling the party wall cavity with insulation. Graphs showing the solar corrected heat loss curves both before and filling the party wall cavity are illustrated in Table 16 and Table 17.

Table 13 – Summary of Raw Coheating Test Data: Houses No.15 and No.16

Test House	**Heat Loss Coefficient Before Filling Party Wall Cavity (W/K)**	**Heat Loss Coefficient After Filling Party Wall Cavity (W/K)**	**Difference in Heat Loss Coefficient (W/K)**
No.16 (Test House)	153.8	148.9	4.9
No.15 (Access House)	133.9	125.7	8.2

Table 14 – Summary of Solar Corrected Coheating Test Data: Houses No.15 and No.16

Test House	**Heat Loss Coefficient Before Filling Party Wall Cavity (W/K)**	**Heat Loss Coefficient After Filling Party Wall Cavity (W/K)**	**Difference in Heat Loss Coefficient (W/K)**
No.16 (Test House)	158.8	150.1	8.7
No.15 (Access House)	138.7	128.6	10.1

Figure 16 – Solar Corrected Heat Loss Curves before and after Filling Party Wall – House No.16

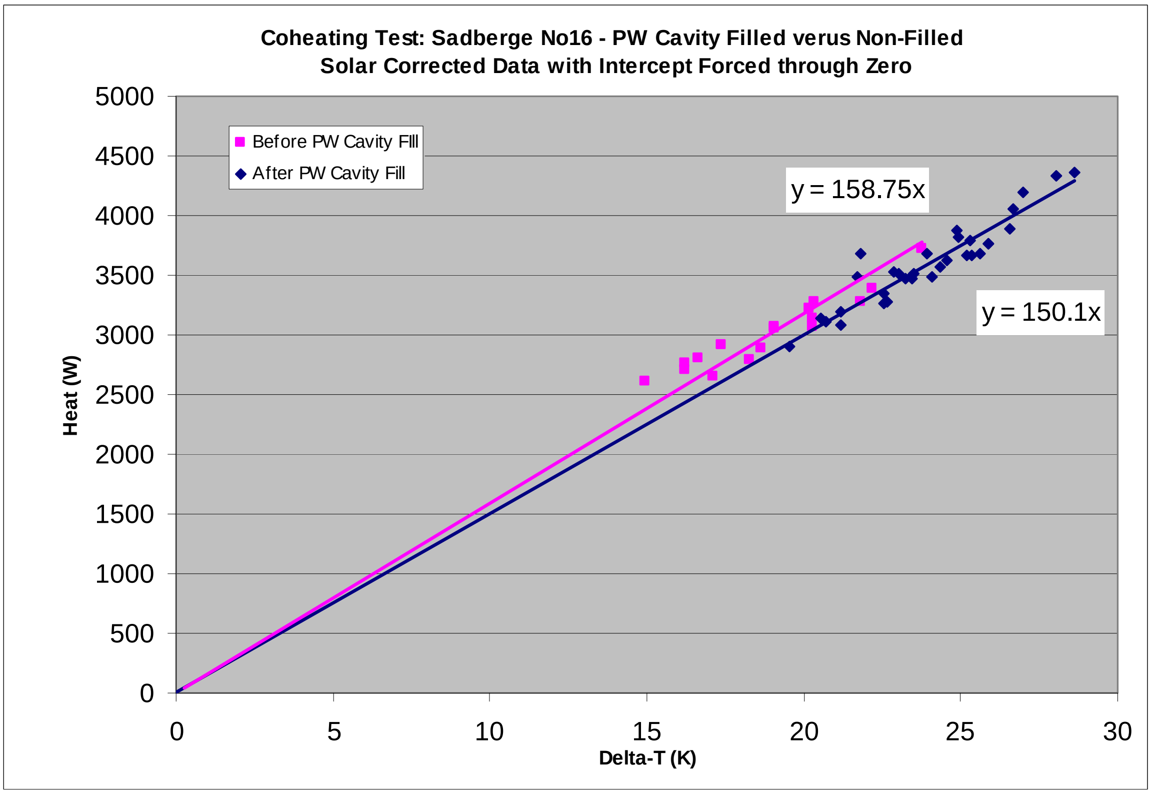
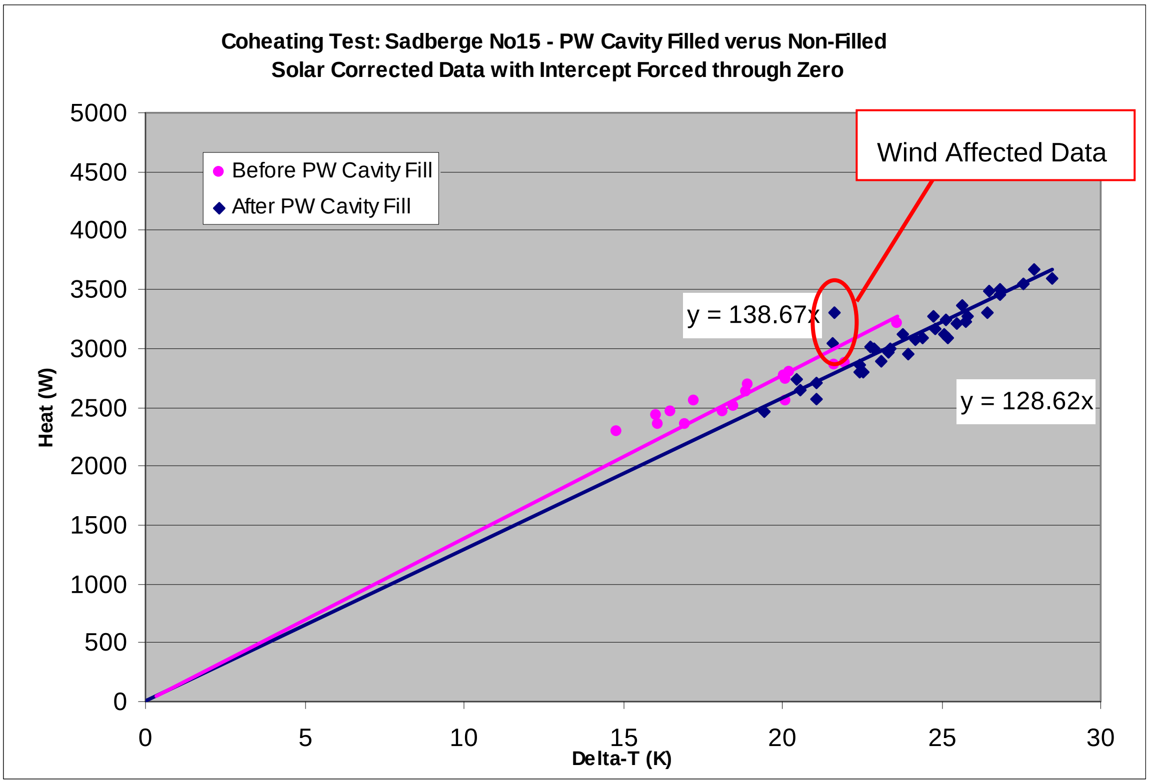


Figure 17 – Solar Corrected Heat Loss Curves before and after Filling Party Wall – House No.15



24 The regression coefficients and associated standard errors from the multiple regression analyses of the coheating test data are given in Table 15. It can be seen that the regression correlation

coefficients ranged from 0.64 to 0.86, indicating that in all cases there is a high probability of the data being significant.

Table 15 – Multiple Regression Coefficients from Analysis of Coheating Data

Test House	Solar Insolation Variable (m^2)		Delta-T Variable (W/K)		r^2 Correlation Coefficient
	Regression Coefficient	Error	Regression coefficient	Error	
No.15 before fill	-2.50	1.12	138.67	2.78	0.64
No.15 after fill	-1.80	0.62	128.62	1.34	0.78
No.16 before fill	-2.60	1.09	158.75	2.67	0.79
No.16 after fill	-0.77	0.64	150.10	1.35	0.86

25 A comparison of the predicted heat loss coefficients with those measured in the coheating tests is shown in Table 16. It can be seen that for both houses with empty party wall cavities, the measured heat loss was between 11% and 12% higher than that predicted. After filling the party wall cavity, the measured heat loss falls so that is around 2% less than that predicted. Taking into account experimental error, this means that after filling the cavity the measured and predicted whole house heat loss coefficients are the same. By the same token, this would also mean that the empty party wall cavity is a source of significant heat loss that is unaccounted for in the standard thermal model. Previous work would suggest that this will most likely be due to a thermal bypass.

Table 16 – Comparison between Predicted and Measured Heat Loss

Test House	Predicted Heat Loss Coefficient (W/K)	Measured Heat Loss Coefficient (W/K)	Difference (W/K)
No.15 before fill	127.72	138.67	+10.95
No.15 after fill	130.77	128.62	-2.15
No.16 before fill	146.80	158.75	+11.95
No.16 after fill	151.74	150.10	-1.64

26 If it is assumed that the discrepancy in the between measured and predicted heat loss is due to a thermal bypass in the empty party wall cavity, then the magnitude of the bypass expressed as an effective U-value can be estimated by dividing the difference in the heat loss coefficient by the area of the party wall. In order to normalise the data for any changes in airtightness over the test period, the heat loss difference has to be corrected for the heat loss attributable to the difference in mean air permeabilities as given in Table 8. The calculated effective U-values are given in Table 17. For House No.16 the minimum effective U-value is 0.53 W/m^2K and for House No.15 is 0.51 W/m^2K. It is worth noting that, despite the high U-values ascribed to the party wall, the overall effect of the thermal bypass on heat loss for the houses at Darlington is relatively small, accounting for around 9% of the measured heat loss coefficient as shown in Table 18. This is mainly due to the small size of the party wall relative to the overall envelope area. For 3-storey dwellings with low width to depth ratios, and for mid terrace houses with two party walls, the effect of the bypass would likely have been much more significant.

Table 17 – Minimum Effective U-Value of Party Wall Thermal Bypass

Test House	Reduction in Heat Loss after Filling Party Wall (W/K)	Increase in Heat Loss due to Increase in Air Permeability (W/K)	Total Change in Heat Loss (W/K)	Area of Party Wall (m^2)	Effective U-Value (W/m^2K)
No.16 (Test House)	8.7	4.9	13.6	25.8	0.53
No.15 (Access House)	10.1	3.1	13.2	25.8	0.51

Table 18 – Contribution of Party Wall Bypass to Overall Heat Loss

Test House	Measured Whole House Heat Loss with Empty Cavity (W/K)	Heat Loss Due to Party Wall Bypass (W/K)	Percentage of Heat Loss due to Party Wall Bypass
No.16 (Test House)	158.8	13.6	8.6%
No.15 (Access House)	138.7	13.2	9.5%

27 The coheating test data show that wind speed has a small effect on heat loss. Example data that show increased heat loss at high wind speed are highlighted by the red circle shown on the heat loss graph in. In order to allow for this wind effect, a second multiple regression analysis was carried on the data from both test houses with delta-T, solar insolation and wind speed as the three independent regression terms, with heat as the dependent term and with the fitted curve forced through the origin. The resultant regression coefficients are given in Table 19. In order to normalise the heat loss data for wind speed it is necessary to correct the delta-T variable to a standard wind speed for the data both before and after filling the party wall cavity. The mean wind speed over the whole test period was 1.5 m/s, so all data were corrected using the appropriate wind regression coefficient for a wind speed of 1.5 m/s. The heat loss curves using the data normalised for wind speed at 1.5 m/s are shown in Figure 18 and Figure 19. A summary of the heat loss coefficients derived from these data are shown Table 20. The magnitude of the party wall bypass U-value was recalculated using the wind normalised data as shown in Table 21. Using the data the effective U-value for the party wall thermal bypass is 0.42 W/m^{2}K for House No.16 and 0.40 W/m^{2}K for House No15.

Table 19 – Multiple Regression Coefficients from Analysis of Coheating Data with Wind Data

Test House	Solar Insolation Variable (m^2)		Delta-T Variable (W/K)		Wind Speed Variable (m/s)		r^2 Correlation Coefficient
	Regression Coefficient	Error	Regression Coefficient	Error	Regression Coefficient	Error	
No.15 before fill	-1.72	0.66	126.81	2.64	106.73	18.98	0.89
No.15 after fill	-0.90	0.37	120.64	1.21	119.53	14.09	0.93
No.16 before fill	-1.95	0.74	148.70	2.90	90.08	20.45	0.91
No.16 after fill	-0.01	0.49	143.80	1.57	95.92	18.52	0.79

Table 20 – Heat Loss Coefficients Derived Normalised for Wind Speed at 1.5 m/s

Test House	Heat Loss Coefficient (W/K)	r^2 Correlation Coefficient
No.15 before fill	135.19	0.92
No.15 after fill	128.01	0.94
No.15 - Difference between empty and filled PW cavity	7.18	-
No.16 before fill	155.71	0.94
No.16 after fill	149.75	0.94
No.16 - Difference between empty and filled PW cavity	5.96	-

Table 21 – Minimum Effective U-Value of Party Wall Thermal Bypass Normalised for Wind Speed

Test House	Reduction in Heat Loss after Filling Party Wall (W/K)	Increase in Heat Loss due to Increase in Air Permeability (W/K)	Total Change in Heat Loss (W/K)	Area of Party Wall (m^2)	Effective U-Value (W/m^{2}K)
No.16 (Test House)	6.0	4.9	10.9	25.8	0.42
No.15 (Access House)	7.2	3.1	10.3	25.8	0.40

Figure 18 – Heat Loss Curves before and after Filling – House No.15 – Wind Corrected Data

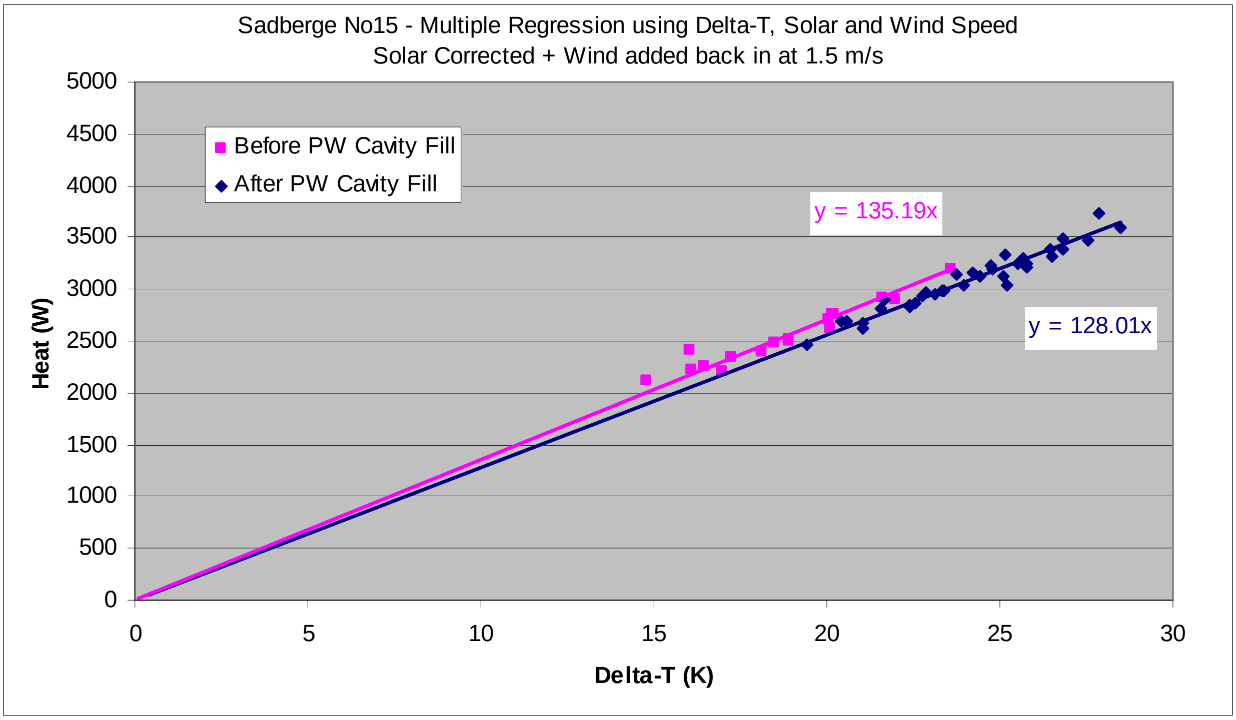
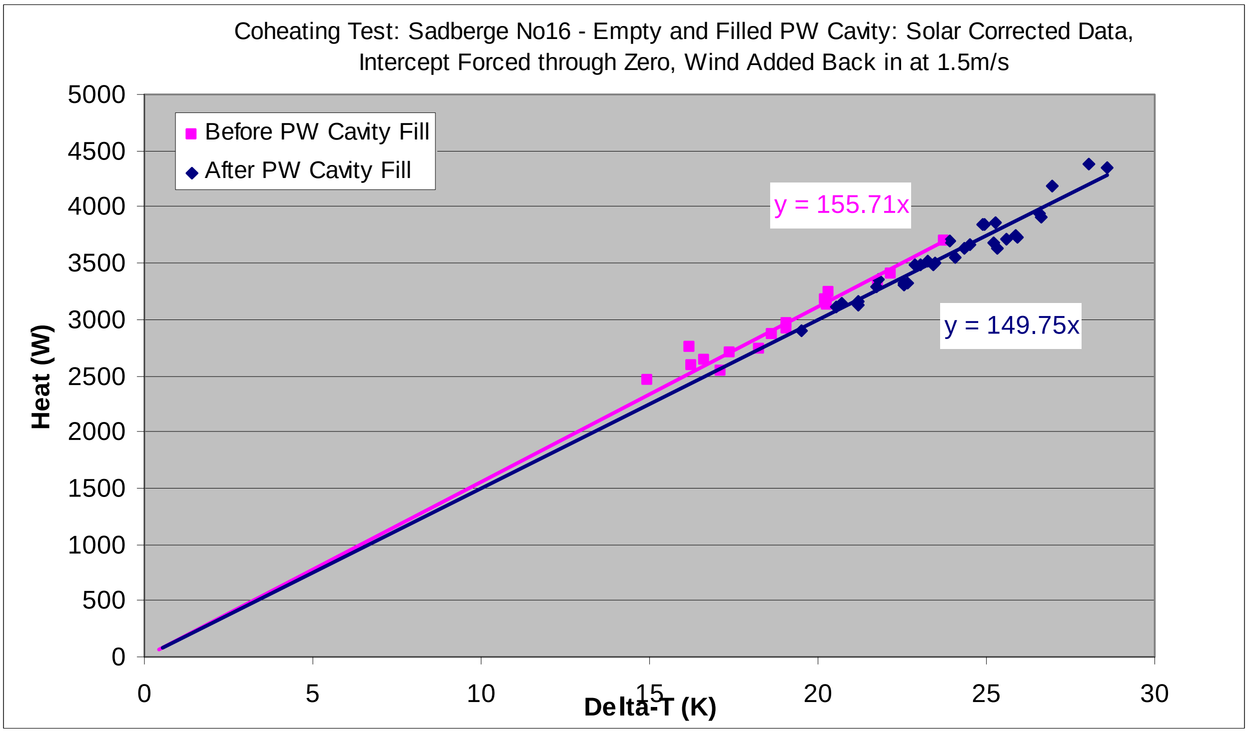


Figure 19 – Heat Loss Curves before and after Filling – House No.16 – Wind Corrected Data

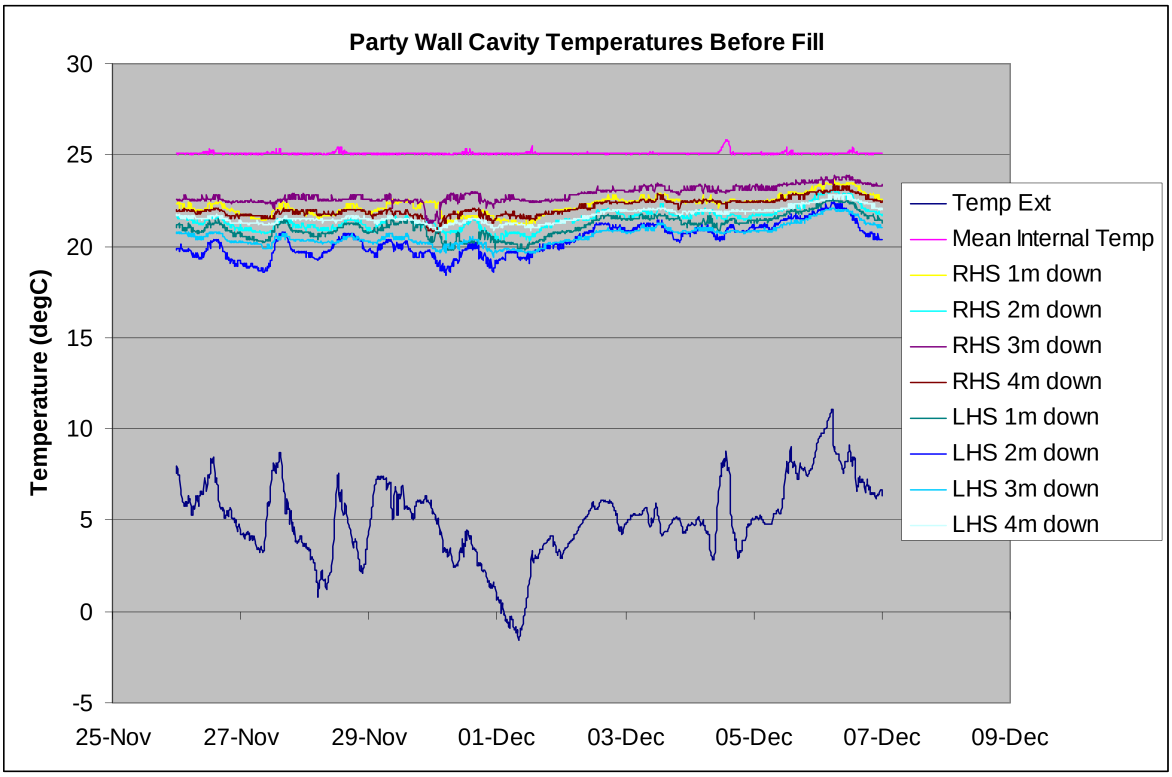


Temperature Measurements in Party Wall Cavity

28 It was not possible to drill holes through the party wall in order to insert temperature probes in the cavity, as the holes would have been difficult to seal afterwards at the sheathing layer. These holes could potentially have affected acoustic performance and airtightness. Instead, eight thermocouple probes with long cables were dangled into the party wall cavity via the gap in the party wall in the loft space. The thermocouples were dropped into the cavity near the centre of the party wall. The

lengths of cable were measured so that the sensor heads were at approximately 1m, 2m, 3m and 4m into the cavity relative to the ceiling. It was not possible to control exactly the position of the sensors tips, so it is likely that some were in the cavity proper, but most would probably have been in contact with the inner surfaces of the OSB sheathing. It was only possible to obtain temperature readings for the empty cavity as the temperature probes had to be removed for the filling process to avoid damage. A graph showing the trend in cavity temperatures relative to the inside temperature and external temperature is shown in Figure 20.

Figure 20 – Trend in Party Wall Cavity Temperatures for Empty Cavity



29 It can be seen in Figure 20 that the cavity temperatures in the locations measured were between 2°C to 7°C lower than the internal temperatures inside the houses. It can also be seen that the trend in temperatures follows the trend in external temperature, showing that cold external air must be getting into the party wall cavity. These cavity temperature measurements therefore confirm that a thermal bypass must be operating in the cavity despite the presence of edges seals to the cavity and insulation to the sides of the party wall. However, is not possible to use to data to estimate overall heat flow into the cavity as the small number of sensors used were only located towards the centre of the cavity, and would not therefore be representative of the mean conditions inside the cavity as a whole.

Heat Flux Measurements

30 Heat flux sensors (Hukseflux HFP-01) were affixed to various locations in the two dwellings. The majority of these were concentrated on the party wall in the Access House (No.15), with others on the party wall in No.16, the external walls in No.15, the ground floor in No.15, and the ceiling in No.15. The heat flux sensors on the party wall and external wall were positioned to avoid any hidden timber studs. Daily effective U-values for the sensors on the party walls were calculated from the heat flux readings and inside-outside temperature difference (U-Value = Mean Daily Flux/Delta-T). Graphs of the party wall U-value data are shown in Figure 21 and Figure 22. It can be seen from the graphs that the U-values at the sensor points before filling the party wall cavity range from around 0.1 to 0.7 W/m^{2}K., with the majority of readings being towards the lower end of the range. As the heat flux sensors were deliberately located away from any timber studs in the panels, then this would indicate that, as would be expected, the insulated areas of the party wall do reduce heat loss via the party wall. The higher U-values are likely to be caused by the sensors being in proximity to timber studwork.

Figure 21 – Daily U-Values for Heat Flux Sensors on Party Wall in House No.15 (Access House)

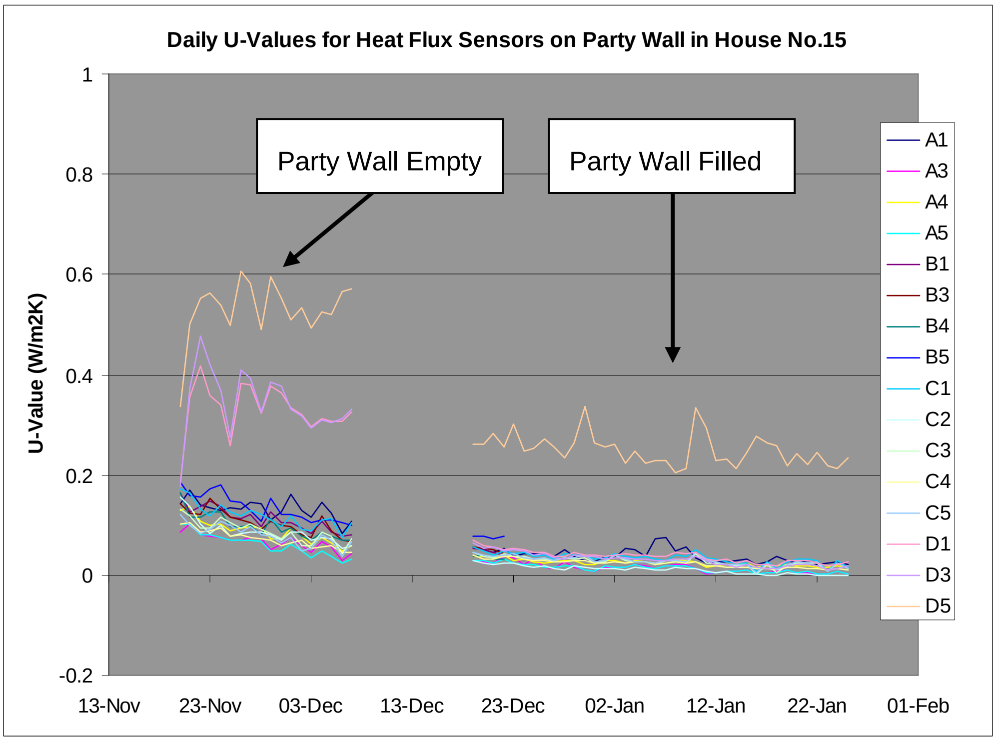
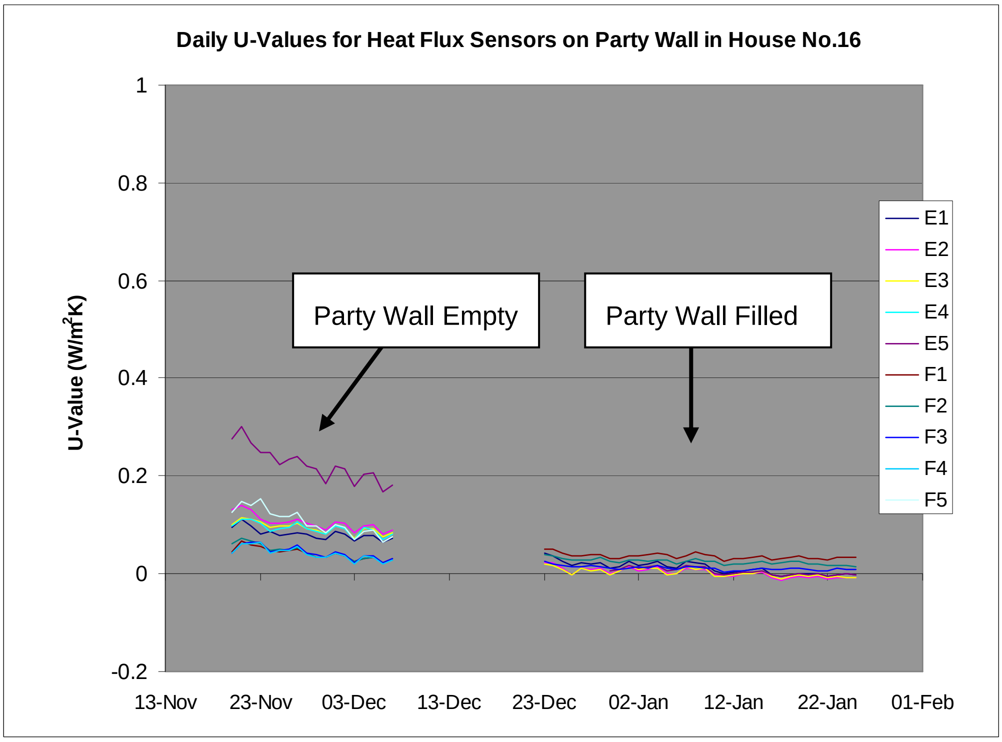


Figure 22 – Daily U-Values for Heat Flux Sensors on Party Wall in House No.16 (Test House)

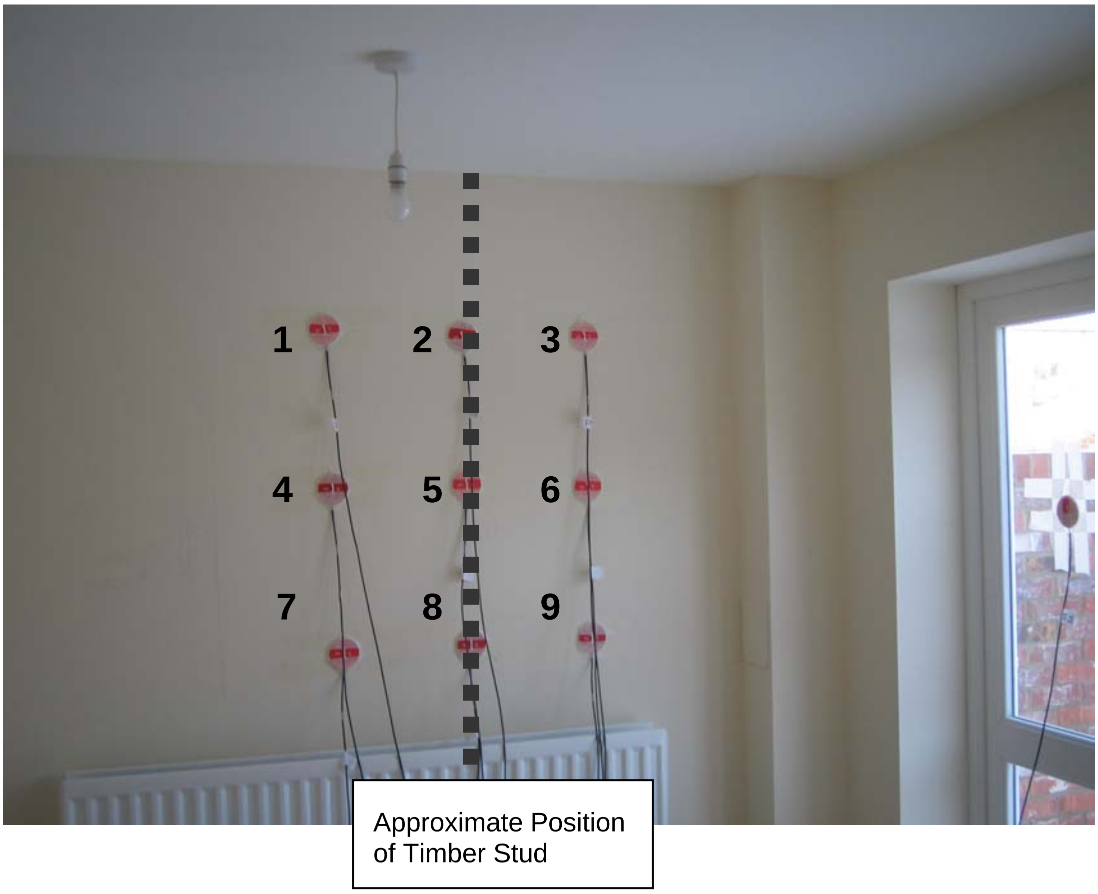


31 To account for the measured effective U-value for the whole party wall of ~0.4 to 0.5 W/m^{2}K, it can therefore be concluded that the majority of heat flow into the party wall is occurring through the timber and at the edges of the cavity. The is also likely to be some contribution to party wall heat losses due to the step in the terrace between the two houses, and also due to the gap in the party wall in the loft. The percentage of area of the party wall comprising timber (studs, wall plates, sole plates and intermediate floor structure) rather than insulation was calculated from the timber panel drawings to be 17.4%.

32 After the party wall cavity had been filled then there was a significant drop in heat flux through the party wall, although it does not fall to zero at all the sensors, indicating that there is still some residual heat flux in the filled cavity. This shows that filling the central party wall cavity with mineral wool insulation does reduce heat flow into the party wall.

33 A grid of nine heat flux sensors was used to measure the U-value of one of the north facing external walls in House No.15 for a period of 12 days. A picture of the sensor grid is shown in Figure 23. The grid was set up as a 3x3 array, with the centre line of the grid approximately over the position of one of the hidden vertical timber studs (see dotted line in Figure 23).

Figure 23 – Grid of Nine Heat Flux Sensors on External Wall in House No.15



Approximate Position of Timber Stud

34 The mean U-value for all 9 flux sensors in the grid over the 12 day test period was 0.31 W/m^{2}K. This compares to the nominal architects design value of 0.29 W/m^{2}K as used in the calculations of fabric heat loss in Table 3 and Table 4. A graph showing the daily U-values for each of the nine heat flux sensors is given in Figure 24. It can be seen from this graph that the U-values at the individual sensor positions ranges from a low of just over 0.2 W/m^{2}K to a high of around 0.6 W/m^{2}K. The average for the 6 flux sensors over an insulated part of the wall panel with no timber stud (Flux sensors 1,3,4,6,7,9 in Figure 23) was 0.25 W/m^{2}K. U-values calculated according to BS EN 6946 are given in Table 22 for a range of different assumptions about the timber fraction in the wall and for the thermal resistance of the wall cavity. The calculated U-value for a wall with 100% insulation range from 0.22 to 0.24 W/m^{2}K. The measure value of 0.25 is at the top end of this range indicating that general assumptions about the resistance of the external cavity may not hold true. Some product manufacturers claim a thermal resistance of around 0.66 m^{2}K/W for the external cavity and in addition around 0.12 m^{2}K/W for the metallised bubble breather membrane, which would give a calculated U-value of 0.2 W/m^{2}K for the wall with 100% insulation. The measured data from Darlington are around 25% higher than this and therefore do not support such assumptions about the performance of the external cavity. The mean measured U-value for the sensors close to the position of a timber stud (Flux sensors 2,5,8 in Figure 23) was 0.43 W/m^{2}K. The small size of the flux sensor and difficulty in locating the stud precisely mean that this value can only be an indicator of heat flow close to the timber studs.

Figure 24 – Darlington External Wall Heat Flux Measurements – Daily U-Values

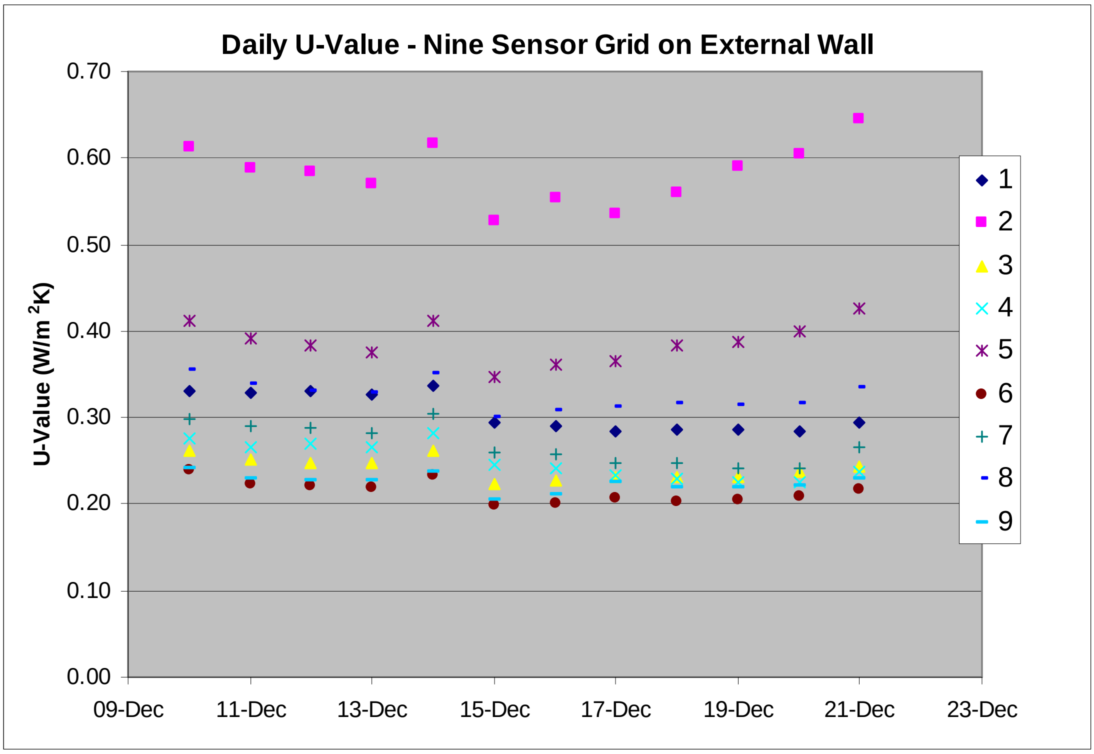


Table 22 – Calculated U-Values for External Wall at Darlington

Construction of Timber Frame Component of Wall - % Ratio of Insulation to Timber	Calculated U-Value (W/m^{2}K)		
	Ventilated Cavity, No Foil Facing (Cavity Resistance = 0.09 m^{2}K/W)	Unventilated Cavity, No Foil Facing (Cavity Resistance = 0.18 m^{2}K/W)	Unventilated Cavity, Foil Facing (Cavity Resistance = 0.44 m^{2}K/W)
100% Insulation, 0% Timber	0.239	0.234	0.22
90% Insulation, 10% Timber	0.283	0.275	0.255
85% Insulation, 15% Timber	0.304	0.295	0.272
0% Insulation, 100% Timber	0.630	0.596	0.516

35 A summary of measured U-values obtained from the heat flux sensors on other elements (ground floor, ceiling and glazing) are given in Table 23. It can be seen that, like the external wall, the measured U-values are in general agreement with the nominal design data. A small dependency of the U-value on external wind speed was noted for the floor and ceiling U-values. The can be seen in the plots shown in Figure 25 and Figure 26.

Table 23 – Darlington Elemental U-values

Fabric Element	Location of Heat Flux Sensors	Mean Measured U-Value (W/m^{2}K)	Nominal Design U-Value (W/m^{2}K)
Ground Floor	2 heat flux sensors on ground floor of living room in No.16. One sensor near floor perimeter and one towards middle of floor.	0.236 (sensor near perimeter) 0.213 (sensor near middle)	0.23
Ceiling	One heat flux sensor on ceiling in front bedroom in No.16.	0.157	0.15
Glazing	One heat flux sensor in middle of glazing unit of window in front bedroom of No.16.	2.002	1.80 (whole window U-value)

Figure 25 – Darlington: Measured Ground Floor U-values versus Wind Speed

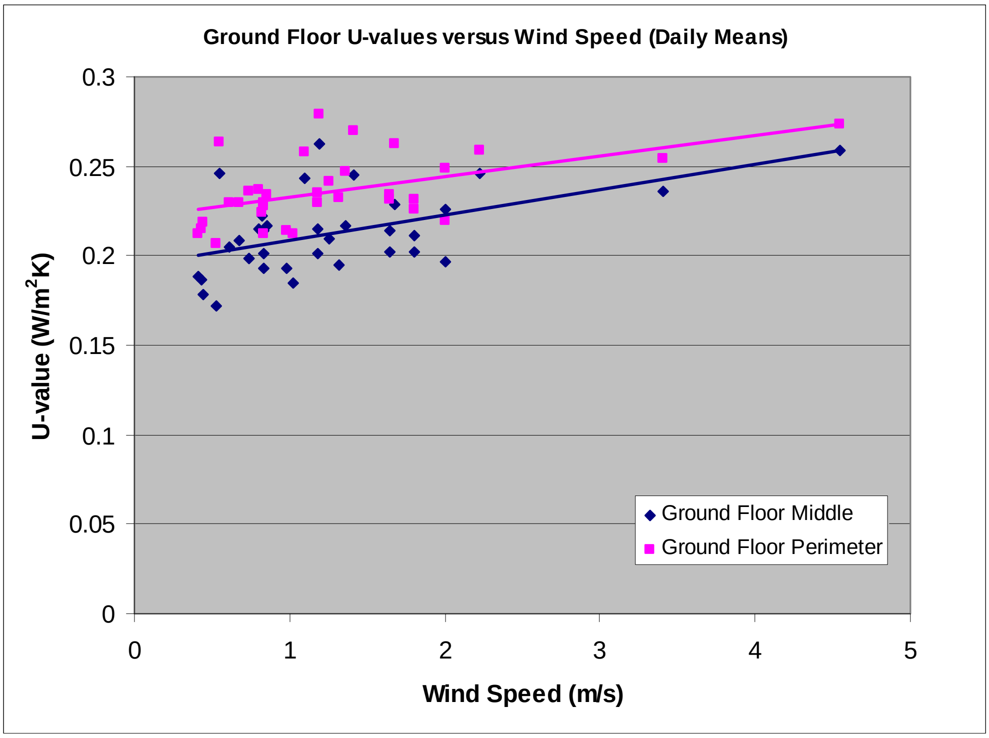
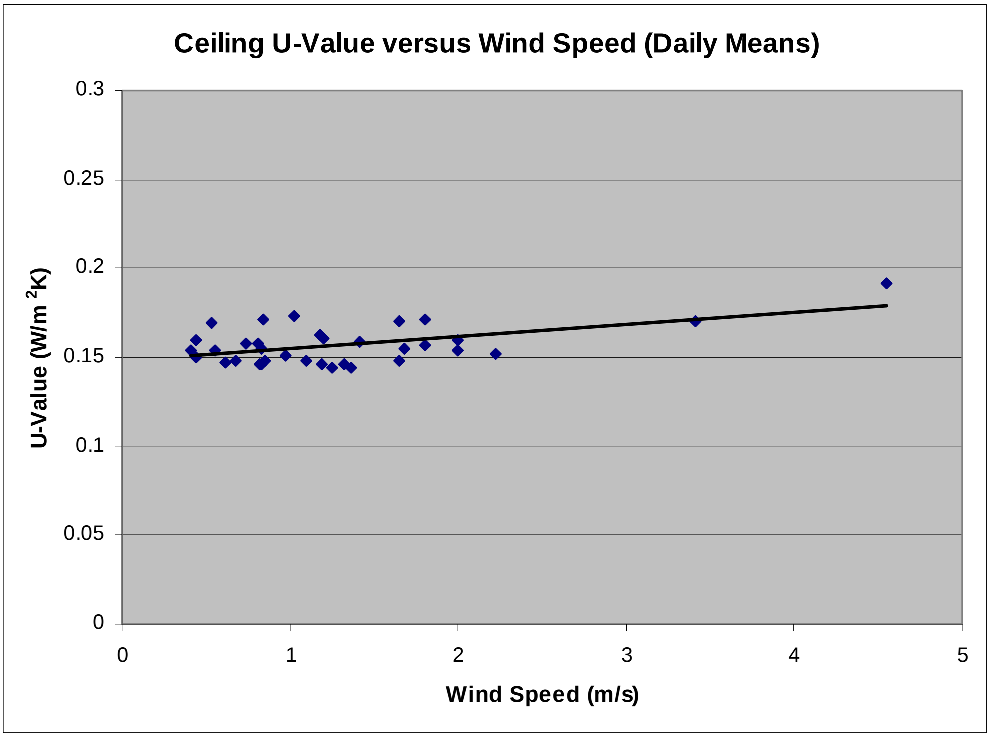


Figure 26 – Darlington: Measured Ceiling U-values versus Wind Speed



Thermal Images

36 Thermal imaging of the test dwellings was carried out using either a FLIR Thermacam B4 or FLIR Thermacam B620. Observations were made over several days, both from inside and outside the dwellings, with range of external conditions (e.g. windy, sunny, and overcast). Very few significant thermal anomalies were found. Heat plumes were observed at the party wall in both lofts as

illustrated by the images shown in Figure 27 and Figure 28. These heat plumes are further evidence of a thermal bypass operating in the party wall cavity.

Figure 27 – Photograph and Thermal Image of Party Wall in Loft of House No.16

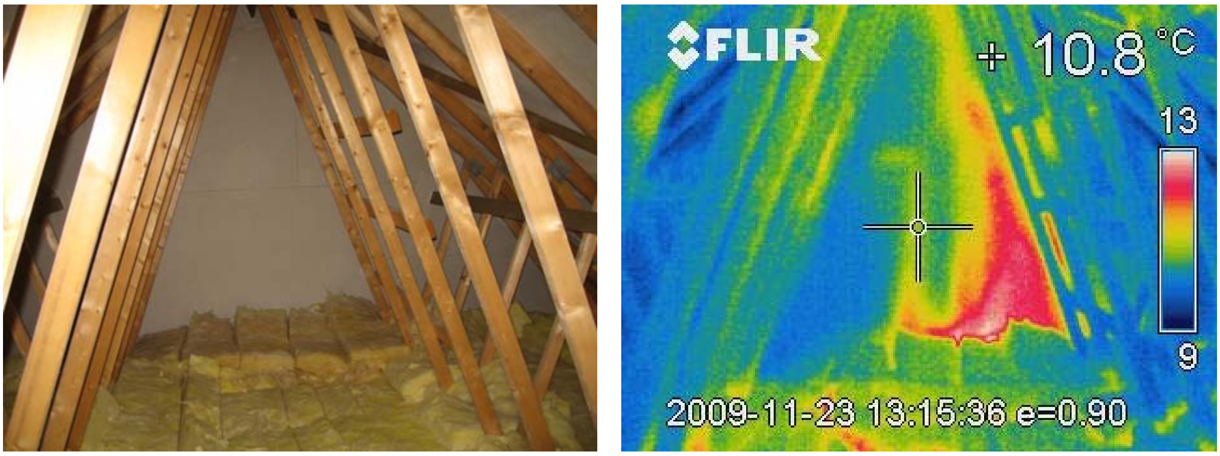


Figure 28 – Photograph and Thermal Image of Party Wall in Loft of House No.15

Final Comments & Discussion

37 Analysis of the data from the coheating test at Darlington suggests that the timber frame party wall as constructed had an effective U-value in the region 0.4 to 0.5 W/m^{2}K. This is slightly less than the effective U-value of around 0.7 W/m^{2}K that was measured for a masonry party wall at Bradford in the previous Eurisol project (Wingfield, Miles-Shenton, Bell & South 2009). These values are all comparable to the nominal U-value of 0.5 W/m^{2}K that is given in Table 3.6 of v9.90 of SAP 2009 (see Table 24) for unfilled cavity party walls without effective edge sealing (BRE 2010). The results from Darlington show that, even when the party walls are insulated, the combination of an unfilled cavity with the lack of effective edge sealing can still give rise to significant heat losses. The data indicate that the nominal U-values given in SAP 2009 for party walls provide a good estimate of the thermal performance of cavity party walls in the field for timber framed dwellings

Table 24 – U-values for Party Walls given in SAP 2009 (after BRE 2010)

Party Wall Construction	**U-value (W/m^{2}K)**
Solid	0.0
Unfilled cavity with no effective edge sealing	0.5
Unfilled cavity with effective sealing around all exposed edges in line with insulation layers in abutting elements	0.2
Fully filled cavity with effective sealing at all exposed edges in line with insulation layers in abutting elements	0.0

38 The design of the vertical edge seal for the test houses at Darlington is shown by the detail in the plan drawing in Figure 29. This shows a vertical cavity barrier that extends into both side of the external wall and also into the party wall cavity. This detail differs from that as shown in the Part E Robust Details catalogue for both E-WT-1 and E-WT-2 as shown in Figure 30. This shows the cavity sock in the external wall only.

Figure 29 – Extract from Darlington Plan Drawing showing Cavity Barrier at Staggered Junction between Eternal Walls and Party Wall (taken from as-built drawings)

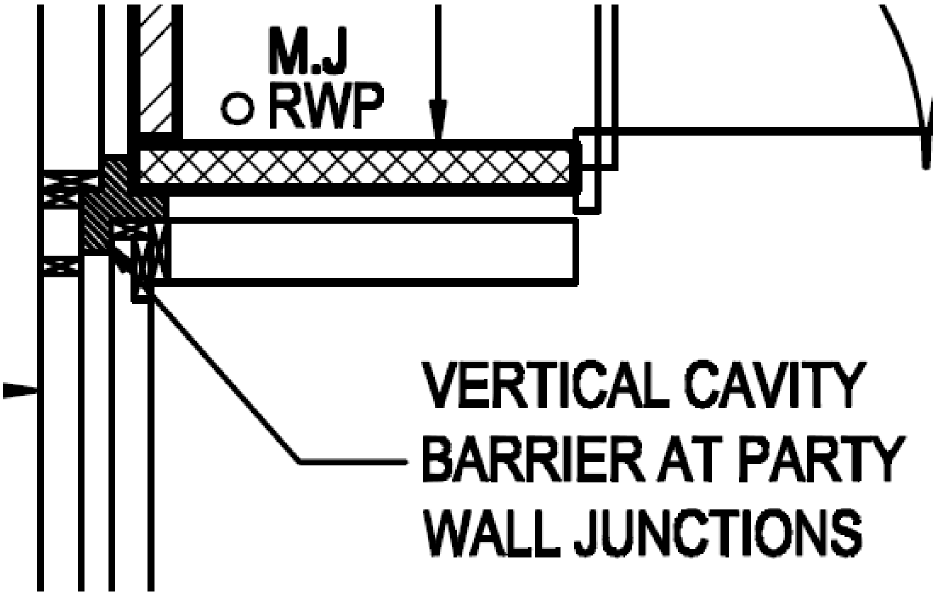
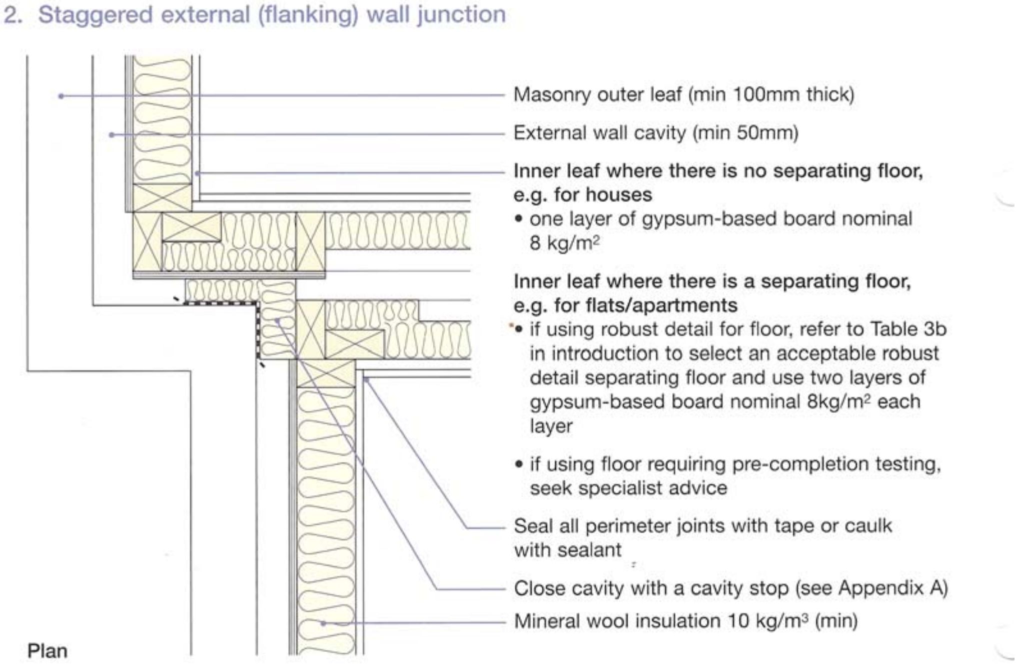
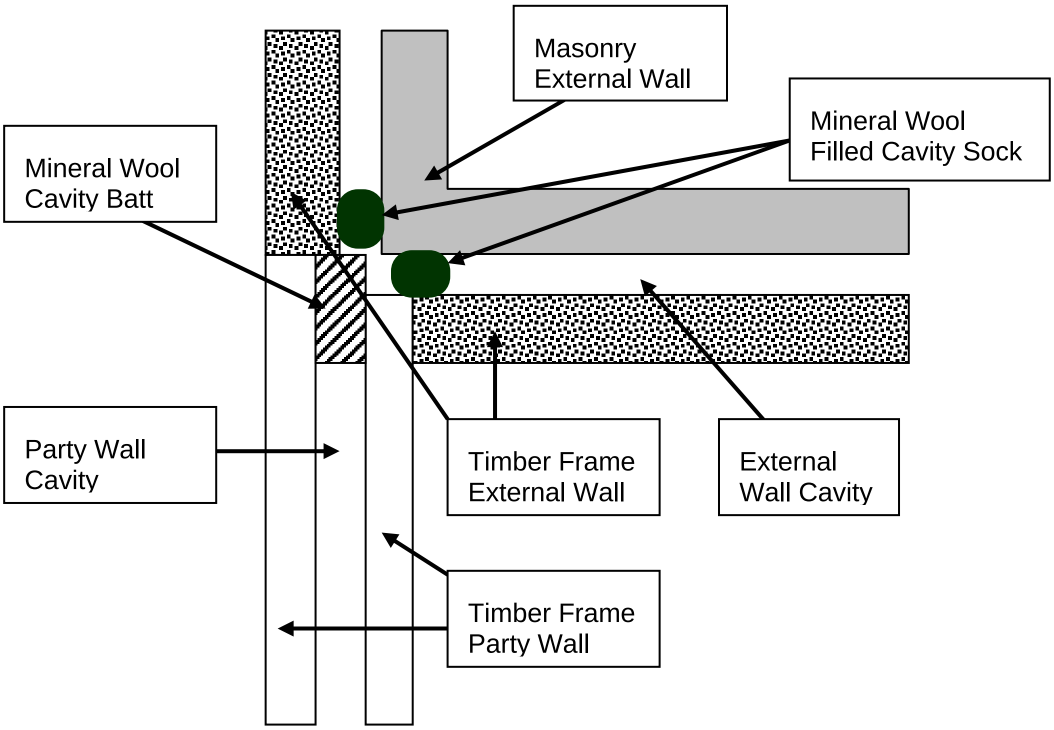


Figure 30 – Schematic of Staggered External Wall Junction from Robust Detail E-WT-1 (Robust Details 2009)



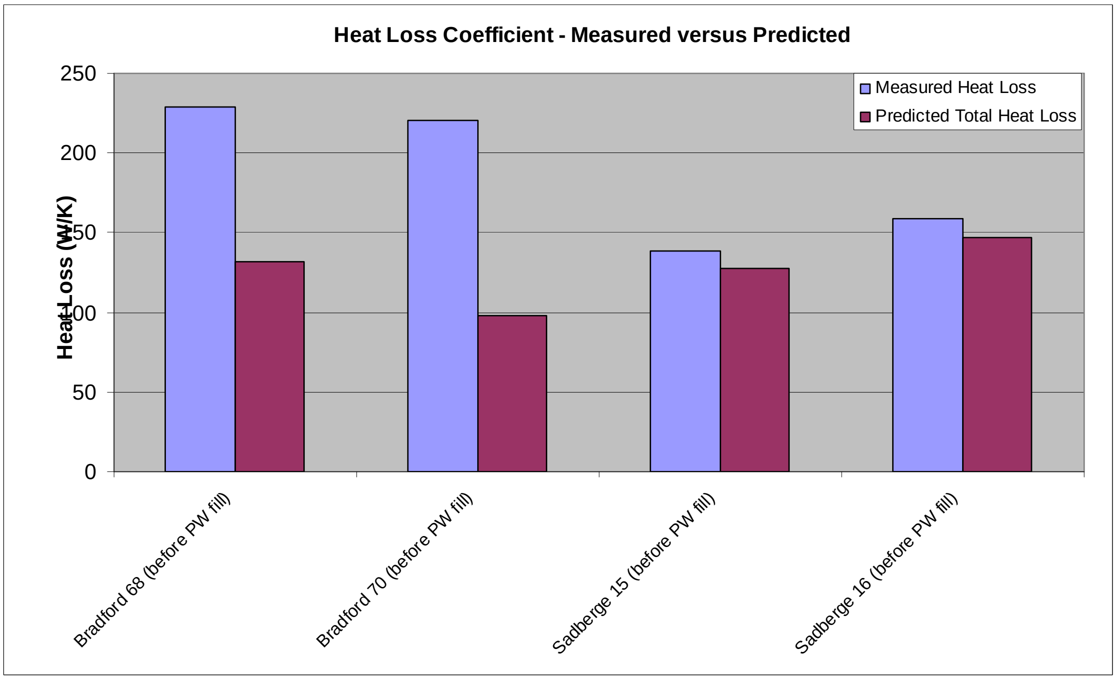
39 The detailing of the party wall-external wall junction as constructed at Darlington differed from both the nominal design and the Part E detail. A schematic of the detail as constructed is illustrated in Figure 31. Observations on site and borescope investigations showed that there were two vertical socks in the external wall and also a mineral wool batt that penetrated around 150mm into the party wall cavity. These edge seals combined with a membrane closing off the bottom of the party wall cavity meant that there was some form of edge seal along three sides of the party wall.

Figure 31 – Schematic of Staggered External Wall Junction at Darlington as Constructed



40 A comparison of the calculated and measured heat loss coefficients before and after filling the party walls in both the timber frame Darlington test houses and the masonry test houses at Bradford is shown by the graph in Figure 32. The graph highlights the relatively poor performance of the Bradford houses compared to the Darlington houses. This is in part due to the large party walls in the Bradford houses combined with a high effective party wall U-value.

Figure 32 – Eurisol Test Houses: Measured & Predicted Whole House Heat Loss



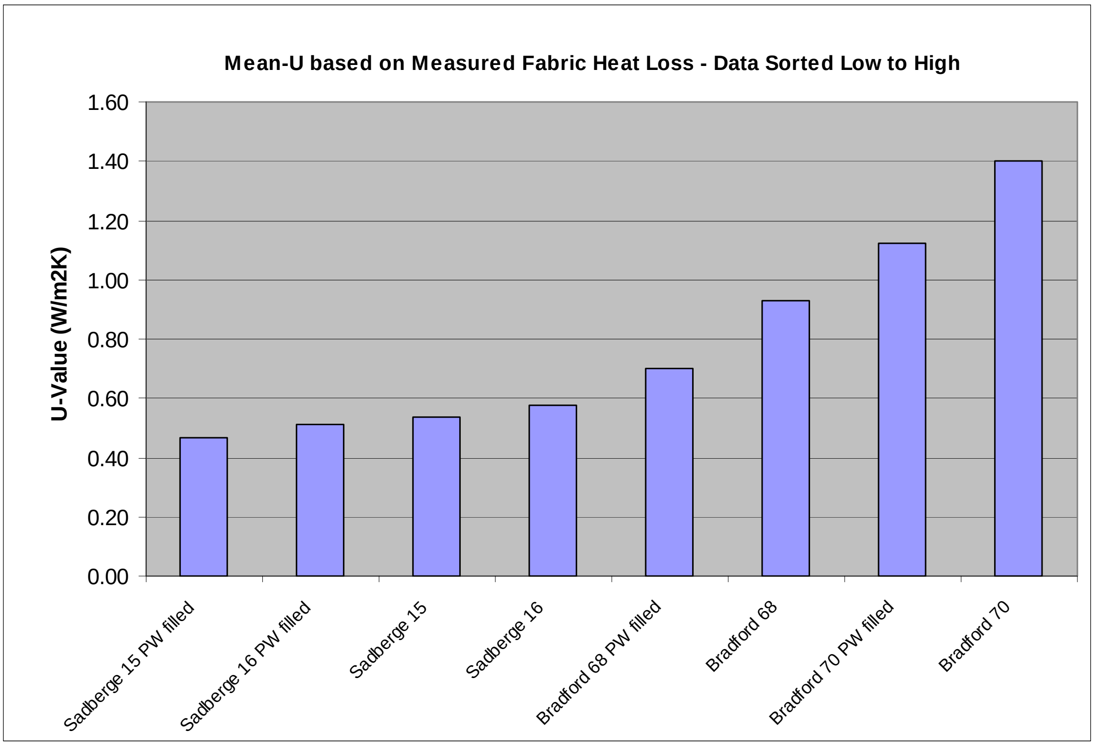
41 Another way to compare the performance of the test houses is to derive a mean U-value for fabric heat loss. This is calculated from the difference between the measured whole house heat loss coefficient and the ventilation heat loss (derived from air permeability) divided by the exposed area (excluding party walls). The advantage of comparing fabric U-values is that it excludes the effect of changes in ventilation loss due to the testing, and normalises the data. Fabric U-values are given in

Table 25 and also shown in Figure 33 with the data sorted from lowest to highest. The house with the lowest mean U-value (0.47 W/m^{2}K) was Darlington No.15 after filling the party wall, compared to the highest U-value (1.4 W/m^{2}K) for the mid terrace at Bradford.

Table 25 – Measured Mean Fabric U-values

Test House	**Measured Heat Loss (W/K)**	**Exposed Area (m^2)**	**Mean U (including ventilation loss) (W/m^{2}K)**	**Measured Ventilation Loss (W/K)**	**Measured Fabric Loss (W/K)**	**Mean U (excluding ventilation loss) (W/m^{2}K)**
Darlington 15	138.7	201.6	0.69	31.0	107.7	0.53
Darlington 16	158.8	211.1	0.75	36.8	122.0	0.58
Bradford 68	229.1	200.3	1.14	43.2	185.9	0.93
Bradford 70	220.6	132.6	1.66	34.9	185.7	1.40
Darlington 15 PW filled	128.6	201.6	0.64	34.0	94.6	0.47
Darlington 16 PW filled	150.1	211.1	0.71	41.7	108.4	0.51
Bradford 68 PW filled	191.4	200.3	0.96	50.8	140.6	0.70
Bradford 70 PW filled	189.7	132.6	1.43	40.9	148.8	1.12

Figure 33 – Measured Mean Fabric U-values: Data Sorted Low to High



42 It was not possible to determine the exact mechanism for the party wall thermal bypass at Darlington. The complex nature of the construction of the timber frame party wall as built meant that there were a range of potential air flow paths that could give rise to the bypass. For example, the gap in the party wall just above the ceiling could have allowed air flow directly into and out of the cavity. In addition, experience of other party walls would suggest that external air will likely flow into the cavity party wall around gaps in the vertical cavity socks, and at the junctions between the vertical socks and ground floor and roof. It is likely that there will be more potential for air movement and bypassing in the party wall panels with partial fill insulation compared to those party wall panels with full-fill insulation. Furthermore, there is the potential for a convective loop between the party wall cavity below the level of the ceiling and the party wall cavity in the loft. It is likely that all these effects will contribute in some way to heat loss via the party wall.

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