Centre for Low Carbon Futures 2050

LEEDS METROPOLITAN UNIVERSITY
Leeds Sustainability Institute

Building Confidence – A working paper

AUTHORS

Dr. A Stafford
Prof. M. Bell
Prof. C. Gorse

Leeds Metropolitan University

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The term 'performance gap' is often used to refer to the difference between the design thermal performance, and the measured thermal performance of buildings, treated as a whole system.

Reducing the performance gap is important to ensure we achieve real and significant energy savings from the built environment: critical if we are to reach the UK's 2050 target of an 80% reduction in carbon emissions.

The purpose of this paper is to offer an analysis of the accumulated Leeds Metropolitan University data around as-built thermal performance for new build and retrofitted homes. What are the key factors that determine the performance gap? The analysis enables stakeholders to consider targeted processes or standards which can improve performance, helping the industry to move towards minimising, and eventually eliminating, the performance gap.

LEEDS METROPOLITAN UNIVERSITY

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INTRODUCTION FROM THE CENTRE FOR LOW CARBON FUTURES

In the recent Centre for Low Carbon Futures report 'The Retrofit Challenge', produced by Leeds Metropolitan University,we presented the research evidence for the gap between as-designed and as-built energy performance of retrofitted homes.

In this analysis, 'Building Confidence', we begin identifying the determinants of the performance gap for different house types, both newbuild and retrofitted. The aim is to begin a dialogue with the construction industry about taking action – about the processes or standards which can improve as-built energy performance in the most cost-effective ways.

Why does the performance gap matter? The drive towards zero carbon homes from 2016 in England means rapidly tightening building regulations and a growing interest from customers in low energy/ low carbon homes. Customers who make the investment in a low carbon home need to know that it will achieve the warmth, comfort and low bills promised. Similarly, the Government have signalled their intention to require the industry to demonstrate the achievement of zero carbon standards in practice as well as in theory. These pressures will bring significant commercial risks for house builders, risks that will need to be mitigated through effective systems that assure real performance.

The Centre for Low Carbon Futures is committed to helping the house building industry provide certainty to clients around the real delivered energy standards of their homes. We want to work with the home building and retrofitting industry in two areas:

Firstly to establish the evidence base of real, measured energy performance of homes. This new research report is based on an analysis of 34 thermal performance tests of homes. We believe it's the best available dataset in the country, but there's clearly a lot more data that needs to be gathered. That's why the Centre for Low Carbon Futures is developing an Energy Systems Performance National Data Centre. This centre will provide a highly flexible repository to store and analyse the widest possible dataset of building energy performance data. We will be working with the construction industry to gather that data.

Secondly, in a continuing collaboration with Leeds Metropolitan University and with a small number of construction industry partners, we will identify and work on the process improvements that can start to close the performance gap, building on the analysis in this report.

Our successful transition to a low carbon economy by 2050 rests on a rapid decarbonisation of our built environment. We have to get it right, first time.

1.INTRODUCTION

The term 'performance gap' is often used to refer to the difference between the design thermal performance and the measured thermal performance of a dwelling treated as a whole system.

Many years of experience in co-heating testing and associated forensic analysis at Leeds Metropolitan University indicates the possibility that the incidence of such performance gaps may be widespread, and in many cases worryingly substantial. Although the number of full investigations undertaken to date is limited (due to the comprehensive nature of the testing involved), the majority of tests demonstrate a performance shortfall.

This is not unexpected, since many other studies have identified significant underperformance of building elements in situ. A review of evidence relating to the performance gap is given in Bell et. al., 2010, and a summary of that review is provided in Appendix A. The underperformance of building elements must be considered together with the fact that build processes are also necessarily imperfect. As a result, performance gaps are almost inevitable, especially in the absence of a design process which uses tolerances to take account of shortfalls [Bell et. al., 2010].

The purpose of this paper is to offer an analysis of the accumulated Leeds Metropolitan data, (which deals specifically with whole-house heat loss), in a form which may enable stakeholders to consider processes or standards which could be used in improving developer confidence and performance, helping the industry to move towards minimising, and eventually eliminating, the performance gap.

This fits in well with many of the aims identified in the Zero Carbon Hub (2010) report and forms an initial attempt to address their assertion that "it will be of particular importance that the commercial risks of underperformance are sufficiently salient as to reward those designers and developers who invest in improvements and penalise those who do not." Furthermore the recent DCLG consultation proposals for amendments to Part L of the Building Regulations [DCLG, 2012a] suggest a requirement for some form of Quality Assurance process relating specifically to thermal performance, which will perform exactly this function.

The Zero Carbon Hub (2010) report stresses that a distribution of carbon performance is naturally to be expected, leading to a necessity for an enhanced regulatory system that is sensitive to performance variability and is able to accommodate different approaches to achieving the required as-built standards. In an ideal world all housing producers would rapidly improve their development and control processes to the point where their performance distribution was known to them, was as tight as possible and satisfied the appropriate regulatory requirements. It is recognised that not all developers will be able to undertake the necessary investment to achieve this, at least in the short term, so provision should be made for an alternative approach which incorporates a degree of 'overdesign' to compensate for a somewhat wider and less controlled distribution in as-built performance. However, provision for rewarding and encouraging investment in the more controlled and evidence-based approach is also appropriate, especially if the resultant learning can eventually be co-ordinated and disseminated to the benefit of the industry as a whole.

1.1 BACKGROUND ON CO-HEATING TESTING

The whole house heat loss is determined by means of a co-heating test, where essentially the energy required to maintain internal conditions at a constant elevated temperature is compared with the internal/external temperature difference. However, the technique of co-heating testing, (as performed by Leeds Metropolitan University Buildings and Sustainability group), encompasses much more than simply obtaining an experimental figure for the heat loss coefficient.

In fact the main value and purpose of the co-heating test lies in 'closing the loop', which involves identifying and measuring or estimating the contribution of different factors to the performance gap, and thus explaining the reasons for the performance gap's existence and magnitude in any given case. In order to achieve this, a range of additional techniques must be used, from construction observations and thermography to heat flux measurement of building elements. Construction observations may identify, for example, cases where product substitutions have been made, or specified procedures not followed. Heat flux measurements establish the in-situ performance of elements such as external walls, party walls, floors and windows.

The performance gap to be explained is simply the difference between the measured heat loss coefficient and the predicted value. In this context the predicted value is that which would be calculated according to standard heat loss calculations for dwelling fabric (U-values and thermal bridging ψ-values) as used in SAP assessment procedures. Ventilation losses are also taken into account, but this aspect of the predicted value is calculated from experimental results, either via air permeability measurements or via background ventilation rate from tracer gas measurements, so that any performance gap identified by this method would be due to fabric and thermal bridging losses only, and not to higher than expected direct ventilation losses[1].

1. Air permeability is measured using a fan and blower door according to the ATTMA technical standard (ATTMA, 2006), with the background ventilation rate calculated using the n/20 rule of thumb. Alternatively background ventilation rate may be measured directly using a tracer gas (normally CO2) which is delivered as a pulse in order to track its concentration decay. The measured value of the background ventilation rate is then used as part of the total heat loss prediction.

In order for the whole exercise to have maximum validity, researchers need to have confidence in both the prediction methodology and the testing and assessment methodology. Clearly neither methodology is perfect and both should be subject to a continuous process of refinement. For example increased understanding of the party wall bypass mechanism has recently led to changes in the regulations regarding the way this element is assessed. However, work is currently on-going to improve some aspects of our understanding of the effects of solar radiation on co-heating test results.

A summary of the methodology of co-heating testing is given by Wingfield et. al. (2010a). Using this, or an equivalent methodology, results may be regarded with reasonable confidence where a good spread of external temperatures leads to data-points (heat input vs temperature difference) being distributed along a well-defined straight line, once solar and wind conditions have been taken into account.

In total, 34 co-heating tests have been undertaken by Leeds Metropolitan University on a variety of dwelling types over the last six years. Some were multiple tests on one dwelling (e.g. before and after interventions). The majority (though not all) were on new-build developments where the research team were able to observe construction from an early stage and consult with site operatives as necessary. Although statistically 34 is only a very small number, it represents by far the most extensive dataset of its kind in existence in the UK. Furthermore, it is not only the range of tests but also the depth of engagement with each individual test that adds significantly to the richness of the Leeds Metropolitan dataset.

Although some of the results reported in this paper have been published, this does not apply to all. In order to avoid ethical and contractual issues all results are presented in anonymous form.

2. THE PERFORMANCE GAP: ANALYSIS OF LEEDS METROPOLITAN DATA

Of the 34 tests referred to in the last section, 30 showed a performance shortfall to some degree. Fig. 2.1 shows a simple distribution of the percentage performance gap for all the tests performed (i.e. the percentage difference between the predicted and measured whole house heat loss, including both fabric and ventilation losses). While this is a useful starting point, clearly it represents highly aggregated data which skims over a number of important issues and distinctions (discussed in detail in the following sections), and therefore caution should be exercised in drawing conclusions from this data alone.

The following paragraphs in this section give a brief overview of some of the issues which are considered in the further analysis of this data.

Fig. 2.1 shows the performance gap as a percentage difference between the measured and predicted heat loss coefficient (the total rate of heat loss per degree of temperature difference, in units of W/K). This heat loss coefficient (both measured and predicted) will be affected by parameters such as dwelling size and type, but the magnitude of the performance gap may also be affected to some extent by these parameters. For example, if the primary causes of performance gaps in a particular development are due to the external wall performance, then detached houses may show a greater gap than mid-terraces. Conversely if the primary problems are associated with party walls, then the opposite may be true. Of course, this simple picture is also complicated by the fact that the primary problem is not necessarily the same either between developments or even within a single development, and also that there is likely to be a complex mixture of significant factors (see section 3). The influence of dwelling type is discussed further in Section 2.1, and factors relating to dwelling size are considered in Section 2.2.

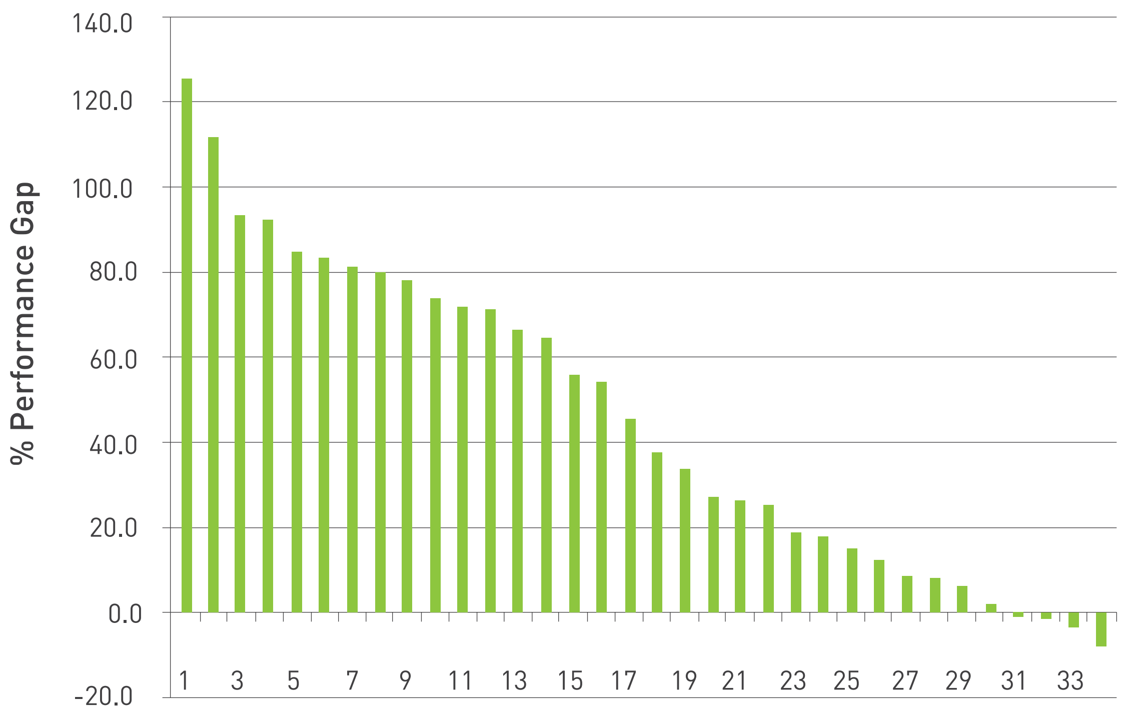

Fig 2.1: Raw Co-heating test data (tests in order of performance gap)

Of the four tests which show a negative discrepancy (measured performance apparently exceeds predicted performance), the two with the higher negative values are both tests which took place on existing dwellings. For this reason, less confidence could be placed in the predicted values used, as the precise details of products, construction methods and thermal bridging calculations were not known and had to be estimated according to rdSAP[2] procedures for older dwellings. Issues relating to retrofit are discussed in more detail in Section 2.3.

The other two negative discrepancy tests arise as a result of a physical intervention (full insulation of party walls), but the negative values are small, and given the uncertainties in the testing procedures may be regarded as zero, thus indicating that in these two cases, after the physical intervention, the dwellings were in fact effectively meeting the as-designed performance expectation.

It has been suggested that expressing the results as a percentage obscures the fact that for very low energy dwellings a substantial percentage gap may represent only a very small absolute additional energy consumption (over the design target), while for dwellings with a less stringent target, even a modest percentage gap may represent a large energy loss. This is discussed in more detail in Section 2.5. We note here, however, that an alternative method of presenting the data is in terms of the absolute measured and predicted heat loss for each test. Fig. 2.2 below shows the data presented in this form, in exactly the same order as in Fig. 2.1.

In Section 2.6 data is presented on the effects of remedial interventions, particularly those relating to amelioration of the party wall thermal bypass.

Finally, in Section 3, we demonstrate how in-depth knowledge of the different contributory causes of underperformance can be used to understand and characterise the performance gap in individual cases.

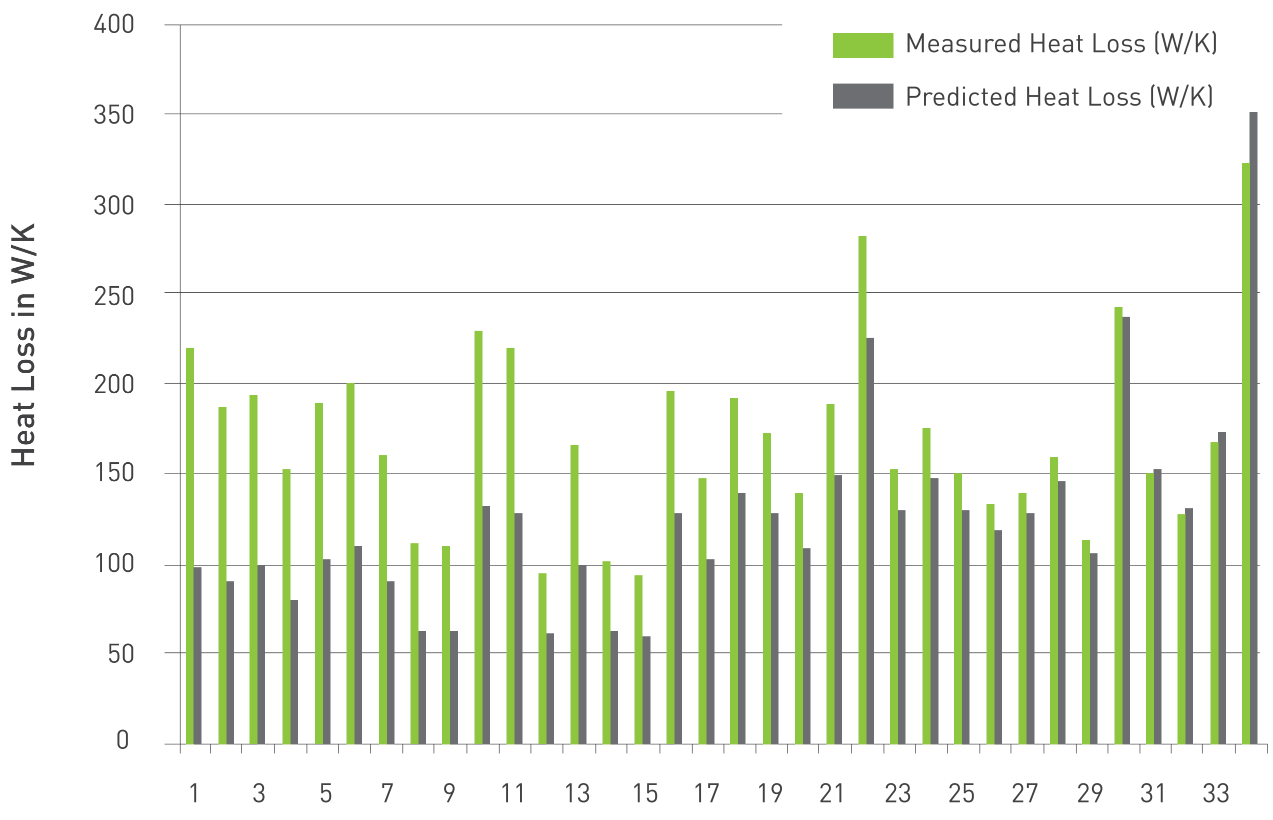

Fig 2.2: Data from Fig.2.1 shown as absolute values of measured and predicted heat loss

2. rdSAP is the version of the National Calculation Method used to calculate the energy performance of existing dwellings, where full data is not available and therefore standard estimates based on factors such as dwelling age are used.

2.1 INFLUENCE OF HOUSE TYPE

House types may be divided simply into detached, semi-detached or end-terrace (one party wall) and mid-terrace (two party walls).

In order to draw out any potential differences, Fig.2.1 has been repeated in Figs 2.3a, 2.3b and 2.3c, with those tests performed on the house type of interest shown in blue and/or grey

The majority of dwellings tested have fallen into the end-terrace/semi-detached category, with only five tests taking place on dwellings in each of the other categories. However, it is clearly noticeable that the mid-terraces are clustered at the higher end of the distribution, with the detached dwellings occupying lower or mid-range positions. This is almost certainly attributable largely to the party wall bypass effect, which was not recognised by regulations at the time the dwellings were constructed. Since mid-terrace houses have two party walls, the additional heat loss due to the bypass is greater in this type of dwelling.

However, now that the effect has been recognised, and Part L changed accordingly, the predicted heat loss in the future should match the experimental heat loss more closely, i.e. the measured performance gap should be somewhat less for these types of dwellings in any tests performed after adoption of the new Part L (whether due to reduced design expectations or to increased performance due to build modifications such as filling the party wall). It is worth noting that a recent test (not shown in the figures) on a mid-terrace dwelling has demonstrated a performance gap of the order of 20%, using a predicted U-value for the party wall of 0.2 W/m².K (i.e. the new Part L value for an edge-sealed party wall).

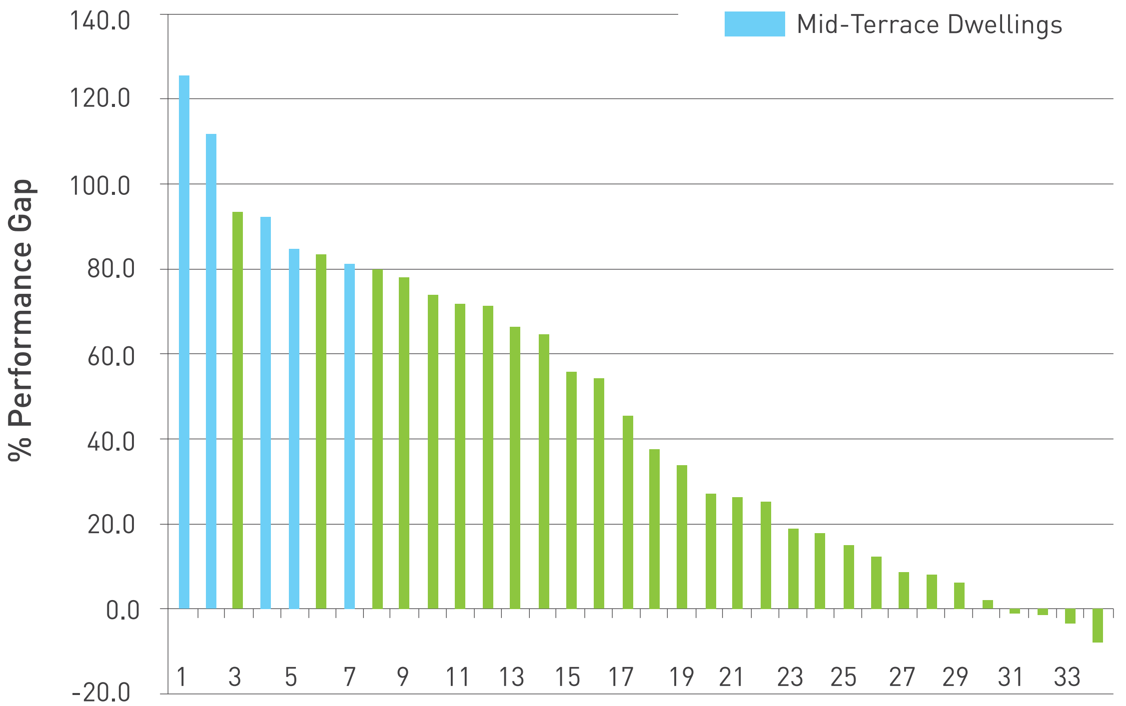

Fig 2.3a: Part of distribution occupied by Mid-Terrace dwellings

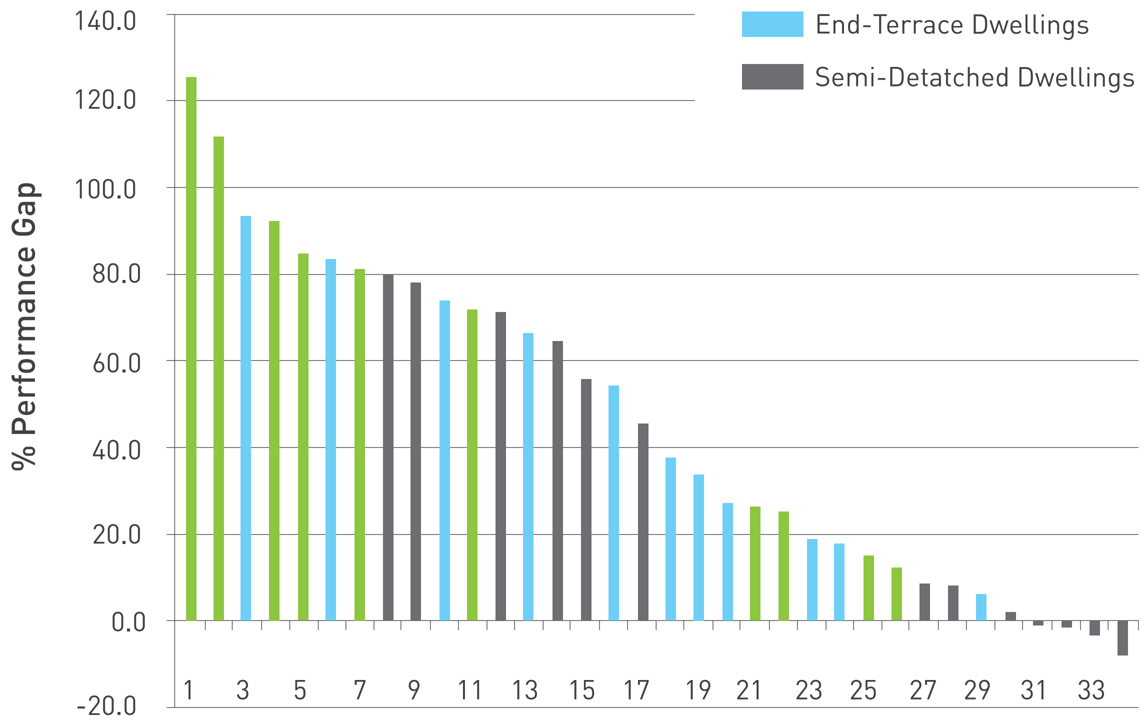

Fig 2.3b: Part of distribution occupied by end-terraces and semi-detatched dwellings

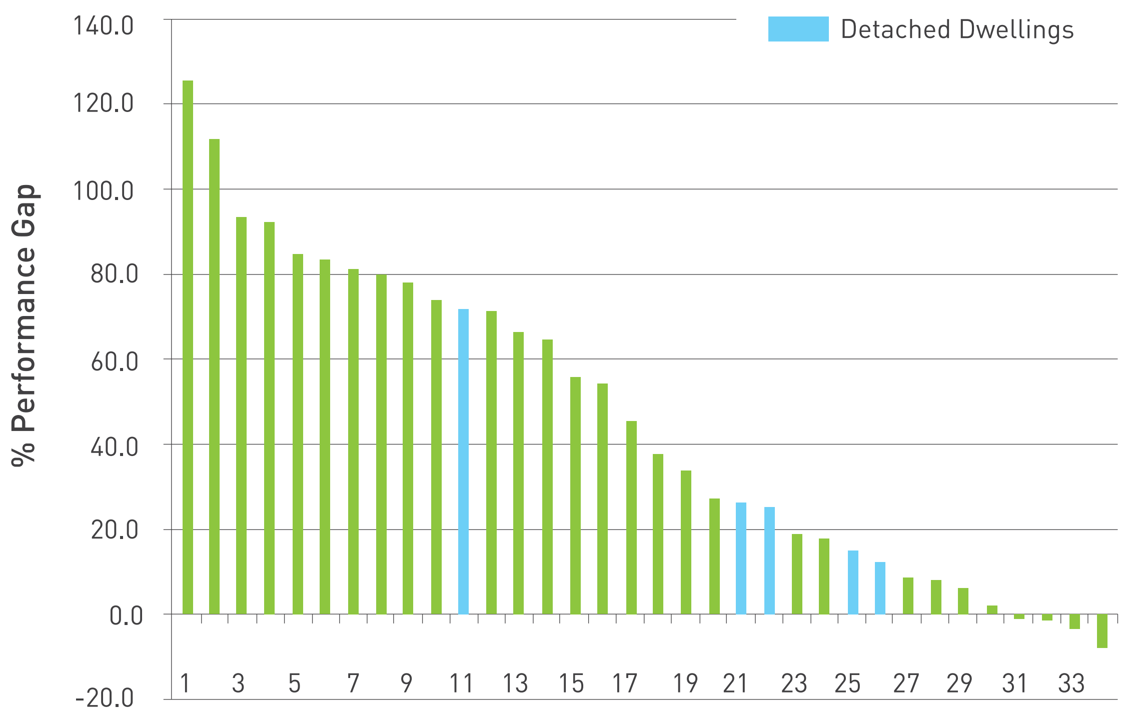

Fig 2.3c: Part of distribution occupied by detached dwellings

In fact the five mid-terrace tests shown in Figure 2.3a represent only three dwellings – one of which was tested only once and the remaining two tested both before and after a physical intervention. Both interventions were related to the party wall (either fully filling or edge sealing), and resulted in each case in a reduction in the performance gap. This represents a real and genuine improvement in performance, but the predicted heat loss used in the calculations was still zero (according to the 2006 regulations), so that the percentage performance gap figures are still somewhat misleading in each case. A better assessment of these dwellings for our purposes would be to recalculate the performance gap for all five tests based on a U-value of 0.5 for an unfilled party wall, 0.2 for edge-sealing only, or 0 for a fully-filled party wall, in accordance with 2010 regulations, as if these regulations were applied retrospectively. If we perform this exercise we find that the picture looks rather different (see Fig 2.4), with the mid-terrace dwellings now at the middle and lower end of the performance gap distribution.

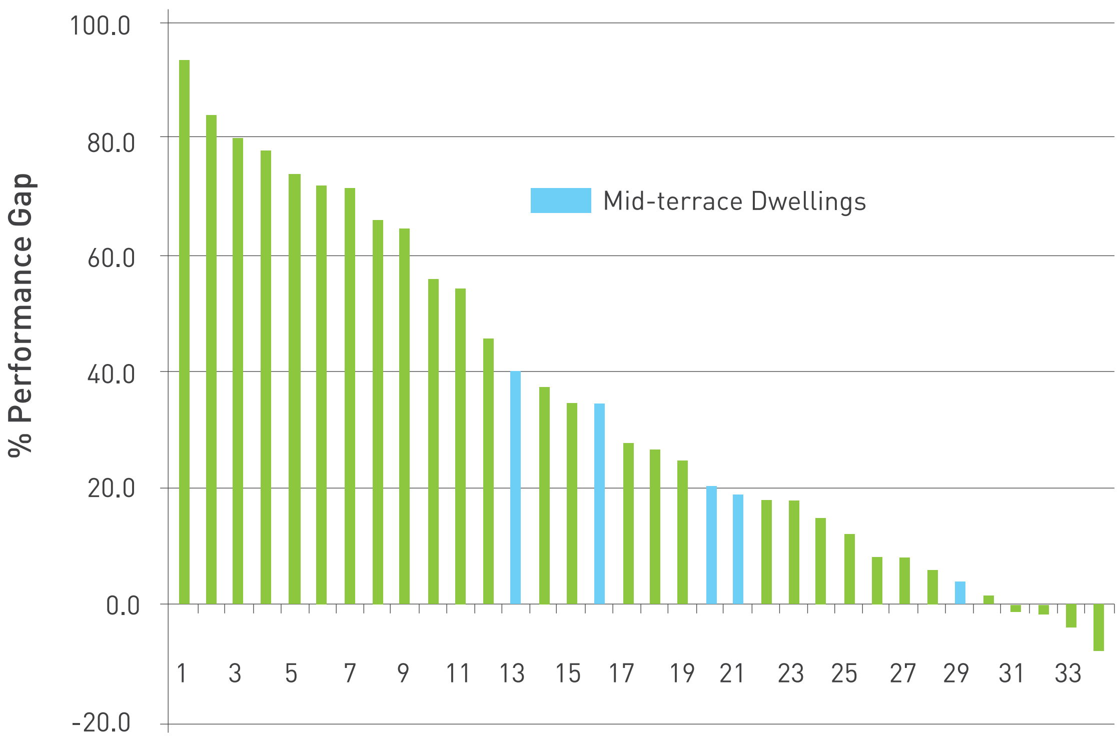

Fig 2.4: Effect of retrospective use of 2010 regulations on calculations for mid-terrace dwellings.

This clearly demonstrates the vital importance of the party-wall bypass mechanism and the new regulations in making more realistic predictions of actual heat loss.

Indeed, we may go further, and point out also that many of the remaining end-terrace and semi-detached dwellings will also have predicted heat loss values which are underestimated compared with the estimations that would have been made according to the 2010 regulations (if they have unfilled or only edge-sealed party-wall cavities). In figure 2.5 below, we re-draw Fig. 1 as far as possible using retrospectively applied regulations for the party walls in all cases.

Even allowing for the increased predicted energy loss through the party wall, we still see a large number of performance gaps at around 30% or more, indicating that there are other heat loss mechanisms and/or process issues not accounted for (i.e. the performance gap is by no means associated with the party wall issues alone). Some of these additional issues are discussed further in section 3, where "closing the loop" is discussed with particular reference to the Elm Tree Mews report (Wingfield et. al., 2011)

Note that in Fig. 2.5 the performance gap figures for dwellings which were not new build (existing dwellings) have not been altered. This was in some cases because the party wall was of solid construction, and the prediction would therefore not be altered under the 2010 regulations, or in other cases because the precise details of the party wall were unknown.

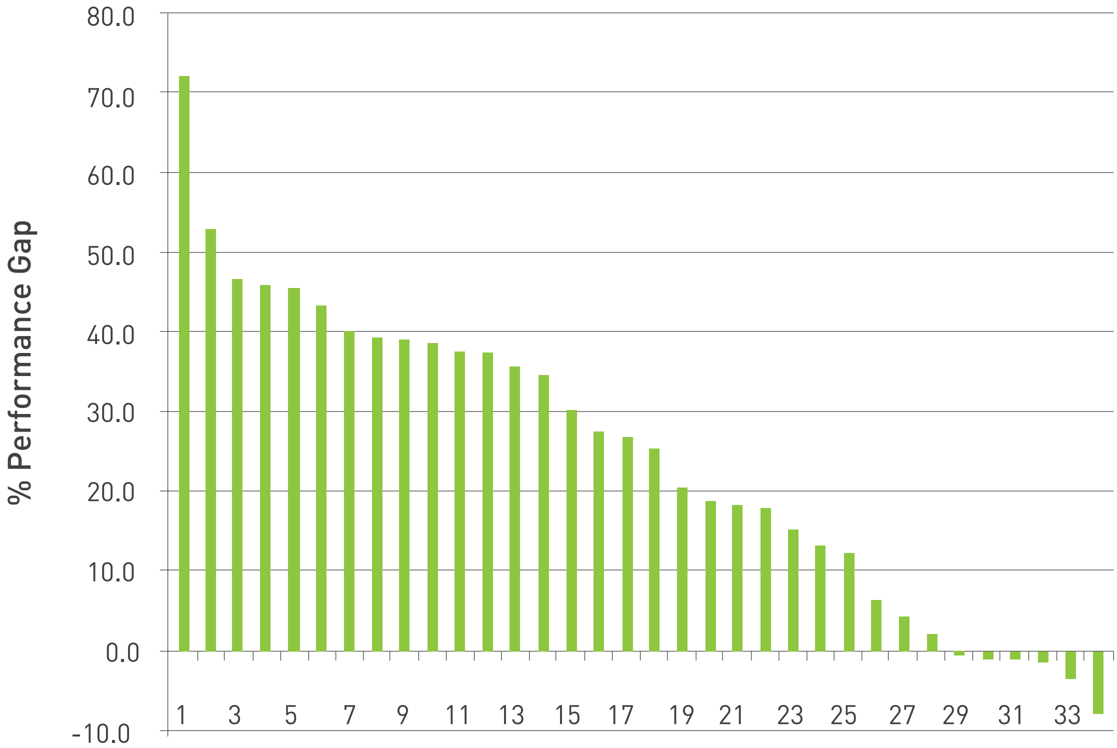

Fig 2.5: Recalculated performance gaps in all tests using 2010 regulations retrospectively.

2.2 INFLUENCE OF DWELLING SIZE

The procedure for examining the influence of dwelling size will involve dividing house sizes into groups by gross floor area, and looking at the distribution of performance gaps in terms of the different groups.

The English Housing Survey (EHS) Headline Report (DCLG, 2012b) divides dwellings into five groups according to floor area. These five groups are:

- under $50m^2$
- 50-$69m^2$
- 70-$89m^2$
- 90-$109m^2$
- above $110m^2$.

However, only one of the dwellings tested had a gross floor area of under $70m^2$, so we have here combined the first three EHS groups into one category labelled 'smaller'. The 'medium' and 'larger' categories shown below correspond to the fourth and fifth EHS groups.

Using these categories, it is difficult to discern any clear trends with regard to physical dwelling size, as all three categories are distributed fairly evenly throughout the figure.

In terms of air-tightness, however, both theoretical and anecdotal evidence suggests that stringent values of air permeability ($m^3/h.m^2$) are more easily attained in larger dwellings. Air permeability is a function of envelope area, so both size and shape are contributory factors. Since experimentally determined values of ventilation rates are used in the performance predictions, effects related to differences in air permeability would not show up in Fig 2.6.

Fig 2.7 shows the value of the absolute performance gap divided by the gross floor area (in $W/K.m^2$) divided into the three size groups.

Again, it is difficult to draw any firm conclusion. This may be due to some extent to the small number of dwellings in the sample, or the width of the categories. However, the twelve dwellings in the 'larger' category represent gross floor areas between approximately $112m^2$ and $167m^2$, and there is no discernible correlation between actual size and position on the diagram within this category.

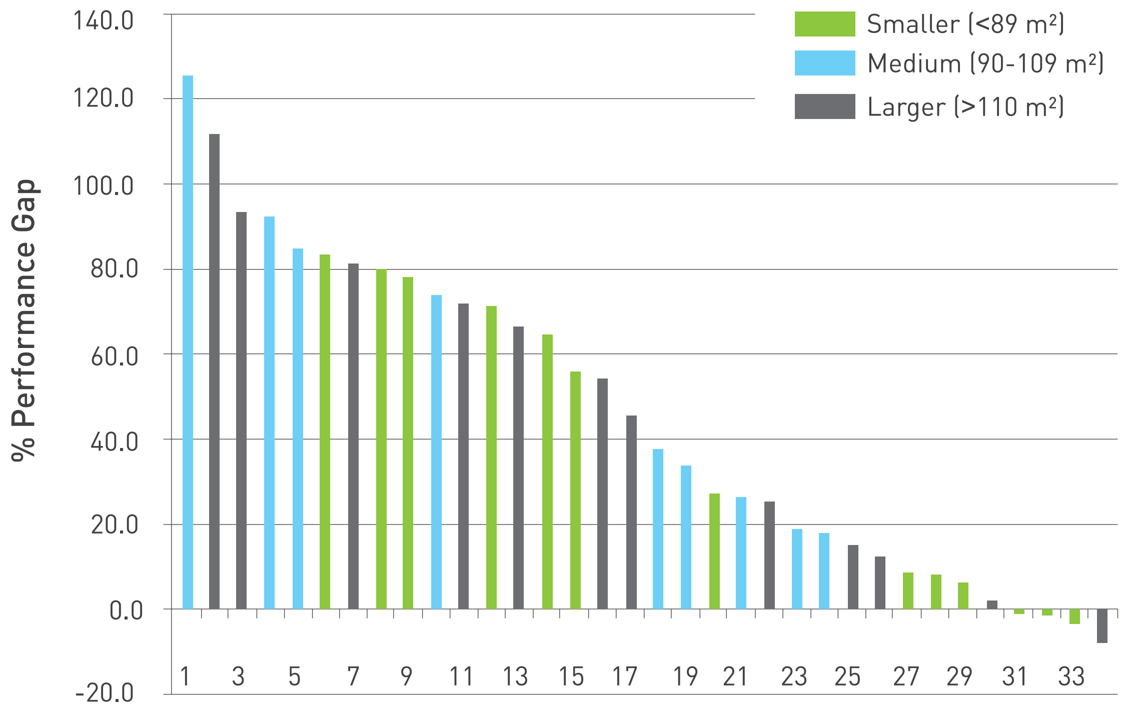

Fig 2.6: Percentage performance gap for different dwelling sizes

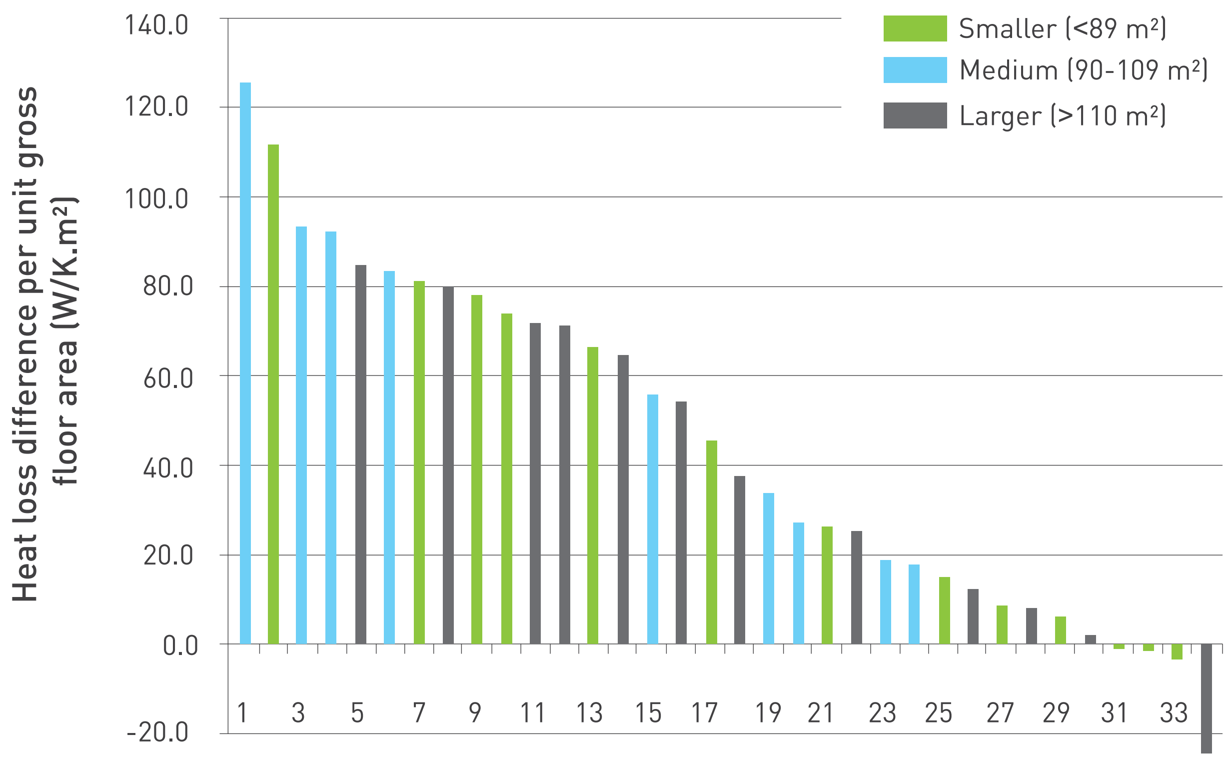

Fig 2.7: Absolute heat loss difference (between predicted and meaured) per unit gross floor area

2.3 INFLUENCE OF CONSTRUCTION TYPE

The vast majority of dwellings tested have been of standard cavity wall brick/block masonry construction (26 of 34). The remaining few are mostly timber frame but also include one or two less traditional construction types. None of the timber frame dwellings tested demonstrated a performance gap of more than 55%, though it is difficult to draw any firm conclusions from this fact since the five tests in question were performed on only three different dwellings (in two cases tests were performed both before and after an intervention – see Section 2.5).

2.4 NEW BUILD OR RETROFIT

The majority of the dwellings considered here were new-build dwellings where it was possible to have reasonable confidence in the predicted heat loss coefficient, at least insofar as Part L1 of the Building Regulations can be expected to deliver realistic values for thermal transmittance of elements, thermal bridging etc. The risk of inaccurate predictions based on design values for elements or procedures, which were subsequently changed on-site, was mitigated by the fact that the construction process was carefully observed. Such in-construction changes to the design are far from uncommon. Examples observed by the Leeds Metropolitan group include substitution of specified elements such as doors or windows, changes from wet-plastering to plasterboard and vice-versa, and changes in insulation products.

In fact only four of the tests under consideration were on existing properties. One was a social housing bungalow that was temporarily vacant. It was possible to perform pressurisation testing, basic co-heating testing, thermography and smoke detection for air-leakage pathways, but it was not practicable to investigate the U-values of elements via heat flux measurements. Furthermore, it was not practicable to heat the neighbouring dwelling to the same temperature during the co-heating test, as is the standard practice, since this neighbouring dwelling was occupied. Therefore the heat loss through the party wall during the test had to be estimated, and the estimate subtracted from the measured heat loss. The predicted heat loss coefficient was based upon the estimated U-values and thermal bridging values given in rdSAP for buildings of the appropriate age and type. In fact, despite all these difficulties, the experimental heat loss coefficient was very close to the predicted value (performance gap -3.6%). However, it is difficult to determine whether this is due to particularly good fabric performance in this dwelling, or to the possibility that SAP may generally overestimate U-values and thermal bridging estimates for older dwellings, perhaps implicitly allowing an extra tolerance as a safety margin.

The other three tests performed on an existing dwelling were all performed on the same building, firstly as-found and subsequently after two separate rounds of interventions. Again, in the as-found test, the performance gap was negative (-8.0%). After some basic interventions the performance gap remained negligible at 1.9%, but after the final round of interventions it increased to 45.5%. It must be emphasised that the absolute building performance improved markedly after each intervention round, and it is merely the difference between 'expected' and 'measured' heat loss coefficients that became wider. Possibly this may lend weight to the idea that as more became accurately known about the fabric (after various interventions had taken place), the predictions became more realistic.

More examples of co-heating tests on existing buildings are necessary in order to build up a better picture of the actual energy performance of the existing stock. Of course this observation also applies to new-build.

2.5 EFFECT OF DESIGN TARGET

As mentioned in the introduction to Section 2, developments that are attempting very high thermal performance standards may fall short by a relatively large percentage, but the shortfall may still represent lower actual energy loss than a small percentage gap in a development with less stringent aspirations.

Therefore it may be considered appropriate to allow wider proportional tolerances for such ambitious projects. However, it should be noted that this argument applies also to dwellings which have a low total expected heat loss (W/K) for other reasons – e,g, small size and/or simple design, even where the U-value specification of elements is not especially high.

Many of the co-heating tests in this analysis were performed on new-build dwellings with thermal performance design targets based only on the current building regulations at the time (2006 Regulations). A few however, were intended to be low-energy designs, with the targets being either specified by consultation with Leeds Metropolitan for that particular development, or specified by some other method such as Ecohomes rating.

Fig 2.8 shows the absolute difference between predicted and measured heat loss divided into 'standard' and 'low-energy intent' groups (where 'low energy intent' signifies that the developer has attempted a low-energy standard over and above the current (2006) Building Regulations).

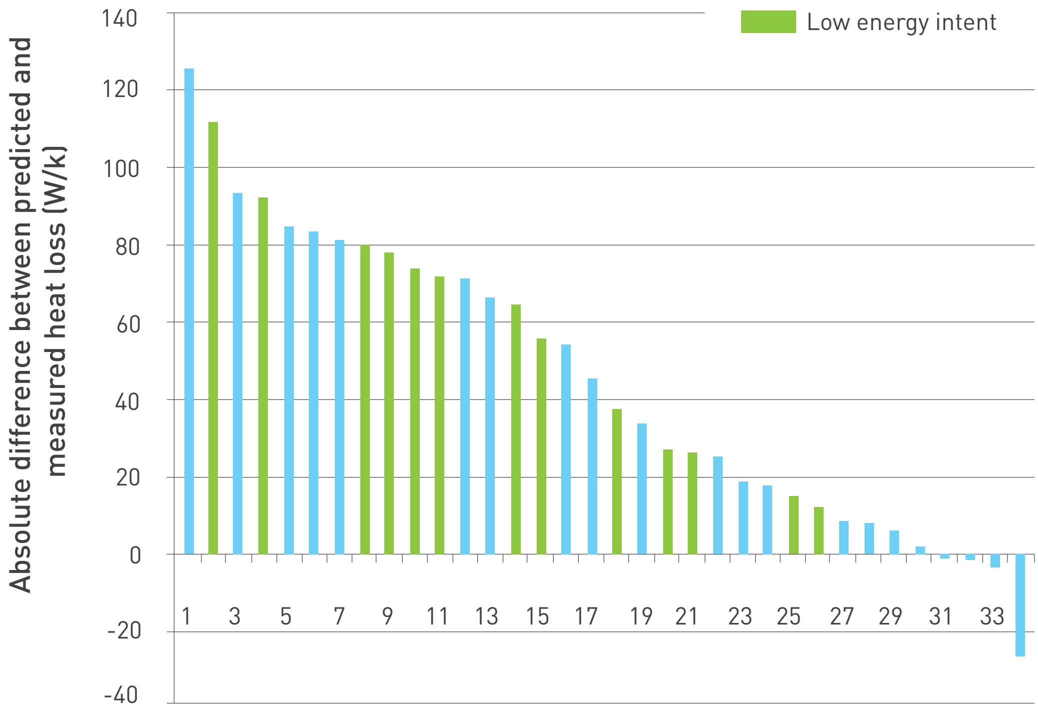

Fig 2.8: Dwellings where there was a specific intent on the part of the developer to adhere to enhanced energy standards

The differences between predicted and measured heat loss for the 'low energy intent' dwellings range from under 20 W/K up to around 100 W/K. One of the 'standard' dwellings shows a higher heat loss difference at just over 120 W/K but many show differences which are similar to, or less than those for the low energy group.

Of course the absolute value of the additional energy loss over the predicted value, as shown here, is related to other factors, such as dwelling size, as well as fabric underperformance. In addition, taking account of the 2010 regulations in respect of the party wall bypass will increase many of the predicted values, thus decreasing the absolute difference values accordingly.

Fig 2.9 attempts to account for these factors by re-plotting Fig 2.8 in terms of absolute difference between predicted and measured heat loss per unit gross floor area (W/Km²) using predicted values which have been amended as for Fig 2.5 (retrospectively applied 2010 regulations). This results in a slightly more optimistic picture though there are still many dwellings in the 'low energy intent' group which occupy the middle section of the diagram.

Note also that because the actual measured air permeability is used in the predicted heat loss values, poor performance in this aspect may result in relatively high predicted heat loss even where the design is intended to be low-energy.

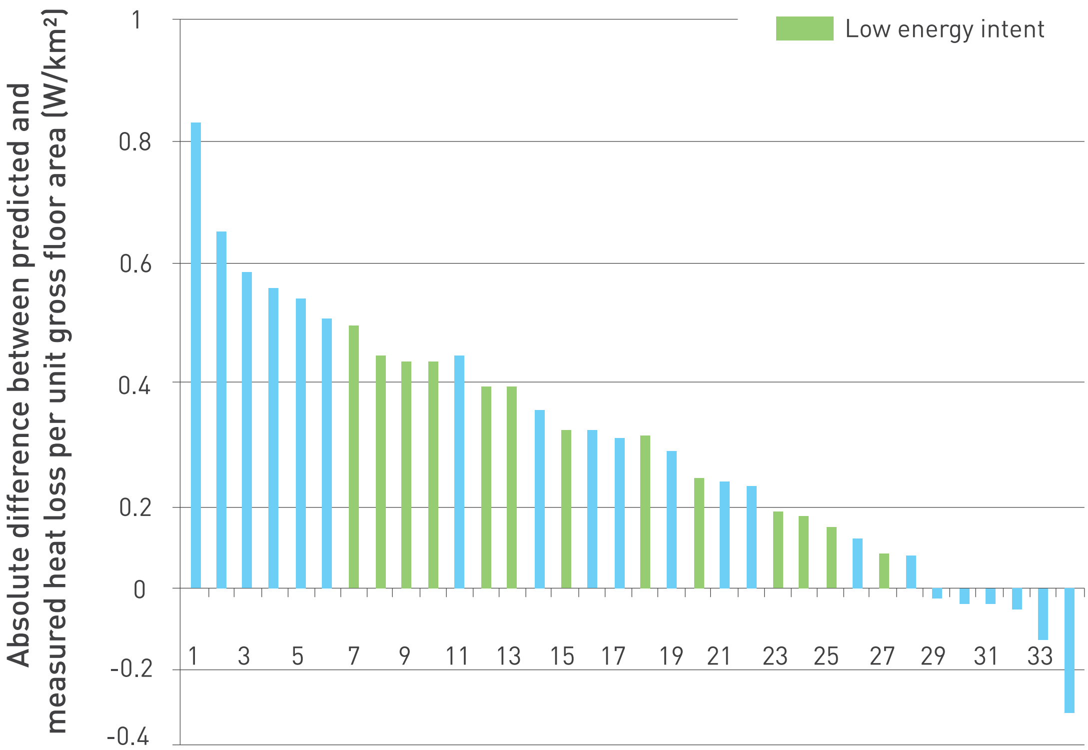

Fig 2.9: As for fig. 2.8 but expressed as a heat loss difference per unit gross floor area, and using 2010 regulations retrospectively in respect of party walls.

2.6 EFFECTS OF INTERVENTIONS

The 34 co-heating tests analysed in this paper represent tests performed on a total of 21 different dwellings.

This is because some tests were done both before and after physical interventions. In many cases the interventions were associated with investigation of the party wall bypass effect, though in one case an intervention involved additional insulation to external walls. In another case, the interventions were various upgrades to an existing dwelling.

PARTY WALL INTERVENTIONS

Four pairs of tests were done on dwellings before and after the insertion of a party-wall sock to mitigate air movement in the party wall. The reductions in the absolute performance gaps following this procedure were as shown in Table 1 (in each case the predicted heat loss assumed a U-value of 0 for the party wall).

Thus in these four dwellings (all from the same development, but not all by the same builder), an improvement in the measured heat loss of between around 8 W/K and around 27 W/K could be achieved by the addition of a party wall sock. Note that Case 1 represents a mid-terrace dwelling where only one of the party walls was modified, and therefore a larger change in the measured heat loss might be expected if both had been modified. Cases 3 and 4 represent smaller dwellings than 1 and 2.

Similarly six pairs of tests were done before and after fully filling the party wall cavity. Once again, a reduction in measured heat loss is seen (in all cases the predicted heat loss assumes no heat loss through the party wall, and is therefore unchanged after the intervention).

Again, in all cases, the measured heat loss is reduced by fully filling the party wall. In the case of 3 and 4, the performance gap is effectively removed altogether by this intervention, but in the other cases, there are clearly other issues which are also affecting the underperformance. In Table 2, Case 2 represents a mid-terrace dwelling where only one party wall was filled. Again, had both been filled, a greater reduction in measured heat loss might have been expected.

	ABSOLUTE DIFFERENCE IN HEAT LOSS (predicted-measured) before (W/K)	ABSOLUTE DIFFERENCE IN HEAT LOSS (predicted-measured) after (W/K)	CHANGE IN MEASURED HEAT LOSS (W/K)	% CHANGE IN MEASURED HEAT LOSS
1	99.4	72.2	-27.2	-27.4
2	93.3	66.1	-27.2	-29.2
3	43.2	33.9	-9.3	-21.5
4	48.1	40.0	-8.1	-16.8

Table 1: Heat loss data before and after modification of party walls (edge-sealing)

	ABSOLUTE DIFFERENCE IN HEAT LOSS (predicted-measured) before (W/K)	ABSOLUTE DIFFERENCE IN HEAT LOSS (predicted-measured) after (W/K)	CHANGE IN MEASURED HEAT LOSS (W/K)	% CHANGE IN MEASURED HEAT LOSS
1	97.3	52.2	-45.1	-46.4
2	122.8	87.2	-35.6	-29.0
3	10.9	-2.2	-13.1	-120.2
4	12.0	-1.6	-13.6	-113.3
5	91.1	29.9	-61.2	-67.2
6	43.9	24.3	-19.6	-44.6

Table 2: Heat loss data before and after modification of party walls (fully insulating)

3. CLOSING THE LOOP

The object is not merely to identify a performance gap, but rather to explain its existence quantitatively in terms of the underperformance of different elements and processes, thus opening potential pathways to improved future performance.

Fig 3.1 gives an example of this 'closing the loop' exercise, where the as-built (measured) U-values of several different elements (together with a more realistic estimate of the total thermal bridging) were substituted cumulatively for the design values, resulting in a full explanation of the observed performance gap. The example is taken from the Elm Tree Mews Field Trial (Wingfield et. al., 2011).

In this particular case, there were a number of almost equally important factors contributing to the observed gap, including party wall, external walls, windows and thermal bridging. A small contribution was also made by the roof performance.

The fact that so few closed loop studies of this type exist means that it is not possible as yet to analyse the most common areas of shortfall in any meaningful statistical sense. However, as more studies are completed, this may perhaps become possible. Such a meta-analysis might help developers to address the most fruitful areas for improvement first, thus optimising shorter-term gains in performance and performance reliability.

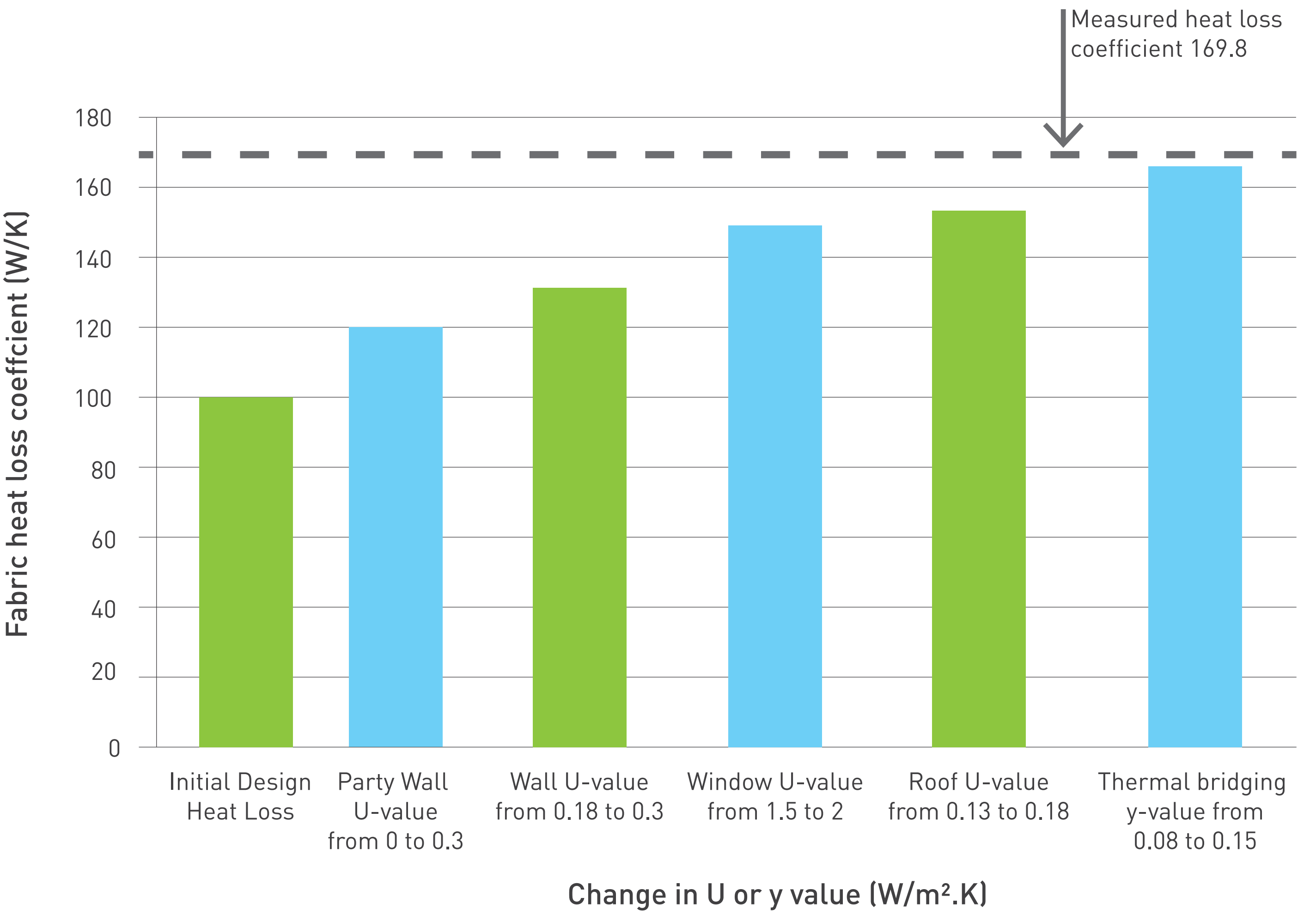

Fig. 3.1: After a figure from Elm Tree Mews Field Trial: Final Technical Report, (Wingfield et. al, 2011)

CONCLUSIONS

In the majority of the cases studied, substantial performance gaps have been demonstrated. The shortfalls can result from a whole range of different sources including party wall losses, underperformance of other building elements in-situ, process issues, lack of understanding of the principles of thermal performance, on-site alterations and substitutions and higher than expected thermal bridging. To this list, we should also add that there may still exist other heat loss mechanisms (apart from the party wall bypass) which are not yet fully understood and therefore not accounted for in the predicted heat loss calculations. The implication for the house-building industry is that a complex and ongoing process of research, feedback, education and training will be necessary if the gaps are to be fully understood and closed.

It is clear from the evidence presented here that a significant contributor to the performance gap in the past has been the issue of underestimated predictions due to a lack of understanding of the party wall bypass. To some extent this has now been addressed via the new (2010) regulations, and in the future predictions may be expected to be more realistic. The solutions of insulating and sealing cavity party walls have been accepted in the current regulatory framework, though field-testing of these solutions has been limited, to date, to the few cases included in this review. As always, we should not rest content with the new estimates of U-values for party walls, but should continually review further evidence to assess whether these new estimates are optimal, or require adjustment.

The rapid learning, which will be necessary in the case of new-build, should be applied also to retrofit projects designed to improve the thermal performance of existing buildings. The evidence base in the case of retrofit projects is unfortunately even more scant than for new-build, and there is a serious need for this to be urgently addressed. Some of the potential additional difficulties associated with studying existing buildings are discussed in Section 2.4.

Fig 2.9 suggests that the intention to attempt enhanced low-energy standards on the part of the developer can result in achieving performances relatively close to the design target when dwelling size is taken into account. However, this is by no means universally the case and additional energy losses (above the design expectations) of over 0.4 W/K per m2 of gross floor area have been observed in several cases. For dwellings where the intent was limited to compliance with current building regulations, additional energy losses above the design expectations range from very small up to over 0.8 W/K per m2 of gross floor area.

APPENDIX

APPENDIX A: SUMMARY OF KEY EVIDENCE ON THE PERFORMANCE GAP [AFTER BELL ET. AL, 2010].

GENERAL LEVELS OF TECHNICAL PERFORMANCE –

Energy and carbon performance, particularly when seeking to achieve low and zero carbon standards, is dependent on a very low incidence of defects in insulation layers, air barriers and the installation and commissioning of services. This led the group to review material on technical performance in general. It highlighted concerns about customer satisfaction, number of defects and compliance with the building regulations raised in the reviews by Barker (2004) and Callcutt (2007) as well as more specific work on defects, including insulation defects, undertaken by the BRE in the 1980s and 1990s (Bonshor and Harrison 1982 and Harrison 1993) and more recent work undertaken for CLG in support of regulation (Oreszczyn et al., 2011 and Bell et al. 2005). All studies demonstrated that defects were relatively common and that tackling the issues involved remained a challenge for the industry. The group concluded: "Given that most of these concerns were in relation to quality factors that could be observed directly, it would be surprising if energy and carbon performance, which is not so amenable to direct observation, was immune to problems of underperformance."

FABRIC HEAT LOSS –

Measurements of whole house heat loss undertaken on some 16 dwellings drawn from a variety of schemes including low energy and mainstream developments demonstrate the potential for a very wide performance range (see: Bell et al., 2010, Wingfield et al., 2010b, Wingfield et al., 2008, Wingfield et al., 2009 and Stevenson and Rijal, 2008). Of the 16 dwellings tested, 11 had heat losses between 120% and 40% higher than predicted, the remaining five less than 20% higher. In most cases whole house measurements have been supported by forensic analysis including design and construction observations and measurements of heat flux through the thermal envelope. Other work on heat loss from construction elements corroborate much of the work from whole house measurements. Work by Siviour (1994) and Doran (2005) show a wide variation in the discrepancy between calculated and as-built U values. Theoretical and laboratory work in Belgium (Hens et al., 2007) demonstrate the impact of air movement through and around insulation materials, with test results for as-built U values ranging from 0% to 350% higher than calculated depending on the closeness of fit. The emergence of an understanding of thermal bypassing (Wingfield et al., 2008 and Lowe et al., 2007) has identified a heat loss mechanism that further explains some of the gap in fabric performance, particularly in attached dwellings with cavity party walls. Although the available evidence (Wingfield et al. 2009) indicates that the party wall bypass could be reduced to zero by a combination of full filling and edge sealing, this is only part of the solution to closing the fabric heat loss performance gap.

AIRTIGHTNESS –

The group noted an encouraging improvement in airtightness of dwellings since the introduction of regulatory airtightness testing of dwellings in 2006. The data indicated that the average permeability had fallen from just over 9 m3/h.m2 (Grigg 2004) to just over 6 m3/h.m2 (NHBC 2008). However, it was acknowledged that much lower levels are likely to be required in order to achieve low and zero carbon standards. The impact of testing on airtightness was noted and provide a good indication that low levels of permeability could be achieved given the right processes and control mechanisms, backed up by testing and feedback.

HEATING AND HOT WATER SERVICES –

The group reviewed work by the Carbon Trust (Carbon Trust, 2007) and the Energy Saving Trust (Orr et al. 2009) on the performance of gas condensing boilers. Both studies suggesting that, on average, as-installed, in-use efficiencies are likely to be around five percentage points below their SEDBUK2005 ratings. In addition, carbon performance (mainly as a result of electricity loads for pumps and fans) can vary considerably with the Carbon Trust study suggesting that it could vary by a factor of two. Total systems effects from case studies of gas condensing boilers and a communal heat pump (Wingfield, et al. 2008 and Bell et al. 2010) were noted, indicating that such effects could be large and leading to the suggestion that there was a need for robust design and calculation methods that took systems effects into account.

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CONTACTS

Centre for Low Carbon Futures

Director: Jon Price

jon.price@lowcarbonfutures.org

Centre for Low Carbon Futures

IT Centre

York Science Park

York YO10 5DG

Telephone: +44 (0)1904 567714

www.lowcarbonfutures.org

Twitter: @clcfprojects

ABOUT US

The Centre for Low Carbon Futures is a collaborative membership organisation that focuses on sustainability for competitive advantage. Founded by the Universities of Hull, Leeds, Sheffield and York, the Centre brings together multidisciplinary and evidence-based research to both inform policy making and to demonstrate low carbon innovations. Our research themes are Smart Infrastructure, Energy Systems and the Circular Economy. Our activities are focused on the needs of business in both the demonstration of innovation and the associated skills development. Registered in the UK at Companies House 29th September 2009 Company No: 7033134.

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