Good Homes Alliance

GHA Monitoring Programme 2009-11: Technical Report

Results from Phase 1: Post-construction testing of a sample of highly sustainable new homes

Acknowledgements

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- Kingerlee Homes
- Greenoak Housing
- AECOM
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- Technology Strategy Board
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- A & G Architects
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Front cover images:

One Brighton, Temple Avenue (image Richards Partington Architects), Old Apple Store (image Ecos Homes)

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Table of Contents

Acknowledgements

Executive Summary

This executive summary provides an overview of the findings, observations and recommendations resulting from Phase 1 of the Good Homes Alliance (GHA) monitoring programme. Phase 1 is based on post-construction testing of a series of new-build residential projects, across a range of construction types.

This research programme has been developed in response to the Government's ambitious targets for incremental changes to building regulation standards, which are intended to achieve zero carbon new housing from 2016 onwards. Achieving these targets is theoretically possible and prototype designs and projects have been produced for very low and zero carbon housing. However, many of these solutions are at present untested, and there is growing concern that there is a gap between as-built performance and design intent in the energy performance of new homes.

This project provides:

- An evaluation of the 'as designed' and 'as built' fabric energy efficiency performance of four very low energy properties, tested prior to occupation.
- Lessons for the development of zero carbon housing and the implications for government policy; and
- Recommendations to government and to house-builders about steps needed to achieve low and zero carbon homes.

The four test properties comprised three detached dwellings and an apartment. Further properties, including a range of other dwelling types, will be tested in future phases of the GHA programme, but could not be included here. All the tested dwellings varied in terms of size, built form and construction technique.

In each case, the test properties achieved an as-built, measured heat loss performance significantly better than the contemporary Building Regulations requirement and also exceeded anticipated performance levels for homes built to 2013 standards. This shows that it is possible to design, construct and deliver sustainable homes that achieve very low levels of heat loss in reality.

The house builders who participated in this monitoring programme were all members of the Good Homes Alliance and are therefore committed to building highly sustainable homes with very good energy performance and hence very low fabric heat loss. They also understand the benefits of being involved in a monitoring programme such as this. However, a number of changes will be required to encourage the wider house-building industry to address the as-built energy performance of new homes and to monitor their actual performance.

The project team has therefore made a number of recommendations to industry and to Government about the changes that are likely to be required in order to achieve the widespread delivery of low and zero carbon homes.

Recommendations

1. House-builders should measure the as-built performance of their dwellings, evaluate the results and then feed this information back to their development teams, including their supply chains.

2. Housing professionals and regulators should improve the modelling predictions and tools for the fabric, energy efficiency and carbon emission performance of new build homes, such that they reflect the reality of as-built performance.

3. The Government should encourage and incentivise the house-building industry to gather evidence about the fabric performance of their homes.

4. Lessons learnt from post construction testing should be fed into regulatory modelling and prediction tools such as SAP.

5. The Government should support research to subject further dwellings to post construction testing, covering a greater range of dwellings types and build systems, in order to build a representative sample of homes across the UK and to provide an evidence base of as-built performance.

6. The results of post construction testing should be examined in order to identify and help address common design and build problems encountered in the move towards 2016 zero carbon targets. This may require additional streams of government funding to assist with the research.

7. The Government should work with industry and stakeholders to develop a national feedback and learning programme, which should include:

   - education and training - for instance around identifying and solving areas of heat loss
   - research and development - for instance about how to achieve good levels of as-built performance
   - a process change programme - for instance through pilot studies

8. Research should be commissioned to assess whether two levels of standard testing could be developed: one cheap and simple version to enable wider application of testing suitable for quality assurance; and a second tier of more expensive, detailed and forensic testing to be used on pilot or prototype homes.

9. Further research should be undertaken into developing the co-heating test methodologies, for example their application in apartments, so that consistent co-heating testing protocols can be developed for widespread application across the industry.

10. Other standard methodologies, which can be used at any time of year, should be developed for post construction testing.

List of figures

List of tables

SECTION 1 – The need for monitoring

1.1 Government Policy and targets for carbon reduction

Energy used in domestic housing in the UK produces over one quarter of the UK's total carbon dioxide emissions[1] which contribute to climate change. In order to reduce carbon emissions from the domestic housing sector, all new homes are required to meet minimum Building Regulation standards, including Part ADL1a Conservation of Fuel and Power, which requires compliance with SAP 2009, (SAP, the Standard Assessment Procedure, is an energy efficiency design target included in Part ADL1a of the Building Regulations). In addition, all homes in receipt of public funding are required to meet the Code for Sustainable Homes (CSH)[2].

The Government has set ambitious targets for incremental changes to building regulatory standards, which are intended to achieve zero carbon new housing from 2016 onwards[3]. With the application of improved fabric measures (such as better insulation), improved efficiencies in building services (including more efficient heating and hot water systems, lights and appliances and better controls) and the addition of low and zero carbon renewable energy generation, this is theoretically possible; prototype designs have also been produced for very low and zero carbon housing.

However, many of these solutions are at present untested, and there is growing concern within the housing industry that, in practice, even current energy efficiency and carbon emission standards are not being achieved i.e. that there is a gap between as-built performance and design intent. Furthermore there is concern that this performance gap has the potential to undermine zero carbon housing policy[4]. In the UK, we know very little about the way homes perform post construction, except on air-tightness. Initial studies, such as Low Carbon Housing: Lessons from Elmtree Mews[5] suggests a deficiency can exist between design and actual performance of the building fabric and services.

Further research, for example by Wingfield et al[6] and Bell et al[7] has shown many of the new homes in the sample they tested were not achieving their

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[1] The Energy Saving Trust. Fabric first**.** Focus on fabric and services improvements to increase energy performance in new homes. CE320, September 2010

[2]. Code for Sustainable Homes Technical Guide. November 2010. DCLG ISBN 9781859463314

[3] HMS Treasury The Plan for Growth published by Department for Business Innovation and Skills, March 2011. Construction p121.

[4] Carbon Compliance: Setting An Appropriate Limit For Zero Carbon New Homes: Findings And Recommendations, Zero Carbon Hub February 2011.

[5] The Elm Tree Mews Project, Joseph Rowntree Foundation - Bell, M., Wingfield, J., Miles-Shenton, D. and Seavers, J. (2010) Low Carbon Housing: Lessons from Elm Tree Mews. Joseph Rowntree Foundation, York. ISBN: 978-1-85935-766-8 (pdf). [www.jrf.org.uk/publications]

[6] Wingfield, J., Bell, M., Miles-Shenton, D., South, T & Lowe, R.J. (2007) Evaluating the Impact of an Enhanced Energy Performance Standard on Load-Bearing Masonry Construction – Final Report: Lessons From Stamford Brook - Understanding the Gap between Designed and Real Performance, PII Project CI39/3/663, Leeds Metropolitan University, Leeds

[7] Bell, M., Black, M., Davies, H., Partington, R., Ross, D., Pannell, R. And Adams, D. (2010) Carbon compliance for tomorrow's new homes: A review of the modelling tool and assumptions. - Topic 4: Closing the Gap Between Designed and Built Performance. Report number ZCHD130210, Zero Carbon Hub, London. [www.zerocarbonhub.org]

design energy and ventilation performance standards. This performance gap may have implications for the long term physical integrity of the building fabric of homes, (for instance missing insulation and high levels of air leakage could result in increased risk of damp and condensation which could contribute to a quicker deterioration of the property fabric) as well as the achievement of carbon reduction, energy efficiency, thermal comfort and affordable warmth objectives.

Designers and house-builders can model and predict building energy performance using tools such as SAP; most regulatory requirements are also based around energy design targets modelled using SAP. Although SAP is a useful modelling tool there are a number of inherent assumptions made when using SAP software, and it has limitations, particularly in terms of effectively modelling low energy homes.

Ultimately, SAP and modelling software can never provide evidence to both the regulator and the constructor of what level of performance has actually been achieved in reality. Currently there are no requirements for proof that new build homes have achieved their planned energy performance in reality.

It is evident that there would be benefit in new build housing schemes undergoing some form of comprehensive post-construction testing and monitoring in order to evaluate and evidence whether they have achieved their anticipated energy efficiency and carbon performance in reality.

The Good Homes Alliance (GHA) is particularly interested in the actual performance of new homes at point of completion (post-construction). This is the point up to which house-builders have the most control, and from which the building fabric and systems greatly influence the energy use within the home during occupancy.

The GHA's biggest concerns about post-construction performance relate to unintended heat loss, which is explored in more detail in the next section.

1.2 Causes of heat loss

Complying with Building Regulations and meeting the energy requirements of the Code for Sustainable Homes requires a significant reduction in the amount of heat loss from dwellings. This can be achieved by improving the thermal performance of the fabric, reducing the impact of thermal bridging and reducing uncontrolled infiltration.

The Energy Saving Trust reported that better detailing and improved airtightness can reduce a dwelling's annual carbon dioxide emissions by up to 10%[8]

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[8] The Energy Saving Trust. CE302. Enhanced Construction Details: Thermal bridging and airtightness. 2009

The application of simple design principles can improve the thermal performance of key details such as lintels, wall to floor junctions and ceiling to gable wall junctions by over 85%.

1.2.1 Causes of fabric heat loss - thermal bridging

Around 30%[8] of the total heat loss through a building's fabric can be caused by thermal bridging. Thermal bridges can occur at any junction between building elements or where the building structure changes.

Thermal bridges fall into two categories:

(a) Repeating thermal bridges (such as timber joists, mortar joints, mullions in curtain walling). The additional heat flow due to this type of thermal bridge is included when determining the U-value of the particular building element which contains these bridges.

(b) Non-repeating thermal bridges (such as junctions of floor and roof with the external wall and details around window and door openings) where the additional heat flow due to the presence of this type of thermal bridge is determined separately.

1.2.2 Causes of fabric heat loss - thermal bypasses

Thermal bypass can occur when heat transfer bypasses the conductive or conductive-radiative routes between two regions. Research by Wingfield et al (2010)[9] shows one example of a thermal bypass, where heat loss in a party wall is driven by upwards air movement in the cavity. This air movement is generated by thermal stack effects and by pressure differences caused by the action of wind around the dwelling.

Wingfield et al (2007)[6] reported that there is potential for considerable carbon savings for newly constructed dwellings built with unfilled cavity masonry party walls if measures are implemented to reduce or eliminate the party wall thermal bypass.

1.2.3 Causes of Infiltration heat loss - Air leakage

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of a building. Too much air leakage leads to unnecessary heat loss and can result in occupant discomfort from draughts. In a well-insulated dwelling with a poor standard of airtightness, air leakage can account for up to 50%[8] of the total heat loss, from a dwelling.

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[9] Wingfield, J., Bell, M., Miles-Shenton,(2010) Investigations of the Party Wall Thermal Bypass in Timber Frame Dwellings: Final report. Report for EURISOL – UK Mineral Wool Association. Centre for the Built Environment, Leeds Metropolitan University, Leeds, UK.

Three main types of air leakage paths are found in dwellings[10]:

- Joints around components (e.g. windows in walls).
- Gaps between one element and another (e.g. gaps around floor to wall joints)
- Holes where services pass through the construction

Cold outside air may be drawn into the home through gaps in the walls, ground floor and ceiling (infiltration), resulting in draughts. In some cases, infiltration can cool the surfaces of elements in the structure, leading to condensation.

Warm air leaking out through gaps in the dwelling's envelope (exfiltration) is a major cause of heat loss and, consequently, wasted energy.

1.3 The need to test fabric performance first

If the post-construction performance of new dwellings is to be improved, in terms of both construction technology and the processes through which this is applied, it is crucial that the thermal performance of homes is measured and the analysis is fed back to those involved in building design, construction and product supply and manufacture.

If homes are only monitored in use, it is difficult (if not impossible) to dissociate those effects that arise from occupant behaviour and usage patterns, from the issues associated with the performance of the building fabric itself. It is therefore essential to measure the performance of the building prior to occupancy, as this establishes the building performance free from occupancy impacts.

The measurement of fabric performance is also a beneficial ingredient in subsequently understanding the performance of the dwellings in use – once a baseline has been established for the performance of the building fabric, then it is easier to eliminate this from any measured discrepancies in performance. Any discrepancies will direct the monitoring teams to investigate other issues such as occupant behaviour, or performance of the services (such as the performance of the heating or ventilation systems).

Gaining a better understanding of the actual building performance will also assist housing professionals to improve their modelling predictions for the energy efficiency and carbon emission performance of new build homes.

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[10] The Energy Saving Trust. GPG 224. Improving airtightness in dwellings. 2005

SECTION 2 – Approaches to testing and monitoring

2.1 Developing a testing and monitoring strategy

There are a number of testing and monitoring strategies that can be employed at different stages throughout construction and during occupancy phases. Each of these provides different levels of information with respect to both the post construction and operational performance of new homes. Some of these include:

- Post-construction measurement of fabric heat losses
- Air-leakage tests
- Commissioning of services
- In-use monitoring (during occupation)
- Post occupancy evaluation (POE)

As discussed previously, simply monitoring in-use performance during occupation produces data that can be difficult to understand. Apparent discrepancies between predicted and actual energy performance could be caused by a number of factors, such as occupant behaviour usage patterns, services efficiency or fabric performance. It is difficult to separate out the potential role each of these factors have played in causing any performance discrepancy without doing further detailed investigations. Post-construction measurement of fabric heat losses is therefore likely to be an important component of any meaningful monitoring strategy, as it removes the complexity of occupancy factors.

2.2 Testing strategies to measure fabric heat loss

2.2.1 Co-heating test

A co-heating test is a method of measuring the fabric heat loss in an unoccupied dwelling. It involves heating the inside of a dwelling using electric heaters to a constant, stable internal temperature of 25°C over a period of several weeks (see figure 1 below). By measuring the amount of electrical energy required to maintain the internal temperature each day, the daily heat input to the dwelling can be determined. The heat loss coefficient (W/K) for the dwelling can then be calculated by plotting the daily heat input against the daily difference between the inside and outside temperatures of the dwelling.

The co-heating test is designed only to measure the heat loss through the fabric of a building. Although a background ventilation test is conducted immediately before and after the co-heating test, this is done simply to eliminate the natural background ventilation heat loss from the dwelling, so that this can be separated from the fabric heat loss.

Figure 1: Co-heating test equipment; photograph courtesy Leeds Metropolitan University

The co-heating utilises a tracer gas decay method to confirm the background ventilation rate during the period of the co-heating test. In this, a gas (usually CO_2) is dispensed into the sealed building once daily, and sensors around the dwelling measure the gas concentration over time to determine the amount of gas that has leaked out. Further details of the methodology for co-heating tests are available at Wingfield et al. [11]

2.2.2 Heat flux measurements

The insulation performance of solid elements, such as a wall or a roof, can be measured using local heat flux sensors (see figure 7 below); these measure direct heat flow through various elements of the building fabric. The measurements are used to determine an effective average U-value for each element concerned, and the information can be used to help identify any areas of heat loss from a dwelling.

Figure 2: Heat flux sensors; photograph courtesy University College London

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[11] Wingfield, J. et al. Whole House Heat Loss Test Method (co-heating). Leeds Metropolitan University May 2010

2.2.3 Thermal imaging

Thermal imaging is a non-invasive means of observing and diagnosing the condition of dwellings through temperature differentials. It can be used to check for high heat loss paths in dwellings. It can also assist in identifying building features that create thermal bridges, to check or prove insulation continuity, to find hidden leaks, and a source of damp in a dwelling. If remedial works have been made to the fabric of dwellings subsequent to problems being diagnosed, thermal imaging can also be used to evaluate and verify improvements.

An example of using thermal imaging is described below. In figure 3 below - an infra-red thermal image taken of a terrace of four houses, which included 2 test homes - the heat plumes arising from a party wall thermal bypass can be seen at the top of the party wall. Please note that these images are not from dwellings taking part in the GHA Monitoring Programme.

Figure 3: Infra-red Thermal Image of Terrace containing Test House before filling, [Wingfield, J., et al, 2010[9]]

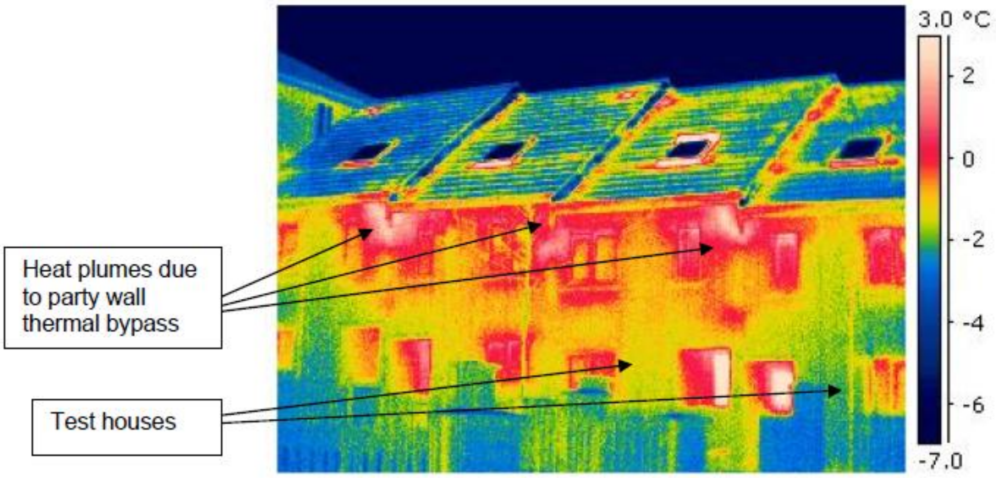
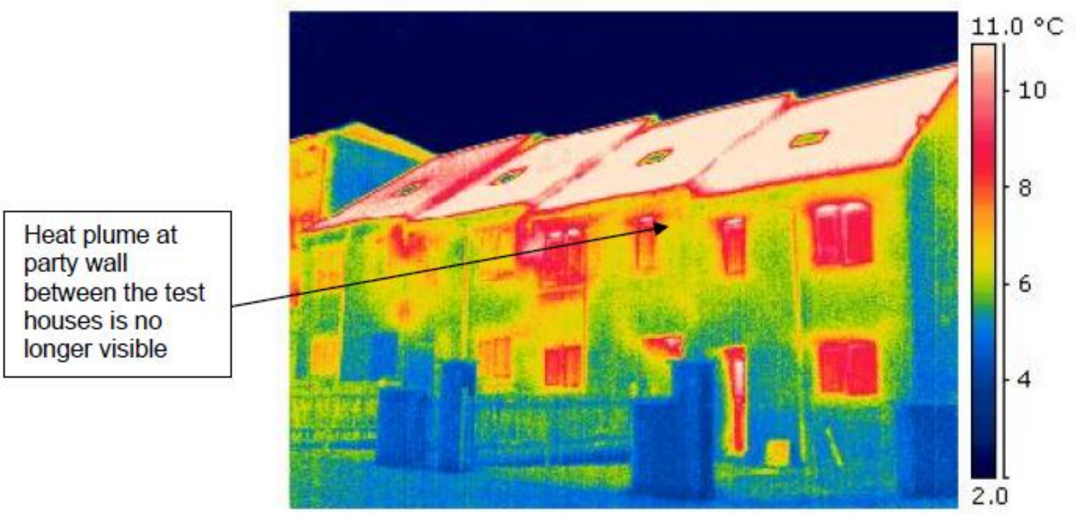


Figure 4 below shows an Infra-red thermal image taken after the party wall cavity between the test houses has been filled with insulation. This shows that the heat plume due to the thermal bypass was no longer visible at the party wall between the test houses but that the plumes were still present in the other houses in the terrace where the party wall cavities remained empty.

Figure 4: Infra-red Thermal Image of Terrace containing Test House after filling, (Wingfield, J., et al, 2010[9])



Heat plume at party wall between the test houses is no longer visible

2.3 Air leakage tests (air permeability/ air-tightness test).

Air leakage is the uncontrolled flow of air through gaps and cracks in the fabric of a building sometimes referred to as infiltration or draughts[12]. It should not be confused with ventilation, which is the controlled flow of air into and out of the building through purpose built ventilators that is required for the comfort, health and safety of the occupants.

Air tightness testing is now a well-established technique and an air tightness pressurisation test, sometimes known as a fan pressure test forms part of the requirements for building regulations compliance. The airtightness test can be used in several ways:

- Assessing the air permeability of the building, (the air leakage from the whole envelope area of the building).
- Identifying the air leakage paths, which will allow for targeted remedial measures such as sealing.
- Measuring the effectiveness of remedial sealing

Air tightness tests can identify air leakage paths in the fabric of the dwelling; while the fan is pressurising the dwelling, hand-held smoke pencils are used to find air leaks. The smoke is released in a small controllable trickle and is a visible means of showing air movement. Smoke can be seen issuing through the gaps and cracks to the outside. Smoke can also be very useful in identifying flanking (or indirect) air leakage paths.

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[12] The Energy Saving Trust. Achieving air tightness in new dwellings. CE248 (2007)

2.4 Commissioning tests

There are now legal requirements for installing, inspecting, testing and commissioning building services, which should be carried out by an approved and competent person, prior to hand over[13]. This will help ensure that the building services have been installed correctly and that they are set to operate in the most efficient way, which should assist in saving carbon emissions. A review of the different approaches to commissioning tests is outside of the scope of this report; outline findings from some commissioning tests on the dwellings in this study will be included in the Phase 2 report, due for publication in late 2012.

2.5 Monitoring in-use performance

2.5.1 Testing the performance of dwellings in use

Testing the performance of dwellings in-use must involve frequent measurement to provide robust data. This can help to determine how the key features of the new designs (enhanced airtightness, improved fabric insulation levels, renewable sources of energy) contribute to energy performance. It is also important to measure how low carbon and renewable technologies perform when they are included in the design, and so understand their contribution to a home's overall carbon budget[14]. Again, a detailed review of the different approaches to testing the performance of dwellings in use is outside the scope of this report; outline findings from in-use monitoring on the dwellings in this study will be included in the Phase 2 report, due for publication in late 2012.

2.5.2 Post Occupancy Evaluation (POE)

Occupant behaviour, dwelling usage patterns, and occupant interaction with their dwellings and building services (including heating and hot water systems, lighting, ventilation and appliances), has a significant effect on the energy efficiency and carbon emissions arising from dwellings.[15]

A review of the different approaches to POE is again outside of the scope of this first report. However more detailed information in relation to post occupancy evaluation will be included in the Phase 2 GHA Monitoring Programme Report, due for publication in late 2012.

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[13] Domestic Buildings Services Compliance Guide (2010). ISBN 978 1859463772. Published by NBS, UK.
[14] The Energy Saving Trust. (2008). CE298 Monitoring energy and carbon performance in new homes.
[15] Gill, Z.M., Tierney, M.J., Pegg, I.M., Allan, N. (2010),). Low-Energy Dwellings: The Contribution Of Behaviours To Actual Performance, Building Research and Information, vol. 38 (5), pp. 491-508

SECTION 3 – The GHA Monitoring programme

3.1 Aims and objectives of the Good Homes Alliance Monitoring Programme.

The aim of the GHA monitoring programme is to help close the gap between design aspiration and as-built performance of highly sustainable, new build homes, by measuring and monitoring their performance, and to help improve the processes for undertaking such measurement.

An initial study, funded by the Energy Saving Trust, investigated the scope of monitoring required and defined the approaches to be adopted for the GHA Monitoring Programme[16]. This was undertaken by the Good Homes Alliance and its partners Leeds Metropolitan University, Oxford Brookes University and University College London, and was completed in May 2009.

The scoping study team suggested that detailed performance monitoring involves 3 main approaches:

Post construction testing: Collection and analysis of data to calculate the thermal efficiency of the building fabric.

Monitoring in use: Collection and analysis of in-use data about energy and water consumption, temperature and internal air quality in occupied dwellings.

Post occupancy evaluation (POE): Analysis of user behaviour patterns, comfort and satisfaction levels and perceptions.

The GHA Monitoring Programme was therefore set up in phases with two objectives:

Phase 1, Post Construction testing – To measure the performance of building fabric post-construction on a series of new-build residential projects, across a range of construction types.

Phase 2, In-use monitoring and POE - Collect in-use performance data from these units in terms of energy and water consumption, indoor air quality and occupant behaviour/ perceptions, including services performance where possible.

The programme is scheduled to run from October 2009 to Autumn 2012. Phase 1, post construction testing, started in January 2010 and was completed in July 2010. Phase 2, in-use monitoring and post occupancy evaluation, started in April 2011 and will report in Autumn 2012.

This report covers the results from Phase 1 – post construction testing.

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[16] GHA Monitoring Programme 2009 – Phase 0: Summary findings, methodology and next steps. GHA May 2009.

3.2 Test methodologies employed

This phase of monitoring focused on the heat loss performance of each dwelling, in order to understand the performance of the building fabric and to set a baseline before any further in-use monitoring was undertaken. Co-heating tests, air tightness tests thermal imaging were therefore employed on each site, along with heat flux tests where possible.

3.2.1 Co-heating tests

In order to enable the co-heating tests to be undertaken simultaneously across the sites, they were carried out by three separate testing teams. Each team was responsible for undertaking the co-heating test within their own geographical area. The teams involved were as follows;

- Leeds Metropolitan University.
- University College London.
- Oxford Brookes University.

To ensure consistency in approach, all of the co-heating tests were undertaken in accordance with a Co-heating Test Protocol developed by Leeds Metropolitan University[13]. The Test Protocol details the testing and monitoring equipment required, and the test procedures involved. In addition, Leeds Metropolitan University acted as the lead testing organisation to provide advice and assistance to the other testing teams.

3.2.2 Heat flux measurements

In three of the co-heating tests, heat flux sensors were installed within the dwellings in order to measure direct heat flow through various elements of the building fabric

3.2.3 Thermal imaging

Thermal imaging was undertaken on each test dwelling, with any anomalies noted and images recorded. On most sites, the infra-red thermal imaging camera was used to identify air leakage paths for further investigation with a smoke pencil. It is beyond the remit of this report to discuss the results from the thermal imaging of the individual dwellings, but they are available from the individual co-heating test reports.

3.3 Details of the test properties

All results are presented in anonymised form i.e. dwelling 1,2, 3, and 4. The dwelling numbers are presented consistently throughout the report (i.e. dwelling 4 is always dwelling 4), but dwelling numbers do not correlate to the order in which the properties are listed below (i.e. results for dwelling 3 could apply to any of the test properties A to D listed below).

3.3.1 Test property A

A 3 bedroom, 2½ storey detached dwelling, built to CSH level 4, constructed using a thin joint masonry cavity wall system. The external walls were parged internally and then dry-lined with plasterboard on dabs. The ground floor comprised a suspended concrete slab with insulation placed below the slab, and the upper floors were constructed using timber I-beams. The roof is of a tiled pitched design and the windows are double glazed, argon filled units with one low-e coating and a warm edge spacer. The house is being evaluated as part of a proposed low carbon housing scheme. The results of the evaluation are intended to inform the development of the remainder of the scheme, which is expected to comprise a large number of dwellings, built in a number of phases by various developers.

3.3.2 Test property B

A one bedroom apartment, forming part of a development of 172 apartments with an ‘EcoHomesExcellent’ Post Construction Review rating. The mixed use development is arranged in two blocks of 9 and 11 storeys, and includes community and commercial space. The apartment was constructed using a concrete frame, in-filled with a single skin of 240mm thick aerated clay blocks, and clad externally with 100mm wood fibre board and render.

3.3.3 Test Property C

A four bedroom, 2 storey detached property, forming part of a small development of 6 dwellings (5 new build and one refurbishment) that was designed to meet Level 5 of the Code for Sustainable Homes. The dwelling was constructed using a 175 x 50mm timber frame that was filled with recycled paper insulation, had an outer layer of wood fibre board and was clad externally in either softwood or lime render. The walls are dry-lined internally with plasterboard on battens. The ground floor comprised a reinforced concrete slab on ground construction with insulation placed below the slab, and the upper floor was constructed using timber I-beams. The roof is of a mono-pitched timber I-beam design and is covered in a waterproof membrane. The windows are triple glazed, argon filled units.

3.3.4 Test Property D

A 3 bedroom, 2½ storey detached dwelling, built to CSH level 4 constructed using a timber-frame structurally insulated panel (SIP) system that was clad externally in brick. The external walls are dry-lined internally with plasterboard on battens, creating an internal service void between the timber-frame and the plasterboard. The ground floor comprised a suspended concrete slab with insulation placed below the slab, and the upper floors were constructed using timber I-beams. The roof is of a tiled pitched design and the windows are double glazed, argon filled units with one low-e coating and a warm edge spacer.

3.4 Date and duration of the co-heating tests

All of the co-heating tests were undertaken between January and April 2010. The precise date and duration of each of the tests varied and is summarised in Table 1 below. The duration of the test is the total time taken to undertake the co-heating test, which includes the setting up and removal of the test equipment.

Table 1. Duration of co-heating testing of properties tested as part of the GHA New build monitoring project.

Test Property	Test period	Test duration
Dwelling 1	4th January to 4th February 2010 inclusive	32 days
Dwelling 2	4th January to 4th February 2010 inclusive	32 days
Dwelling 3	15th March to 1st April 2010 inclusive	18 days
Dwelling 4	11th March to 7th April 2010 inclusive	28 days

SECTION 4 – Performance of the test dwellings

4.1 Predicted performance of the tested properties

The predicted fabric and ventilation heat loss and the whole house heat loss for each of the four test properties was obtained from each of the house builders and is detailed in Table 2 and shown in Figure 5 below.

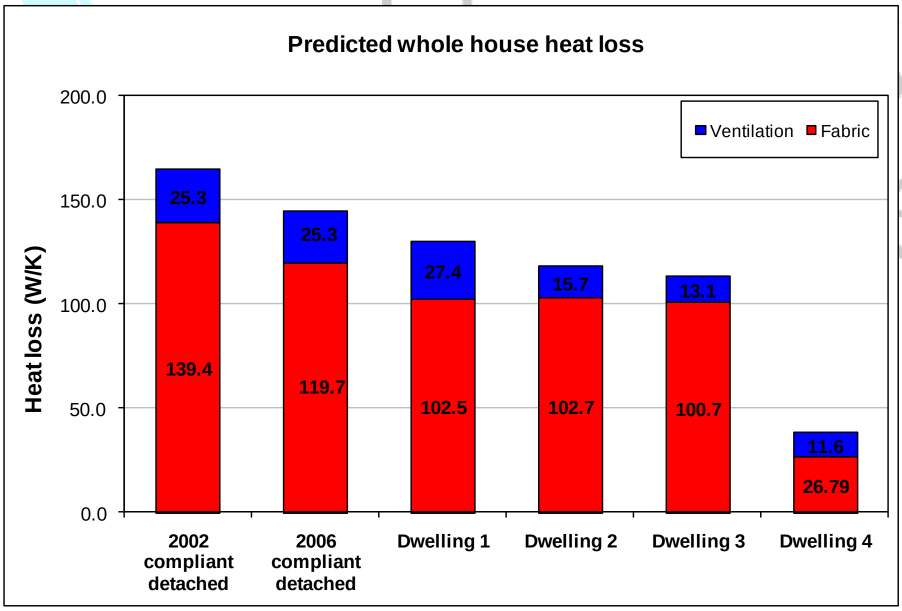
Table 2. Predicted whole house heat loss of the tested dwellings.

Test Property	Predicted Fabric heat loss (W/K)	Predicted Ventilation heat loss (W/K)*	Predicted whole house heat loss (W/K)
Dwelling 1	102.5	27.4	129.9
Dwelling 2	102.7	15.7	118.4
Dwelling 3	100.7	11.1	111.8
Dwelling 4	26.8	11.0	37.8

* Note – this is the heat loss arising from uncontrolled ventilation

The predicted fabric heat loss values, in table 2 were taken from the SAP worksheet supplied by the house builders. The predicted ventilation heat loss figure is actually calculated from the pressurisation tests used during the monitoring process, as it cannot be predicted using SAP. The predicted ventilation heat loss is then added to the predicted fabric heat loss to obtain a predicted whole house heat loss.

Figure 5 – Predicted whole house heat loss of the test dwellings compared to building regulatory requirements[17].



Note: results for 2002 and 2006 compliant properties are based on SAP calculations using a 2 storey detached house with Gross Floor Area of 105m^2.

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[17] Ridley, I. (2010). Private report to Good Homes Alliance

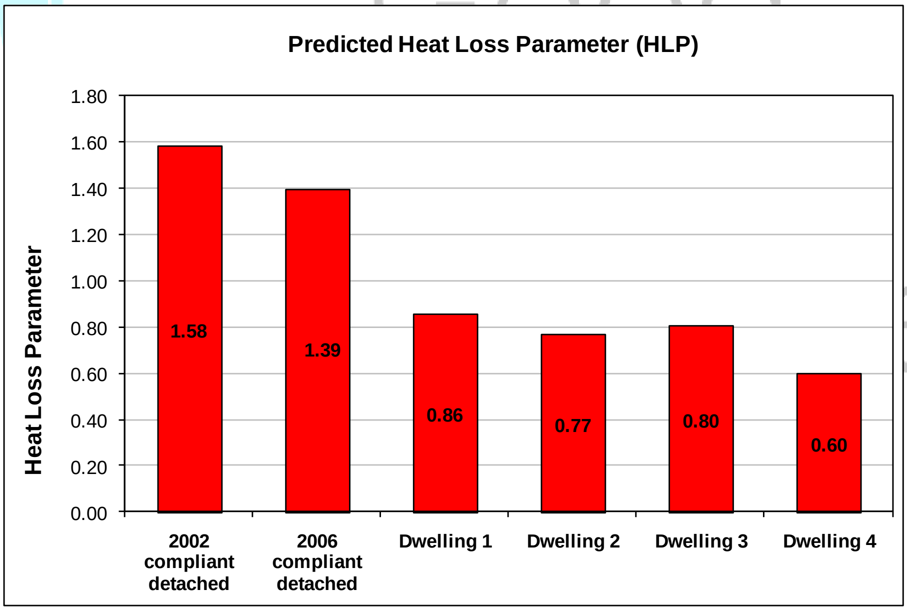
All of the dwellings tested were designed to achieve a whole dwelling heat loss significantly better than the requirements of the 2006 Part L1A building regulations, which were current at the time of testing (see figure 5 above). The heat loss design target for each dwelling was different, as they were built to different standards (for instance Code for Sustainable Homes Level 4 or Level 5).

Obviously, the predicted whole house heat loss figures vary significantly; this is partly because they were built to different standards, but also because they are of different sizes; a larger dwelling built to the same standard as a smaller one is, on balance, likely to have a higher whole dwelling heat loss.

In order to be able to compare the results from one test property to another, the predicted whole dwelling heat loss has therefore been normalised by gross floor area to obtain the Heat Loss Parameter (HLP) for each of the tested properties. The HLP is the total fabric and ventilation heat losses from the dwelling divided by the total floor area (W/m^{2}K).

It is important to note that the size of a dwelling and its built form has an effect on heat loss from homes, for instance it would be expected that an apartment would have a higher level of heat loss than an attached dwelling as an apartment has a higher surface area to volume ratio.

Figure 6 - Predicted heat loss parameter for each of the tested properties compared to building regulation compliance[18].



Note: results for 2002 and 2006 compliant properties are based on SAP calculations using a 2 storey detached house with Gross Floor Area of 105m^2

Again, each of the dwellings was designed to achieve a heat loss parameter significantly better than the requirements of the 2006 Part L1A building regulations (see Figure 6 above). Indeed their design targets were similar to or

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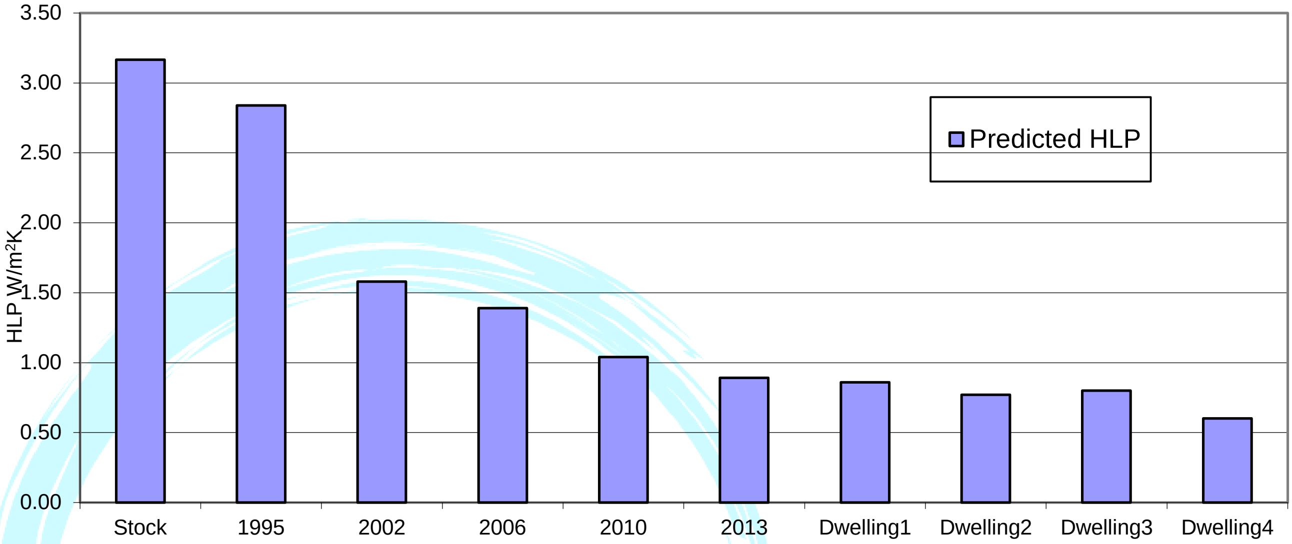
[18] Johnston, D (2011), Private report to Good Homes Alliance.

better than the targets that are considered likely for implementation in the 2013 version of Part L1A of the Building Regulations (see figure 7 below). All the properties were therefore adopting very ambitious targets of extremely low levels of whole house heat loss.

Figure 7 – Heat loss parameter of GHA-tested dwellings compared to the average heat loss parameter of stock and past, present and future building regulatory requirements[7]



4.2 Measured performance

A comparison between the measured whole house heat loss (obtained from the individual co-heating tests) and the predicted whole house heat loss of all of the dwellings tested is detailed in Tables 3 and 4 and illustrated in Figure 8 below.

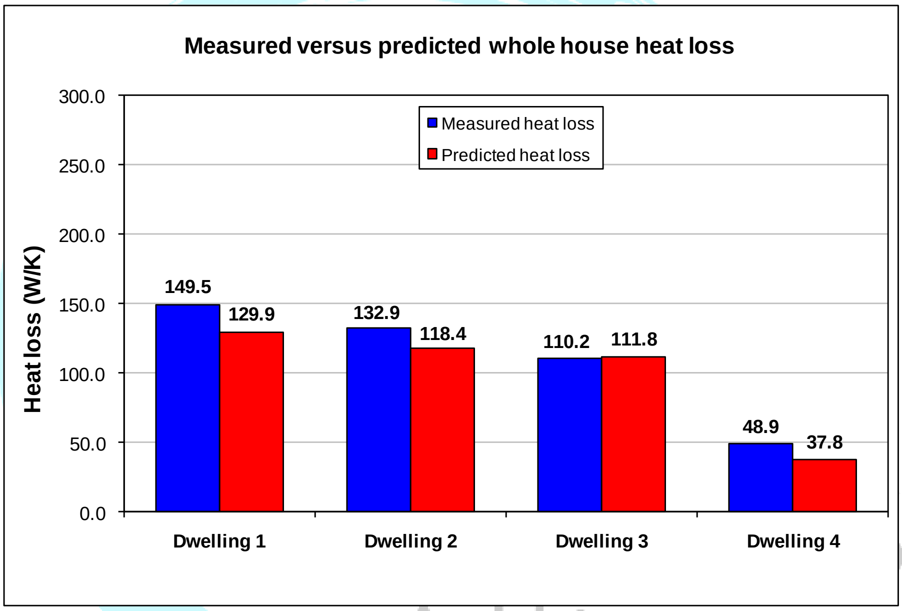
Table 3. Measured versus predicted fabric and ventilation heat loss [Johnston, D., 2011[18]].

Test Property	Predicted fabric heat loss(W/K)	Predicted ventilation heat loss (W/K)	Measured fabric heat loss (W/K)	Measured ventilation heat loss
Dwelling 1	102.5	27.4	122.1	27.4
Dwelling 2	102.7	15.7	117.2	15.7
Dwelling 3	100.7	11.1	99.1	11.1
Dwelling 4	26.8	11.0	37.9	11.0

Table 4. Measured versus predicted whole dwelling heat loss of the tested dwellings, [Johnston, D., 2011[18]]

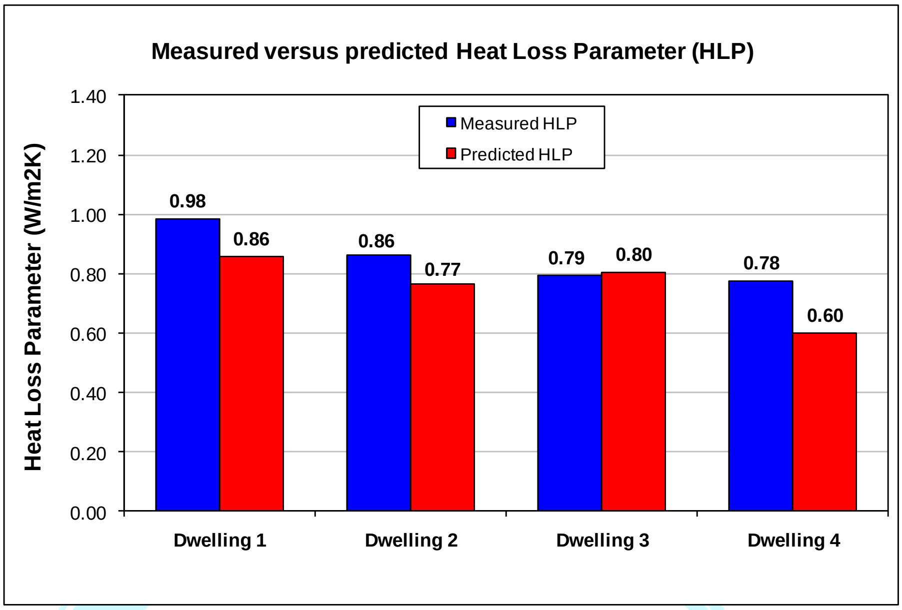
Test Property	Predicted whole dwelling heat loss (W/K)	Measured whole dwelling heat loss (W/K)	Absolute difference (W/K)	Variation (%)
Dwelling 1	129.9	149.5	19.6	+15.
Dwelling 2	118.4	132.9	4.5	+12
Dwelling 3	111.8	110.2	-1.6	-1
Dwelling 4	37.8	48.9	11.1	+29

Figure 8 - A comparison between the measured whole house heat loss and the predicted whole house heat loss of the GHA-tested dwellings [Johnston, D., 2011[18]]



Whole house heat loss is very dependent on dwelling size and built form, as described previously, so comparison of the heat loss parameter for each dwelling is more useful, see figure 9 below. This illustrates that the test properties tested varied considerably in terms of their predicted and measured heat loss parameter.

Figure 9. Measured versus predicted Heat Loss Parameter for the GHA-tested dwellings. [Johnston, D., 2011[18]].

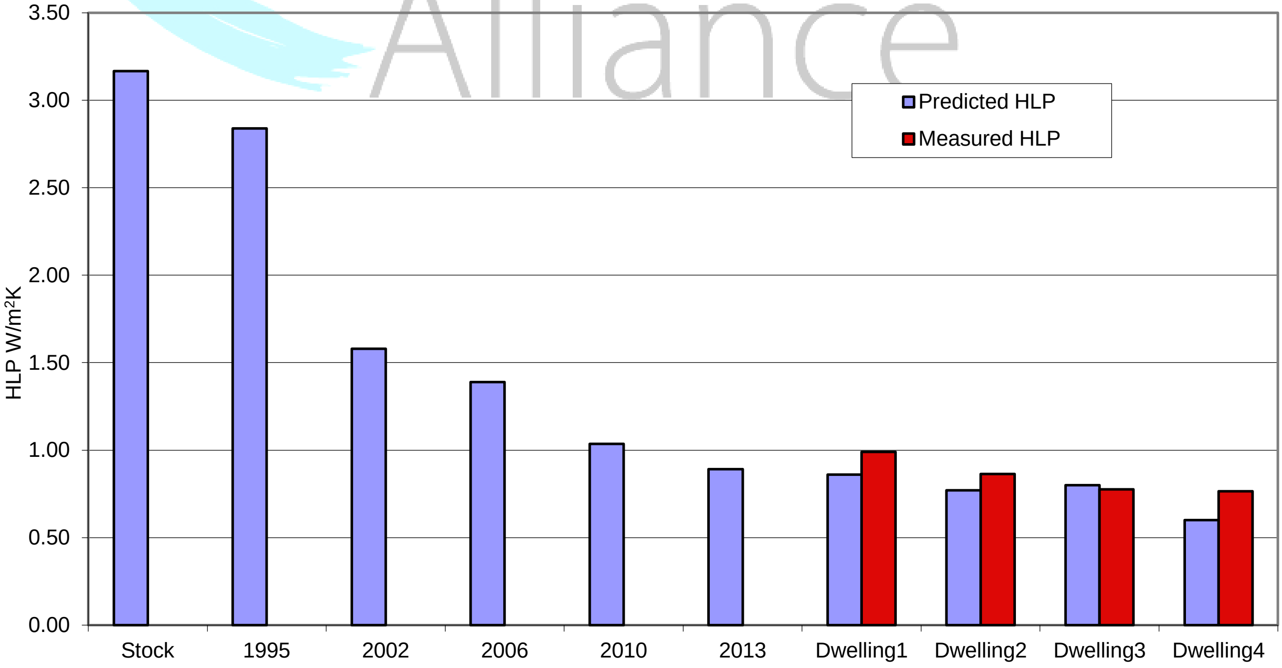


4.3 Analysis of the results

4.3.1 Measured performance in relation to Building Regulations

The results of the measured fabric performance of the test properties are favourable in comparison to the heat loss parameter for a notional semi-detached dwelling that complies with Building Regulations Part L1A 2006(see figure 10 below).

Figure 10. Measured heat loss parameter of the GHA test properties, compared to the stock, past, present and predicted building regulatory requirements. [Ridley, I., 2011[17]].



It is worth noting that each dwelling should be expected to perform better than the Building Regulations Part L1A 2010 target, as each was designed to a lower target than that in the first place. However, given the poor performance evidenced in other research (see section 4.3.4), the success of these schemes should still be celebrated.

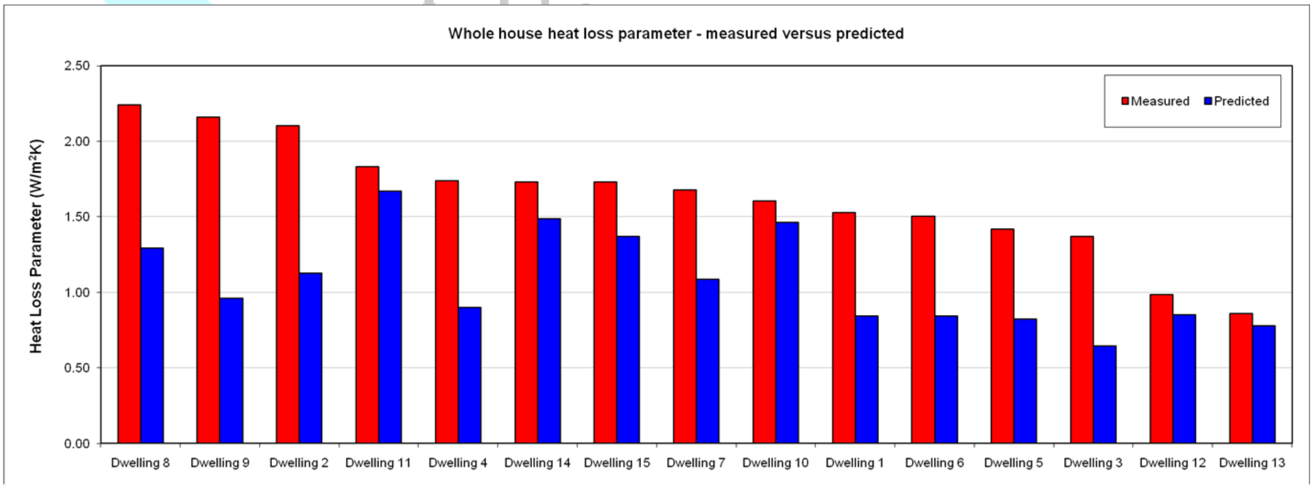
4.3.2 Comparison of measured and predicted performance

Analysis of the data (see table 4 above) illustrates that there is still a performance gap between the measured and predicted whole house heat loss for almost all of the dwellings, with the size of the gap varying considerably, from -1% for test dwelling 3 to + 29% for test dwelling 4.

It is important to note that the predicted heat loss for these dwellings was already fairly small, particularly for dwelling 4, so the percentage gap between measured and predicted heat loss is actually a small number in absolute terms. Any performance gap identified between predicted and actual performance, is also dependent on the assumptions and accuracy of the predictions as well as the measured actual performance. Inappropriate design assumptions used in performance prediction modelling could result in overly optimistic or pessimistic predictions, and so in turn influence a performance gap.

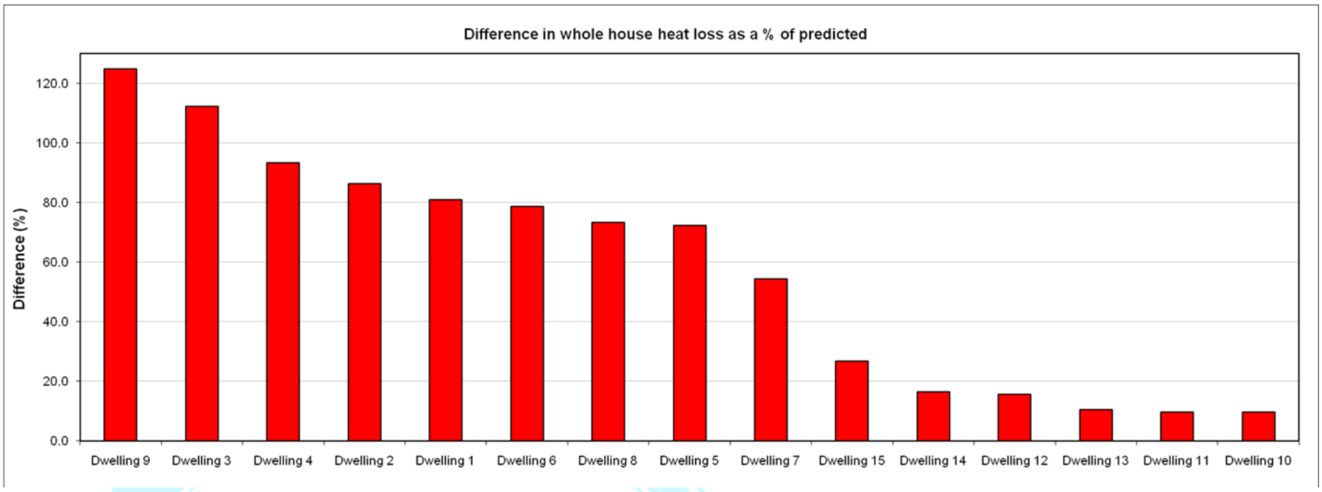
The results from the 4 test properties are in line with research carried out by Bell et al[7], (See figure 11 below). In their sample of 16 new homes built to various standards, (including EcoHomes, building regulations and the Code for Sustainable Homes), they found that that there was a gap between predicted and measured heat loss in the sample of homes they tested.

Figure 11. Difference in Whole House Heat loss, measured versus predicted[7].



However it is important to recognise that the percentage difference between predicted and measured performance of the GHA-tested homes was very good, i.e. low, when compared to the performance of the vast majority of the homes tested by others. All of the GHA-tested homes had a gap between predicted and measured heat loss of less than 30%, whereas Bell et al reported that the gap between predicted and measured heat loss of the homes they tested can be over 100% (see figure 12).

Figure 12. Difference in Whole House Heat loss as a % of predicted.[7]



Note that the dwellings in figures 11 and 12 relate to those tested by others and do not show the results of the GHA-tested homes.

4.3.3 Placing these results in context

In order to understand the relative performance of these properties, the predicted and measured Heat Loss Parameter can be translated into an average predicted and measured U value (see table 5 below).

Table 5. Predicted mean U value compared to the measured mean U value of the GHA test dwellings [Ridley, I. 2011[17]]

Test Property	Predicted Mean U Value (W/m^{2}K)	Measured Mean U Value (W/m^{2}K)	Comparison with Part L1A 2002 Mean target U Value (W/m^{2}K)	Comparison with Part L1A 2006 Mean target U Value (W/m^{2}K)
Dwelling 1	0.30	0.36	0.57	0.49
Dwelling 2	0.29	0.33	0.57	0.49
Dwelling 3	0.31	0.30	0.57	0.49
Dwelling 4	0.50	0.71	1.07	0.95

Note calculations based on 2 Storey detached house with Gross Floor Area of 105m^2 or a mid floor flat with Gross Floor Area of 66 m^2 as appropriate.

Again, these figures show that each of the dwellings achieved a measured, as-built mean U value better than the Part L1A 2006 mean target U value. Three of the test dwellings achieved a measured, as-built mean U value of 0.3 to 0.36 W/m^{2}K, which is a very promising fabric energy efficiency performance.

4.3.4 The gap between measured and predicted performance

There are numerous potential reasons for the gap found between measured and predicted performance. This could be down to problems with the building fabric, such as a thermal bypass or thermal bridging, or it could be down to ventilation heat loss. The team at Leeds Metropolitan University have identified several examples of common heat loss problems[6], including:

- insulation missing at door base, lintels, or junctions
- thermal bridges where internal structural joists are connected with external fabric or where frames are connected for balconies or the roof
- air leakage through penetrations and around windows and doors

In addition, some of the gap in performance could be due to the tests themselves. Current fabric testing methodologies are still at an early stage of development and there are therefore various degrees of uncertainty attached to each of the test results. In particular, the co-heating test had never been used before in the UK to test the whole house heat loss from an apartment.

Further details of the test methodologies and degree of accuracy of the measurements may be available from each developer or testing team on request, although releasing these results is solely down to the discretion of each developer.

In order to identify the cause of any discrepancy between measured and predicted performance, further testing and examination of design details and construction approaches must be undertaken; this would be extremely valuable as a diagnostic and testing tool to assess the performance of new designs, materials, technologies or construction methodologies. However, such further examination was beyond the scope of this project.

Also it is critical to note that assumptions in the modelling can equally lead to a gap between predicted and actual performance.

SECTION 5 - Commentary on the monitoring

5.1 The usefulness of post-construction tests to house-builders

The post-construction testing proved to be a very useful diagnostic tool for the house builders by assisting them to independently verify the performance of their dwellings. The results are particularly useful for:

1. Enabling house builders to identify and highlight detailing and/or construction issues that may exist in their test properties to then be addressed in later units and phases of their respective developments;
2. Identifying potential reasons for the difference between design targets and achieved performance, which can then be investigated and resolved through further testing;
3. Passing information back into house-builder's internal feedback loops for design and construction processes, to drive improved control and tolerance factors that will make their design fabric performance targets more achievable and future home designs better;
4. Helping the house-builders to understand how their dwellings can comply with current regulations and standards and those planned for the future, such as the Fabric Energy Efficiency Standard[19].
5. Providing actual performance data which they can use to inform the future operation and management of their homes. This is of particular relevance where the homes in question benefit from connection to renewable energy generation infrastructure and/or communal energy systems.

There were some limitations in the post-construction testing undertaken as part of this study, mainly due to financial and time limitations:

- The post-construction tests were only used to measure the as-built performance of the test properties. The teams did not then undertake further testing to determine the causes of any discrepancies or gaps against predicted performance. Such further (diagnostic) investigation could be very useful in testing the use of new materials or build systems, particularly when house-builders are trialling or piloting prototype dwellings that aim to meet a new energy target.
- The sample size was very small, so no significant conclusions could be drawn about the performance of particular house types, construction methods or procurement arrangements. This problem should be addressed as the number of properties tested increases, by the GHA Monitoring Programme participants and others.

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[19] Zero Carbon Hub (November 2009). Defining A Fabric Energy Efficiency Standard For Zero Carbon Homes. Task Group Recommendations.

5.2 Encouraging behaviour change amongst house builders

The house builders who participated in the GHA monitoring programme were all members of the Good Homes Alliance and are therefore committed to building sustainable homes with very good energy performance and hence very low fabric heat loss. They were all also aware of the typical performance gap between designed and as-built fabric heat loss that had been identified elsewhere, and recognised that they would benefit from undertaking monitoring of their test dwellings. However, like most of the industry, they were unfamiliar with the methods employed for carrying out post-construction tests on their dwellings.

A key issue for both the testing teams and the house builders was therefore to ensure that everybody involved with the construction of their test homes, including the contractor, subcontractors, suppliers and others were ‘on board’ with the testing procedures and were fully briefed by the testing teams on both the co-heating procedure and issues that can cause heat loss, such as thermal bridging. Each house-builder ran a presentation about the co-heating test, which allowed people to see exactly what was involved in the testing, because the equipment used was still in place and on show.

Each house builder has needed to develop a good communication strategy, to consider how the results from the co-heating test could feedback into their supply chains and their respective design and construction processes. This work has only just started and is likely to continue for several years, as house-builders continue their learning journey to delivering very low-energy homes in reality.

For the wider industry, there is still a lack of awareness about the performance gap identified by Wingfield et al and the implications that this can have for the integrity of the building fabric and dwelling energy consumption. As a result, there seems to be little enthusiasm to undertake post-construction fabric testing until there is some incentive or requirement to do so.

Furthermore, although house builders are becoming more familiar with regulatory compliance tests, such as air tightness testing, they are relatively unfamiliar with the use of a co-heating tests and thermal imaging and how these tests can help to identify problems with the fabric of homes and how they can be used as a method of evidencing performance.

A process of education and awareness-raising, around the performance gap and the likely causes and issues associated with fabric heat loss, and also around the benefits of and methodologies for carrying out post-construction testing, is therefore probably required to encourage behaviour change in house builders and the wider industry.

Even then, testing itself will not improve the performance of new homes unless the lessons learnt from carrying out post-construction tests are fed back into design and construction processes. This will require house-builders to look at their learning processes and develop a feedback loop than ensures their development team take account of these lessons for future housing projects.

5.3 Development of post-construction testing

5.3.1 Comments by the house-builders

It proved quite difficult for the house builders to identify and secure suitable homes for testing in terms of both programme management and justifying to their sales teams that homes should be effectively taken out of the sales process for four weeks or more. To be suitable for wider uptake, the test period would need to be shortened; four weeks is too long for most sites and house builders, as they need to recoup their costs by making properties available for sale or occupation as soon as possible after completion.

There are also some specific problems with co-heating tests. These can only be carried out during the colder months of the heating season and house builders need to allow a suitable lead-in time for securing a property, otherwise the tests may drift towards the end of the heating season, when the co-heating tests are likely to be less accurate. This could be problematic, especially for smaller developers and for development schemes which are nearing completion during the summer months.

For projects completed in the warmer months, it would be very difficult if not impossible for a house builder to keep a test home back until the colder weather. In thinking about mainstreaming testing, this seasonal element needs addressing, either through specially developed research methodologies or through forward planning.

Although the test methods utilised in the GHA Monitoring Programme have been in use in limited circles for several decades, they are still in their relative infancy and so can be considered as currently sub-optimal and requiring refinement through further research, development and application.

One of the house-builders involved in the Monitoring Programme suggested that there would be benefit in exploring development of a simplified test which had the target to provide 80% of the accuracy/results with only 20% of the commitment and complexity in terms of time, resources and cost.

Such a simplified test could be focussed on providing a lower cost building performance testing and verification solution. This could be developed as part of a quality assurance or compliance-related testing regime that could be used on a broader sample of buildings. The more detailed and forensic testing approach undertaken here, particularly when coupled with further investigation of any discrepancies, could then be retained to help increase understanding of trial/pilot and prototype schemes.

5.3.2 Lessons learnt by the research teams

The co-heating test is still a relatively young and evolving methodology and is still being refined as the number of tests being undertaken increases. It proved difficult to completely standardise the approaches taken by the three different research teams involved in this programme, even though significant steps were taken to try to harmonise the approaches – for example the Leeds Metropolitan University team providing initial training and mentored the other two research teams through the process.

Robust and detailed research protocols and procedures are essential so that the same standards are adopted by different testing organisations and/or research teams when carrying out testing. It is also essential to standardise the equipment specifications and calibration used to ensure accurate and comparable results. The methodologies and equipment used therefore need further development to ensure robust and standardised approaches across the industry.

Successful testing of apartments had not previously been undertaken in the UK and raises a significant number of specific challenges, for example due to the large number of party surfaces. To address the issues around the complexity of party surfaces, there may need to be equipment in neighbouring properties and in communal corridors, which poses problems in terms of consents, access, safety and security and would require a lot more equipment (such as heat flux sensors), which would mean more costs. A robust and simple test methodology for apartments therefore needs to be developed for more widespread application.

Careful consideration should be given to the duration of the co-heating test. In particular, dwellings with a high thermal mass will require a longer heat-up phase and hence a longer testing period than those of a low thermal mass, which may have additional planning and cost implications for the house builder. Similarly, testing teams need to pay attention to the time lapsed since completion of the construction phase, as this can affect moisture levels and drying-out of the building materials.

Finally, research teams need to be fully aware of the highly contingent nature of co-heating testing, which relies on a high number of factors falling into place: weather, timing, availability of property, house builder requirements, equipment requirements. Risk and contingency planning is essential to minimise project failure.

5.3.3 The costs of post-construction testing

The costs associated with undertaking the test methodologies adopted in this study were significant – of the order of £30- 50,000 per dwelling - and required considerable grant funding to enable them to take place. Moving forwards, if the intention is to make the testing more acceptable and appealing for wider application on a greater sample of buildings, it will be essential that such costs are reduced. Alternatively, it may be that the rigorous, detailed testing methodology adopted in this study is appropriate for pilot/ prototype testing, and that a lower-cost test should be developed for quality assurance and compliance-testing purposes.

The equipment used in the testing is numerous and expensive. From the research team's perspective there could never be enough sensors and meters deployed. The costs of such equipment may come down in the future due to supply chain efficiencies arising from technological advancement and the fact that more people may be ordering (purchasing or hiring) it.

The amount of skilled staff time is also significant. This includes designing the appropriate testing solution bespoke to the subject building, installing and then subsequently removing the equipment, as well as the time taken to gather, verified and analyse measured data.

These issues will have to be explored and solutions found, wherever possible as the co-heating testing methodology develops. During this study, a number of commercial organisations, including Gastec, BSRIA, Stroma and NBT Consult have started to develop a co-heating testing service starting from around £5,000 per unit tested. However, it is unclear what exactly is included in their methodologies and analysis; further examination of their approaches will be needed, to develop and finalise a protocol that can be used as standard across the whole industry.

5.3.4 The degree of certainty in the results of this study

A number of important issues were identified during the co-heating tests which are likely to have had an influence on the results obtained, including the fact that the co-heating tests for properties 3 and 4 were undertaken towards the end of the testing season. This can potentially make the results more susceptible to the effects of solar radiation, and make it more difficult to maintain and control an adequate temperature difference between the inside and the outside of the dwelling, which may result in uneven temperatures throughout the dwelling which in turn can result in uneven heat flow through the fabric.

Furthermore, as has been noted previously, any discrepancy reported between predicted and actual performance, is dependent on the assumptions and accuracy of the predictions as well as the measured actual performance. Inappropriate design assumptions used in performance prediction modelling could result in overly optimistic or pessimistic predictions, and so in turn affect perceptions of actual measured performance. Attempts have been made to normalise these predictions in this study, by adapting the SAP calculations undertaken for each dwelling; however, it must be recognised that there has not been one standard approach for calculating predicted heat loss for each dwelling.

And finally, interpretation of the measured results involves extrapolation and analysis that inevitably involves some complicating factors. We have not included here any details of the regression analysis, standard deviation, error bars and other details of the performance measurements for each dwelling. These results may be available from each developer and/or testing organisation, although this is solely at the discretion of each developer.

5.3.5 Commercial development of post-construction testing

During the period of this study, a co-heating test was carried out independently by NBT Consult as a commercial offering on ‘The Natural House’ at the BRE Innovation Park (Trinick, J. (2010)[20]). The methodology and results were examined by the Leeds Metropolitan University team and analysis of the test showed a number of discrepancies in the methodology and effectiveness of the testing, particularly in terms of the timing of the test during the construction cycle, (for instance the external walls were sheltered from the elements by plastic sheeting).

Also during this study, a number of commercial organisations, including Gastec, BSRIA, Stroma and NBT Consult have started to develop a co-heating testing service. The Technology Strategy Board have also specified that a form of co-heating test and/or heat flux measurements must be undertaken on dwellings tested as part of their Building Performance Evaluation programme[21]. If all these parties could be persuaded to work together, a protocol could be developed for use as standard across the whole industry.

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[20] Trinick, J., NBT Consult on behalf The Prince’s Trust (May 2010) Co-heating report – The Natural House, BRE Innovation Park. Unpublished, confidential report.

[21] Technology Strategy Board (September, 2010), Building Performance Evaluation, Domestic Buildings – Guidance for Project Execution

SECTION 6 - Conclusions and recommendations

6.1 Conclusions

Four test properties underwent co-heating testing as part of the GHA Monitoring Programme. The test properties comprised three detached dwellings and an apartment. All of these dwellings varied in terms of their size, built form and construction technique.

For each dwelling, the whole-house heat loss was measured post-construction using a co-heating test. This measured performance was then compared with the relevant building regulations requirements. In each case, the test properties achieved a measured, as-built heat loss performance significantly better than the contemporary Building Regulations requirement and also exceeded anticipated performance levels for homes built to 2013 standards. This was perhaps not entirely surprising as the builders of each of the test properties had a stated objective to design and deliver a sustainable and low energy home. It does, however show that it is possible to design, construct and deliver sustainable homes that achieve very low levels of heat loss in reality.

The measured whole-house heat loss was also compared with the predicted heat loss for each dwelling. The results indicated that the measured performance exceeded the predicted performance in all but one of the test properties, but the size of this performance gap was very good when compared to the performance of the vast majority of the homes tested by Wingfield et al[6].

This study shows that it is possible to design, construct and deliver sustainable homes that achieve very low levels of heat loss (better than Building Regulation requirements), which will assist in reducing the energy demand of these dwellings and hence their carbon emissions. This does not guarantee that the overall energy used in each dwelling will be as low as predicted, because user behaviour, performance of the services and commissioning will all have an impact on the energy used in the home. It does mean that energy needed to meet heat losses can be reduced!

However, even the test homes, which were designed and constructed with great attention to detail to achieve low levels of heat loss, had a small gap between predicted and measured fabric performance. The gap in performance highlights the need for the industry and the regulators to develop better energy modelling and prediction tools and the need for post-construction testing to help to evidence minimum regulatory compliance in order to deliver homes with lower levels of heat loss in reality.

Given the small sample size, we were unable to draw useful conclusions from the research about the effectiveness of different build systems beyond the results obtained from each site. To provide definitive information about the effectiveness of different build types in meeting targets would require further testing across a wide range of projects using each build system. However, this project provides a useful first step that will contribute to a broader programme of testing results being undertaken by the GHA and others.

6.2 Implications and recommendations for industry

Previous research by Wingfield et al[5] at Elm Tree Mews provides evidence that a performance gap exists between as-built and designed fabric performance; this research has similar findings, albeit with a smaller performance gap than that for most other dwellings. The industry will need to address the performance gap at some point, either because of regulatory/ compliance requirements, or because fear of potential liabilities will drive behaviour change.

To close the performance gap, house-builders will need to measure the as-built performance of their dwellings, evaluate the results and then feed this information back to their development teams, including their supply chains. Housing professionals will also need to improve their modelling predictions for the fabric, energy efficiency and carbon emission performance of new build homes, such that they reflect the reality of as-built performance.

The GHA recommends that the industry is encouraged to undertake post-construction fabric heat loss testing of a sample of all new homes built, alongside air-tightness testing; this should be mandatory when building to a new standard or using a new build system for larger developments. Air-tightness testing alone is not sufficient to generate this information, as it only measures the air leakage of the dwelling, it does not measure heat loss through the fabric.

The GHA also recommends that the housing industry be encouraged and incentivised to develop a feedback mechanism to ensure that the results of their post construction testing inform the future design and construction decisions for house builders and their supply chains. If this feedback enables future designs to have a lower level of heat loss then this will reduce the need for heat energy in new homes, helping to promote energy efficiency and mitigate carbon emissions from new homes.

6.3 Implications and recommendations for Government

If the Government is to meet its energy efficiency and carbon reduction targets set for 2016 and beyond, then it is vital that more evidence is gathered about the performance of new homes. This should then feed into the development of better modelling, standards, policy and regulatory compliance around achieving better as-built performance. The GHA therefore recommends that house-builders should be encouraged and incentivised to gather evidence about the fabric performance of their homes. The GHA also recommends that the lessons learnt from post construction testing are fed into regulatory modelling and prediction tools such as SAP.

The GHA recommends that further dwellings, covering a greater range of dwellings types and build systems, should be subject to post-construction testing in order to build a representative sample of homes across the UK and to provide the evidence base of as-built performance. The results of post construction testing should be shared with the wider housing and construction industry in order to identify and help address common design and build problems encountered in the move towards 2016 zero carbon targets. This may require additional streams of government funding to assist with the research.

The GHA also recommends that further research be commissioned into whether two levels of co-heating testing could be developed: one which could be a simpler, less time-consuming exercise that would enable wider application of testing to provide benchmarks and is suitable for quality assurance; and a second tier of more detailed and forensic testing to be used on pilot or prototype homes.

The GHA recommends that the Government should work with industry and stakeholders to develop a national feedback and learning programme to help close the performance gap between design and as-built heat loss. Such a programme should include:

- education and training - for instance around identifying and solving areas of heat loss
- research and development - for instance about how to achieve good levels of as-built performance
- a process change programme - for instance through pilot studies

The GHA recommends that further research should be undertaken into developing the co-heating test methodologies, for example their application in apartments, so that consistent co-heating testing protocols can be developed for widespread application across the industry at all times of the year.

Finally, the GHA recommends that standard methodologies that can be used at any time of year should be developed for post-construction testing. This should include a review of the different methodologies being proposed as commercial tests, with the aim of establishing a relatively easy and affordable test that doesn’t compromise the construction timescale or process.

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Glossary

Air tightness testing – Air tightness testing is the procedure to trace any unwanted drafts and uncontrolled airflow through a dwelling. Too much air leakage leads to heat loss resulting in higher CO_2 emissions

Area weighted average U Value – The average 'as designed for' rate of heat loss from the building fabric. It is calculated from the sum of each dwelling element's individual area multiplied by its corresponding u-value divided by the combined sum of all fabric u values.

Background ventilation Heat loss – In order to eliminate the natural background ventilation heat loss from a dwelling, (as this figure is needed to calculate the heat loss from the fabric) a background ventilation test is conducted immediately before and after a co-heating test. These tests are used to establish the amount of heat that is being lost due to natural background ventilation, and separate that heat loss from the fabric heat loss.

Building Fabric – The building fabric is a critical component of any building, since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, floor slabs, walls, windows, and doors, the fabric controls the flow of energy between the interior and exterior of a building.

Co-heating test – A co-heating test is a method of measuring the heat loss (both fabric and background ventilation) in W/K attributable to an unoccupied dwelling. It involves heating the inside of a dwelling electrically, using electric resistance point heaters, to an elevated mean internal temperature (typically 25°C) over a specified period of time, typically between 1 to 3 weeks. By measuring the amount of electrical energy that is required to maintain the elevated mean internal temperature each day, the daily heat input (in Watts) to the dwelling can be determined.

The main output is the heat loss coefficient as calculated in SAP (W/K). This can also be expressed as the heat transfer parameter in W/m^2K by dividing the result by the floor area of the building. It is a very good indicator as to how the total as-built fabric performs against predictions and takes into account build quality and thermal bridging.

CO_2 tracer decay method – Used to help eliminate the natural background ventilation heat loss during a co-heating test. a gas, usually CO_2 is dispensed into a sealed building once daily, and sensors around the dwelling measure the gas concentration over time to determine the amount of gas that has leaked out.

Fabric Heat Loss – Heat loss from a dwelling caused by thermal bridging and or thermal bypass.

Flanking/indirect air leakage path – Heat loss by means of thermal bridging around areas of insulated construction.

Heat flux Measurements – heat flux is the rate of heat energy transfer through a given surface, measured in W/m^2. Heat flux sensors allow measurement of direct heat flow through various elements of the building fabric.

Heat Loss Coefficient - The main output of a co-heating test is the heat loss coefficient as calculated in SAP (W/K). This can also be expressed as the heat transfer parameter in W/m^{2}K. The heat loss coefficient for the dwelling can be calculated by plotting the daily heat input against the daily difference in temperature between the inside and outside of the dwelling (ΔT). The resulting slope of the plot gives the heat loss coefficient in W/K.

Heat Loss Parameter - The building's specific heat loss co-efficient (in units of W/K) divided by the building's floor area (measured internally – i.e. within the thermal envelope). Units are W/m^{2}K. It is a very good indicator as to how the total as-built fabric performs against predictions and takes into account build quality and thermal bridging.

Infiltration - The drawing in of cold outside air into a dwelling through gaps in the walls, ground floor and ceiling, resulting in draughts.

Real Area Weighted Average U Value – The measured average rate of heat loss from the building fabric. It is calculated from the sum of each dwelling's elements individual area multiplied by its corresponding u-value divided by the combined sum of all fabric u values.

Standard Assessment Procedure (SAP) rating - The SAP rating is the 'Standard Assessment Procedure' which provides an indication of the overall energy efficiency of a dwelling. It is measured on a scale of 1-100 where the higher the number, the better the performance.

Thermal bridging – A thermally conductive material which penetrates or bypasses an insulation system; such as a wall tie, metal fastener, concrete beam, slab or column. Thermal bridging lowers the overall thermal insulation of the structure by creating areas where heat loss is greater in one area than it is for another. The effect is to reduce the overall u-value of the construction element. The heat loss per unit length of thermal bridge is known as the Ψ- (psi) value and is measure in W/mK.

Thermal Bypass – Heat transfer enabled by the uncontrolled air movement within and through walls. A recently identified example of thermal bypass occurs within cavity walls acting as separating walls (party walls) between adjoining houses or flats. Cavities in these instances are not normally insulated thus allowing warm air to enter the cavity and by means of convection to rise through the space and escape into an attic or through the roof covering.

Thermal Imaging – A non-invasive means of observing and diagnosing the condition of dwellings through temperature differentials. It can be used to check for high heat loss paths in dwellings. It can also assist in identifying building features that create thermal bridges, to check or prove insulation continuity, to find hidden leaks, and a source of damp in a dwelling. Thermal imaging can be used to evaluate and verify improvements and remedial works made to the fabric of dwellings subsequent to problems being diagnosed

U Value – A U value is the measure of rate of heat loss through a material, such as a wall, floor or roof. The higher the U value the more heat loss.

Whole House Heat Loss – A measure of heat loss from the building fabric and background ventilation. The whole house heat loss is very dependent on dwelling size, and built form, so comparison of the heat loss parameter for each dwelling is useful.