



CLOSING THE GAP BETWEEN
DESIGN



AS-BUILT
PERFORMANCE

Evidence Review Report

March 2014

APPENDICES



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APPENDIX 1

LITERATURE REVIEW

A Literature Review of existing research was undertaken as a key source of evidence for the Performance Gap project.

Evidence was sought to improve understanding of an initial list of potential issues identified by the Steering Group and Work Groups, and to expand this list where additional issues were found. The final list amounts to 55 issues, and is shown in Annex A of the Evidence Review Report.

Evidence Gathering

Evidence for the Literature Review was collected over a period of around nine months ending December 2013. Reports relating to the Performance Gap were gathered from a variety of sources:

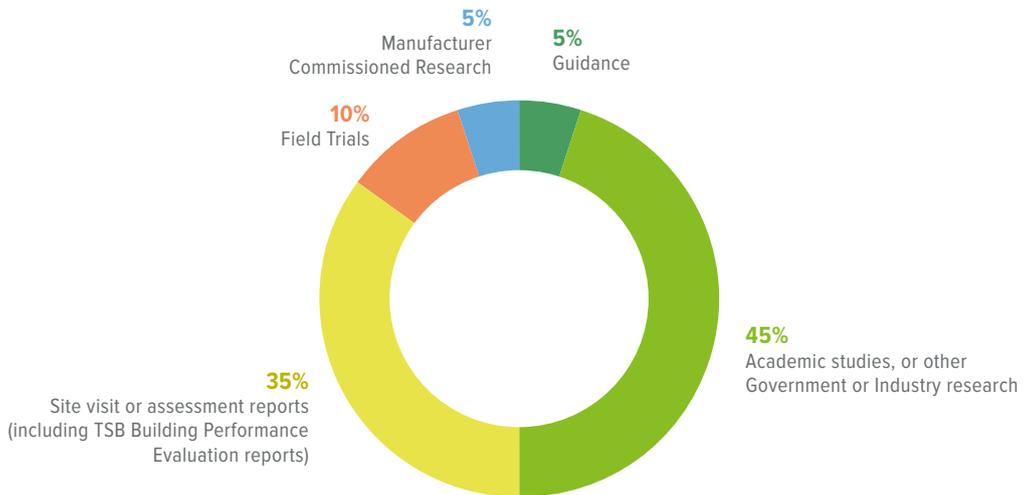
- Work Group members;
- Housebuilders, manufacturers or suppliers, in confidence;
- Universities, in response to a request for relevant information;
- The Technology Strategy Board, with access to the Domestic Building Performance Evaluation Phase 1 reports, given under a non-disclosure agreement;
- BRE catalogues; and
- Reference sections of other reports.

Reports were excluded from the Literature Review if they:

- Related to non-domestic buildings only;
- Related to retrofit of existing dwellings only;
- Related to dwellings outside of the UK;
- Provided guidance on issues only – with the exception of one or two reports which gave examples of issues that had been observed;
- Provided commentary on issues only – with the exception of one or two reports providing useful analysis of other work (for example, some previous work by the Zero Carbon Hub);
- Lacked relevant detail;
- Related to potential Performance Gap solutions rather than evidencing issues;
- Were considered outdated. A specific cut-off date was not set, but literature was ruled out where it might reasonably be expected that the practice or technology studied had moved on very significantly since the report was produced (for example, reports from the late 1980s and early 1990s on heat pumps and solar technologies).

A team of experienced construction professionals reviewed almost 100 reports, split as shown in the diagram below. A list of the non-confidential reports reviewed is provided on the following pages.

Breakdown of literature review report type



Evidence Analysis

The reports were reviewed against the list of potential Performance Gap issues, with sections of text or images which provided evidence being tagged against particular issues. This process was assisted by the use of the software programme NVivo, which aids qualitative analysis. At the end of the Literature Review, all of the evidence for each issue was checked by the evidence review team, and the number and type of sources referenced was recorded. The evidence gathered was then used to inform the rating of issues on the Impact-Evidence prioritisation matrix. The evidence relating to the priority issues is summarised in Section 3 of the Evidence Review Report.

Reports Reviewed

The non-confidential reports reviewed are listed below. In addition to this list, a further 26 confidential reports were reviewed, including reports provided by housebuilders, manufacturers and suppliers, as well as the Domestic Building Performance Evaluation Phase 1 reports provided by the Technology Strategy Board.

- AEA Technology for EEPH and EST, *Compliance with Part L1 of the 2002 Building Regulations (An investigation into the reasons for poor compliance)*, 2006
- AECOM for EEPH and DCLG, *Research into Compliance with Part L of the Building Regulations for New Homes - Phase 2 Main Report*, 2009
- AECOM and Building Sciences Ltd for DCLG, *Ventilation and Indoor Air Quality in Part F 2006 Homes*, 2011
- BBA, *Air Movement & Thermal Performance: An Investigation into the Effect of Air Movement on the Thermal Performance of Domestic Pitched Roof Constructions*, 2012
- Bell, M., Smith, M. and Miles-Shenton, D. (Leeds Metropolitan University for DCLG), *Condensation Risk – Impact of Improvements to Part L and Robust Details on Part C – Final Report*, 2005
- Bell, M. for DCLG, *Nominal vs. Realised Performance of Buildings: A Review of Evidence. Report to the Industry Advisory Group, Working Group 6, Review of the Building Regulations Part L 2010*, 2008
- Bell, M., Smith, M. and Miles-Shenton, D. (Leeds Metropolitan University for EURISOL), *Evaluation of the Party Wall Thermal Bypass in Masonry Dwellings*, 2009
- Bell, M., Wingfield, J., Miles-Shenton, D and Seavers, J. (Leeds Metropolitan University for the Joseph Rowntree Foundation), *Low Carbon Housing: Lessons from Elm Tree Mews*, 2010
- Blackwell, H., *Foiling the Great Escape*, CIBSE Journal, August 2013
- BRE, *Quality in Traditional Housing*, 1982
- BRE, *Site-applied Adhesives - Failures and How to Avoid Them*, 1986
- BRE, *Common Defects in Low-rise Traditional Housing*, 1988

- BRE, Eclipse Research Consultants, Cedar Design Systems and Middlesex Polytechnic, *BREDEM 8, A Monthly Calculation Method for Energy Use in Dwellings: Testing and Development*, 1991

- BRE and De Montfort University, *Testing BREDEM 8 Against Measured Consumption Data and Against Simulation Models*, 1994

- BRE for AEA, *Estimation of Actual Airtightness Based on Design and Workmanship Drawings - Methodology of Assessing Design Drawings*, 2001

- BRE, *DETR Framework Project Report: Field Investigations of the Thermal Performance of Construction Elements As Built*, 2001

- BRE for EEPH and EST, *Assessment of Energy Efficiency Impact of Buildings Regulations Compliance*, 2004

- BRE, *SmartLIFE - Lessons Learned*, 2008

- BRE, *Applying the Code for Sustainable Homes on the BRE Innovation Park*, 2008

- BRE, *DETR Framework Project Report: Thermal Transmittance of Walls of Dwellings Before and After Application of Cavity Wall Insulation*, 2008

- BRE, *A Meta-analysis of Boiler Test Efficiencies to Compare Independent and Manufacturers' Results: SAP 2009 Technical Paper*, 2009

- BRE, *SAP 2012 Default Values for Seasonal Performance Factor for Heat Pumps*, 2011

- BRE, *Lessons from AIMC4 for Cost-Effective, Fabric-First, Low-Energy Housing*, 2013

- BSRIA, *Domestic Ventilation Systems: A Guide to Measuring Airflow Rates*, 2013

- Building Economic Development Committee, *Achieving Quality on Building Sites*, 1987

- Build UP Skills, *United Kingdom Analysis of the Status Quo*, 2012

- Build UP Skills, *United Kingdom 2020 Skills Roadmap and Action Plan*, 2012

- Carbon Trust, *Micro-CHP Accelerator*, 2011

- CIC Start and Edinburgh Napier University, *The Gap Between Build and Design: Construction Compliance towards 2020 In Scotland*, 2012

- Day, A.R., Ogumka, P.I. and Jones, P.G. (London South Bank University), *Are the Targets Being Delivered? The London Plan Energy Policies in Practice*, 2010

- DECC, *Low Carbon Building Programme*, 2013

- DECC and EST, *Detailed Analysis from the First Phase of the Energy Saving Trust's Heat Pump Field Trial: Evidence to Support the Revision of the MCS Installer Standard: MIS 3005 Issue 3.1*, 2012

- DECC and EST, *Detailed Analysis from the Second Phase of the Energy Saving Trust's Heat Pump Field Trial*, 2013

- EST, *Location, Location, Location: Domestic Small-scale Wind Field Trial Report*, 2009

- EST, *Getting Warmer: A Field Trial of Heat Pumps*, 2010

- EST, *Here Comes the Sun: A Field Trial of Solar Water Heating Systems*, 2011

- GASTEC at CRE Ltd, AECOM and EA Technology for DECC and EST, *Final Report: In-situ Monitoring of Efficiencies of Condensing Boilers and Use of Secondary Heating*, 2009

- Good Homes Alliance, *GHA Monitoring Programme 2009-11: Technical Report*, 2011

- Good Homes Alliance, *Ventilation and Good Indoor Air Quality in Low Energy Homes*, 2011

- Gupta, R. and Dantsiou, D. (Oxford Brookes University), *Understanding the Gap Between 'As Designed' and 'As Built' Performance of a New Low Carbon Housing Development in UK*, 2013

- Gupta, R., Gregg, M. and Cherian, R. (Oxford Brookes University), *Tackling the Performance Gap Between Design Intent and Actual Outcomes of New Low/ Zero Carbon Housing*, European Council for an Energy Efficient Economy (ECEEE) Summer study proceedings, 2013

- HCA, *Designed for Manufacture: A Challenge to Build a Quality Home for £60k - Lessons Learnt 2*, 2010

- H. Hens, A. Janssens, W. Depraetere, J. Carmeliet and J. Lecompte (KU-Leuven, University of Ghent), *Brick Cavity Walls: A Performance Analysis Based on Measurements and Simulations*, Journal of Building Physics, Vol. 31 No. 2, 2007

- Hyde Housing Association, *Community Heating Review*, 2010

- Kelly, S., Pollitt, M. and Crawford-Brown, D. (University of Cambridge), *Building Performance Evaluation and Certification in the UK: A Critical Review of SAP? Renewable and Sustainable Energy Reviews*, 2012

- Kiwa GASTEC at CRE Ltd for DECC, *Investigation of the Interaction between Hot Water Cylinders, Buffer Tanks and Heat Pumps*, 2012

- Leeds Metropolitan University and AECOM for DCLG, *Review of the Implementation of Part L 2006*, 2010

- Local Authority Building Standards Scotland, *Verification During Construction: Guidance to Support the Application of Reasonable Inquiry*, 2013

- LowCarb4Real, *GHA Design Collection: Old Apple Store, Bladon, and One Brighton*, 2008

- Miles-Shenton, D., Wingfield, J., Sutton, R. and Bell, M. (Leeds Metropolitan University), *Temple Avenue Field Trial - Evaluation of Design & Construction Process and Measurement of Fabric Performance of New Build Dwellings*, 2010

- NHBC Foundation and Cutland Consulting Limited, *Low and Zero Carbon Homes: Understanding the Performance Challenge*, 2012

- NHBC Foundation, *Designing Homes for the 21st century: Lessons for Low Energy Design*, 2013

- NHBC Foundation, *Assessment of MVHR Systems*, 2013

- NHBC Foundation, *Building Sustainable Homes at Speed: Risks and Rewards*, 2013

- Office of Fair Trading, *Home Insulation: A Report on the Call for Evidence Carried Out by the OFT*, 2012

- Primaroh, M. (McCarthy and Stone), *Evaluation of the Effect on Thermal Performance of a Gap in the Insulation of Laminate Thermal Board Internal Finish*, (unpublished), 2013

- Richard Partington Architects and Leeds Metropolitan University for the Joseph Rowntree Foundation and Joseph Rowntree Housing Trust, *Temple Avenue Project: Energy Efficient New Homes for the 21st Century*, 2012

- Sanders, C. and Phillipson, M. (Glasgow Caledonian University), *Review of Differences between Measured and Theoretical Energy Savings for Insulation Measures*, 2006

- Siviour, J. B. (EA Technology), *Experimental U-values of Some House Walls*, Building Services Engineering Research and Technology, Vol. 15 No. 1, 1994

- Stafford, A., Bell, M. and Gorse, C. (Leeds Metropolitan University), *Building Confidence - A Working Paper*, 2012

- Stevenson, F. and Rijal, H. (Oxford Brookes University), *The Sigma House: Towards an Authentic Evaluation of a Prototype Building*, 2008

- Stevenson, F., and Leaman, A. (Oxford Brookes University and the Usable Buildings Trust), *Evaluating Housing Performance in Relation to Human Behaviour: New Challenges*, Building Research & Information, Vol. 38 No. 5, 2010

- Technology Strategy Board, National Measurement Network and Knowledge Transfer Network, *Building Performance Measurement: Combined Results from Workshops*, 2012

- Wingfield, J., Bell, M., Miles-Shenton, M., South, T. and Lowe, B. (Leeds Metropolitan University), *Lessons from Stamford Brook: Understanding the Gap Between Designed and Real Performance - Final Report*, 2008

- Wingfield, J., Bell, M. & Miles-Shenton, D. (Leeds Metropolitan University for EURISOL), *Investigations of the Party Wall Thermal Bypass in Timber Frame Dwellings*, 2010

- Wingfield, J., Bell, M., Miles-Shenton, M. and Seavers, J. (Leeds Metropolitan University for the Joseph Rowntree Foundation and Joseph Rowntree Housing Trust), *Elm Tree Mews Field Trial – Evaluation and Monitoring of Dwellings Performance - Final Technical Report*, 2011

- Zero Carbon Hub, *Carbon Compliance for Tomorrow's New Homes, Topic 4, Closing the Gap Between Designed and Built Performance*, 2010

- Zero Carbon Hub, *Mechanical Ventilation with Heat Recovery in New Homes*, 2013



APPENDIX 2

HOUSEBUILDING PROCESS REVIEW

A review of the housebuilding process is a key source of evidence for the Performance Gap project.

A range of housebuilders volunteered sites of varying sizes, types and construction methods to be reviewed using interviews, site visits and a study of design information. The review is still underway: included in this report are results from nine sites, with a total of 97 plots assessed. The sites themselves comprise over 1000 plots in total, of which the inspected plots are thought to be representative. All are built under 2010 Building Regulations, some with additional planning requirements such as Code for Sustainable Homes targets or renewable energy provision. Reviews of more sites are currently ongoing or planned over the period to April 2014, the results of which will be included in the End of Term report to be published in summer 2014.

The majority of sites included in the Evidence Review Report and discussed in this appendix were built by larger developers, typically using traditional masonry construction. A wider range of site types and sizes is planned for the remaining stages of the review.

Evidence Gathering

Sites have been identified through a number of routes. Some are sites in which Work Group members were already involved and so were able to obtain permission for us to review; others were volunteered by interested housebuilders.

The reviews are carried out by a team containing a range of disciplines: a developer technical director, a developer build manager, a SAP assessor and an architect, with additional resources from services engineers and academics available where necessary. Any evidence given in the review process is treated completely anonymously.

Information is collected in three stages, outlined below:

1. Preparation and Interviews
2. Design Review
3. Site Visit and Information Collation

Stage One: Preparation and Interviews

The process commences with a high level review of design documents provided by the developer, which the team use to familiarise themselves with the project and identify any areas of potential concern or interest. A series of interviews is then undertaken to help understand the development, including its energy targets, the delivery team communication processes, issues that may contribute to the Performance Gap and examples of good practice.

A structured interview is held with each of the teams or individuals, as set out in the table below. Interviews were carried out on site or in the offices of the attendees. The interview questions are not released prior to the meetings.

DISCIPLINE / PROCESS STAGE	HOUSEBUILDING PROCESS INTERVIEWS TYPICAL ATTENDEES
Planning and Concept Design	Developer's development/design manager and concept architect
Detailed Design	Developer's technical manager and detailed design architect
SAP Assessment	Developer's technical manager and SAP assessor
Procurement	Developer's buyer and surveyor
Construction	Developer's site manager and build manager

The interview structure and questions were developed using contributions from Work Group members and the review team, informed by the findings of the Interim Report. Questions vary across the five disciplines and were designed to help understand whether there are issues in standard industry practices that ultimately contribute to the Performance Gap. Where the initial review of the design documents identified particular issues, these were added to the list of questions.

Some questions are specific to each discipline and some overlap between them to try and establish whether each discipline has a common understanding of the project details. Questions range from broad and general enquiries, such as *"Are there any areas, in your role, where you feel the 'gap' between Design and As-Built performance could occur?"* to more specific points, such as *"Is there a rigorous procedure for Construction Teams to feedback issues on design to the Detailed Design Team?"* An opportunity is also provided for the interviewees to make additional comments.

Stage Two: Design Review

The review team carries out a thorough review of the design documents, to understand how the project requirements are incorporated into the working drawings and to prepare for site visits. Documents typically include specifications, construction details, working drawings, M&E design, the SAP assessment and, where available, as-built data and commissioning sheets for completed plots. These documents give the team a detailed understanding of the design and construction methodology of the site prior to the visit, and at Stage Three allow a review of whether what has been constructed on site matches the design. It gives the site review team an opportunity to identify any areas of missing information, unaccounted thermal bridges, or difficult to build details, which will be checked on site and at the next stage of the review. It also allows them to start assessing any SAP assumptions including U-values and Psi-values.

Stage Three: Site Visit and Information Collation

For each site, plots are reviewed at each stage of the build process where possible, including:

1. Sub-structure
2. Over-site
3. Over-site to joist
4. Joist to roof (including roof structure)
5. Roof to weathertight
6. First fix
7. Dry lining / plaster
8. Second fix
9. Finals and build complete
10. Testing and commissioning

The review team analyses the work on site and records their findings in pre-prepared assessment sheets covering key assessment items that could contribute to the Performance Gap at each build stage. Photographs are taken and where the site review team identify findings on site that differ to the design information, they estimate whether it could be expected to have a minor, intermediate or major impact, and also whether it may result in a thermal bridge unaccounted for in SAP. Instances of good practice are also noted.

Typically the whole evidence collection process takes place over the course of a week. For large sites, this is usually possible because phasing allows different plots at different stages of the build process to be reviewed in a single visit. However, for smaller sites, return visits are made in order to enable the team to observe all the different stages of the construction process. Three of the nine sites visited to date still have at least one follow-up visit planned.

SAP Audits

For each site visited as part of the Housebuilding Process Review, the SAP assessments for one, two or three plots (depending on site size) are reviewed by a dedicated SAP team, based on design information and observations made and recorded during the site visits. Two stages of SAP Audit are carried out for each plot:

1. A review of the original SAP assessment carried out by the developer's SAP assessor, which is re-calculated based on a strict interpretation of the SAP methodology and U-value conventions. This provides evidence of areas where SAP assessors are incorrectly applying SAP conventions, the frequency of errors, and the impact that these have on the Dwelling Emission Rate (DER).
2. A SAP assessment based on site visit observations and findings from the interviews, reflecting any changes made to the constructed dwellings. This provides evidence of changes that are not reflected in SAP assessments, their frequency and the impact that they have on the DER.

For stage 1 of this process, it should be noted that the information provided to the Zero Carbon Hub SAP Audit team by the developers for this review may not in all cases be identical to that provided to the original SAP assessor, though where possible it was attempted to obtain the same information. Additionally, use of defaults was avoided where possible and best practice was followed – so the SAP Audit team always calculated the thermal mass parameter, whereas the developer's SAP assessor may have used a broad category (low / medium / high), which is still acceptable and complies with SAP conventions. However, calculating the thermal mass parameter also allowed the impact of changes at stage 2 to be more fully accounted for.

For stage 2 it should be noted that, given various constraints of the project, it was not possible to check all parts of the SAP assessment when on site. When the site visits were undertaken, it was not always known which particular plot would be assessed for the SAP Audit, so items such as overshadowing could not usually be checked. There was also not enough time to take measurements of areas on site, so only obvious deviations such as significantly different floor to ceiling heights or window areas were picked up. Also, where it was observed on site that the actual thermal bridge details deviated from those in the design, it was not possible for this project to model the actual construction and calculate the likely as-built Psi-values. Therefore where junctions were observed not to follow a known calculated value or Accredited Construction Detail, Psi-values in the stage 2 assessment were set to the relevant default value in SAP Appendix K. This would be in accordance with the SAP conventions but might in some cases under- or over-estimate the deviation. It should also be noted that where available, original As-Built SAPs were used for the comparison to site visit observations, but because construction on some sites was not complete, the Design Stage SAPs had to be used instead in these instances.

Differences found during both stages of the SAP Audit were evaluated in terms of the change to the DER in absolute percentage terms (i.e. whether the change was positive or negative). Some changes, for example those relating to differences in calculating floor areas, would result in changes to both the DER and the Target Emission Rate (TER) and so would not have such a significant impact on overall compliance with Part L1A. However, although a dwelling may still comply in this case, the SAP assessment would not be accurate, creating a Performance Gap.

Comparisons were recorded by individual error, by category and by overall impact of all the errors (the sum of the absolute values). The categories used reflect different sections of the SAP model:

- | | |
|---------------------------------|--------------------------------------|
| 1. Orientation | 7. Thermal Mass |
| 2. Sheltered Sides | 8. Linear Thermal Bridging |
| 3. Overshading (limited checks) | 9. Ventilation |
| 4. Measurements | 10. Lighting |
| 5. U-values | 11. Heating System |
| 6. g-values | 12. Low and Zero Carbon Technologies |

To date, SAP audits have been undertaken for a total of eight plots from four sites, and a draft summary of the results has been collated. Additional sites being reviewed in the ongoing Housebuilding Process Review will have SAP Audits undertaken to contribute further evidence.

Evidence Analysis

The results from the first nine sites and the initial SAP Audits were analysed to establish where common problems are occurring and to review them with reference to the list of issues included in Annex A of the main Evidence Review Report. This allowed a review of the frequency with which each of the issues occurred over the nine sites, and a consideration of their potential impact. The evidence gathered to date was then used to inform the rating of issues on the Impact-Evidence prioritisation matrix. The evidence relating to the priority issues is included in Section 3 of the main Evidence Review Report, and overall initial findings from the interviews, site visits and SAP audits are summarised below. Additional sites will contribute further evidence.

Summary of Interview Findings

Planning and Concept Design

On nearly all of the sites, developers' standard house types were used, usually with some alterations to suit the specific site and Local Planning Authority (LPA) requirements. From the interviews with concept design team members, it was apparent that there were some issues on a number of sites relating to planning permission requirements. One aspect of this was that the LPA may not have fully understood the energy performance implications of requirements targeted at other areas. Another aspect was confusion about energy-related planning requirements which developed between the LPA and the concept design team. On several of the sites it was noted that the concept design teams were unclear whether planning requirements referred to energy or carbon, and what the baselines were.

A possible lack of concept design team understanding of the impacts of their decisions on energy performance or their potential to contribute to the Performance Gap was noted across all sites. The buildability of the designs created at the concept design stage was an issue commonly flagged up later in the process. Construction teams rarely provided feedback to the concept design team. The detailing was sometimes difficult to effectively design at the detailed design stage and was then difficult to correctly implement on site, which was sometimes compounded by a lack of effective handover and communication to the detailed design team. In several cases, a set process for handover was apparently lacking and drawings were rarely provided to the detailed design team. Concept design teams appeared never to consider the impact of orientation on solar gain, overheating or renewables.

The absence of specialists, in particular SAP assessors, was also noted at this stage in the process, indicating a possible lack of consideration for the energy performance of the sites. However, it should be noted that the use of standard house types on a number of the sites reviewed may mean that less SAP assessor input is required at concept design stage as these are often designed to be Part L compliant with a 'worst case' scenario for variables such as orientation. Frequently the details of the strategy for meeting energy performance targets were left to detailed design teams; for example, the siting of solar arrays was not considered. Concept design teams sometimes indicated that the Performance Gap arose mainly due to issues at the construction stage, but many teams also recognised that it could arise at the concept design stage, for example due to issues relating to buildability or complexity of designs.

Detailed Design

The use of standard housetypes with some changes (as used on nearly all of the sites) was found to have both benefits and drawbacks. The fact that the housetypes are fairly standardised and have been used previously gave design teams reasonable confidence that the designs would achieve the energy performance targets required. However this sometimes led to over-confidence in the energy performance, stemming from a lack of understanding of the impacts of changes to the standard designs. Changes were also not always communicated to the SAP assessor.

During the course of the detailed design team interviews, some more specific themes have also been noted. On a couple of sites in particular problems were noted relating to the detailed design teams' understanding of Psi-values and of the level of junction detailing required to ensure that they were achieved on site. Issues relating to air permeability were also raised on a number of sites; one site in particular was noted to have had no additional design or detailing even though a lower air permeability had been targeted than usual. On another site the design team reported that any leaks would be dealt with through the use of mastic. Across all sites, the risk of overheating was either treated as not being an issue or not considered beyond the SAP overheating check.

A lack of integrated design was also noted as an issue across many of the sites at this point in the process. On nearly all of the sites reviewed, service systems were designed by the supplier, which in itself is not an issue but could lead to clashes between services and the building fabric on site due to poor communication and coordination between teams. Often design and supply items such as joists and roofs were designed very late in the process meaning that they could not be fully coordinated. A lack of understanding by sales teams of the impact of changes they had agreed was also noted on a couple of the sites.

Following the site visits, buildability of details was noted as an issue across nearly all of the sites. On the sites that had these issues, there had been little or no site team involvement at the detailed design team meetings. Both construction and detailed design teams frequently commented that the processes used to gain feedback from construction teams and to hand over information from detailed design to the construction teams were insufficient or lacking, potentially leading to Performance Gap issues. Insufficient hand-over from the concept design stage was also raised as an issue by some teams. On a couple of the sites the design teams also commented that the detailed design process was carried out in too short a time frame. Some detailed design teams indicated that Performance Gap issues arose mainly at the construction stage, but design issues were also often noted, for example lack of provision of full design details.

SAP Assessment

Over half of the SAP assessors interviewed had an architectural or construction background. The remainder were recent graduates with a range of degrees including Natural Sciences, Maths, Economics and Construction Management.

Assessor competence was noted as a possible issue on several sites; examples included a failure to check the compatibility of design components and not checking U-value assumptions. Assessors often used defaults for g-values and frame factors for windows, which gave benefits to SAP ratings compared to the specification of the windows actually supplied.

Assessors on a number of the sites commented that they felt they had not been sufficiently included in the design process as none had been involved at concept design stage and only one had attended a detailed design workshop to discuss energy issues.

Around 30% of the assessors interviewed reported that they calculate all U-values, 50% that they use a mixture of supplied and calculated values, and 20% that all calculations are supplied to them. Around 20% reported that they calculate all Psi-values, 20% that they use a combination of supplied and calculated values, and 45% that all values are supplied to them (the remainder did not comment on this). Based on the design review, design details were apparently rarely checked against the Psi-values used. One assessor also commented that the sign-off sheets were not seen as critical.

Variances between the actual buildings and As-Built SAP assessments were noted at various points in the Housebuilding Process Review. A possible contributing factor is the level of checking and sign-off required for SAP assessments. The SAP assessors interviewed did not carry out site visits, except where they were visiting for Code for Sustainable Homes assessments. Furthermore, As-Built SAP sign-offs were sometimes not seen as necessary and according to SAP assessors were most commonly given by technical managers rather than the site managers who would be more aware of any changes made on site. These findings were confirmed during the construction team interviews.

Procurement

Communication between procurement teams and both the detailed design teams and the site teams was often unclear, with procurement teams rarely attending design team meetings and limited handovers from detailed design to procurement. Exact and complete specifications from the detailed design team were sometimes lacking. On the majority of the sites, the g-values were excluded from the glazing specification and not many buyers were aware of g-values and their impact on overall window performance. It was also found during the SAP audits that window specifications were never readily available from developers and had to be requested from the window supplier. On a couple of sites it was noted that the Scope of Works documentation was left as a standard document which did not account for changes made to the housetype designs.

The teams interviewed claimed that there was very little product substitution on the sites reviewed, primarily due to the use of standard housetypes and group deals. However, during the site visits evidence of product substitution was observed on all sites, although it was not always clear whether it was occurring on site, at procurement or due to the supplier. All procurement teams stated that when changes were proposed to them, they would always be sent to the technical team for approval, however frequently these changes did not seem to be reported back to the SAP assessor.

On many of the sites, inadequate consideration of energy-related skills and competency requirements at labour procurement was highlighted as a potential issue. This was indicated by a lack of awareness of BPEC ventilation qualifications which the teams either did not specify or were unaware of on nearly all sites including a couple with mechanical ventilation systems. A lack of procurement team awareness of the Microgeneration Certification Scheme (MCS) was similarly found on many of the sites, including several with renewable energy technologies. Procurement teams usually expressed the opinion that the Performance Gap arose mainly due to issues at other stages of the process, in particular at the construction stage, and also at the detailed design stage. However, some procurement stage issues were also recognised, including insufficient handover from detailed design teams to procurement teams.

Construction

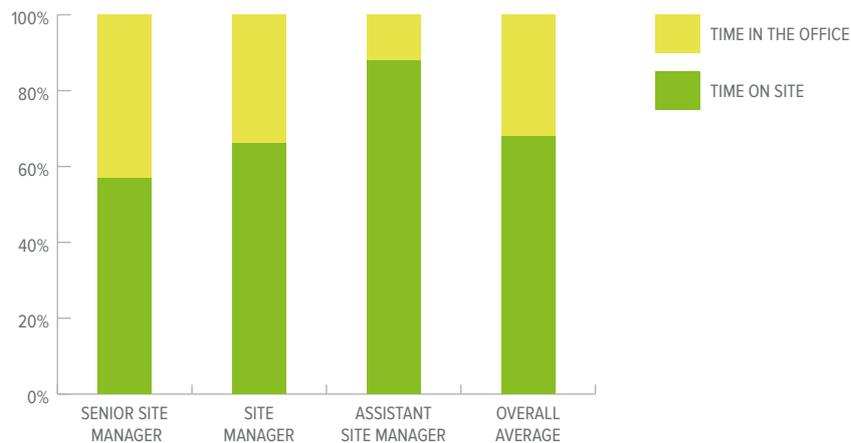
A lack of effective communication and feedback was specifically highlighted as an issue across many of the sites. In particular construction teams noted that they were not sufficiently involved at the design stage; with little attendance of site manager or contracts manager at detailed design team meetings to help understand the design, provide feedback on potential buildability issues and comment on areas where detail was lacking. On the majority of sites there was some formal handover to the site teams, usually in the form of a meeting, though site managers commented that there tended to be limited discussion of design details at these meetings. On many sites full design details were also not available.

Following the commencement of works on site the communication between technical teams and site teams was noted as being limited, partly because some site managers considered it their job to solve problems rather than to refer them to the technical team. Construction teams were not always confident that feedback on buildability issues was being collected or processed well. Some changes were also made by senior management or sales teams on several sites after works had commenced on site, and these were not always reported back to SAP assessors.

All site managers agreed that the Quality Assurance (QA) process on their sites could probably be improved upon to maintain adherence to designs and optimal build quality. On all the sites belonging to larger developers there was a quality logbook or checklist of some sort. However, it was stated that these were not fully implemented on a couple of the sites, and several interviewees felt that the checks were limited and did not focus strongly enough on energy-related performance.

One of the potential reasons suggested by interviewees for a lack of effectiveness in the QA procedures on site was that some site managers felt that they spent too much of their time in the office and not enough time actually on site managing and monitoring the build. The approximate breakdown of where different types of site manager indicated that they spend their time is shown below.

Time on site



The interviews found that understanding of the 'air barrier' varied across the site managers interviewed, however most indicated that it was dealt with primarily at first fix.

All site managers confirmed that they had not been asked to sign-off as-built information for a SAP assessment, although in some cases this may have been because As-Built SAPs had not yet been produced. Site managers were not aware of or did not have British Board of Agrément (BBA) certificates on many of the sites, and similarly Domestic Ventilation Compliance Guide (DVCG) checklists were held on only a couple of the sites according to the construction teams, and were missing on the sites using mechanical ventilation.

Summary of Site Visit Findings

Build Stage 1: Sub-Structure

On several of the sites visited the trench block was missing, and on nearly all sites dense concrete blocks were used instead of the aerated blocks which had been specified in the design. The quality of the blockwork below the Damp Proof Course (DPC) line was generally noted as acceptable, with only one site noted as poor and a couple of the sites as good; cavities were also found to be clean at this stage. The insulation was noted to be missing below the DPC on several of the sites visited. Door thresholds were found to have been constructed with blockwork returns and to fully bridge the cavity on nearly all of the sites.

Build Stage 2: Oversite

It was noted that on sites with proprietary insulated floor systems the quality was quite varied though the correct horizontal floor insulation was used on all the relevant sites. On many of the sites, incorrect materials were used for the insulated upstand to the screed; additionally the screed was noted to 'bleed' over the upstand on most sites. On several sites the screed was carried out to the outer leaf of the brickwork with minimal separation at thresholds.

Service penetrations were generally well sealed at this stage although on several sites there were instances where services had been left below the top of the screed and had to be broken out later leaving large gaps.

Build Stages 3 and 4: Oversite to Joist, Joist to Roof

On timber-framed sites, potential Performance Gap issues observed included the timber content being generally greater than assumed in U-value calculations, packing to sole plates using shimmies creating gaps, and missing sole plate insulation. It was also found that low-emissivity breather membranes were in a poor condition in several areas with large gaps and tears, and that insulation to timber ring beams was missing.

On masonry sites, the blockwork and cavity quality was generally acceptable with the inner leaf blockwork being the correct type and of good quality on all sites. The cavities tended to not be very clean, with only one site using cavity protection, though no sites were found to be excessively dirty. Cavity closers were installed on all sites but were not fitted tight on around half of the sites checked leaving large voids at the window and door junctions.

Partial fill cavity insulation was found to be of the correct type and thickness on nearly all sites using this wall type. One of the recurring issues noted with partial fill insulation was that it tended to 'float' off the blockwork over large areas; this was noted on the majority of sites. Along with the floating issue the insulation was found to have been cut short at junctions on around half of the relevant sites.

Party walls were of varying quality and it was often noted that they would not achieve the zero U-value equivalent performance assumed in the SAP calculations. One of the recurring reasons for this was a lack of compression of the insulation in the cavity, showing inadequate insulation thickness due to variations in the cavity width. Nearly all the sites had the correct type of insulation in the cavity. Another common reason for not achieving the zero U-value performance was the lack of correct edge sealing around the cavity.

One of the sites also had dense block in the party wall instead of the lightweight block specified in the design, which would impact on Psi-values.

Floor joists were often built in and then mortar applied between the timber joists and adjacent blockwork; generally the mortar will slump and shrink away from the joists leaving air gaps.

Four additional areas in this phase of the building process were felt to be likely to contribute to a deviation from the designed thermal performance. One was the construction of bay windows where it was noted that there seemed to be confusion around the detailing and on one occasion the wall cavity was omitted. Another deviation was from unaccounted thermal bridges from beams passing through the envelope; this was noted on around a third of the sites. On several sites, continuous lintel baseplates were used instead of the open lintels which had been specified in the design. Finally the detailing on integral garages at joist level was often problematic, potentially leading to thermal bridging and thermal bypassing.

Build Stage 5: Roof to Weathertight

The fitting of both windows and doors was noted to be of varying quality but generally not in line with the design:

- On many of the sites, windows were found to have been pushed forward from their design position resulting in an overlap with the cavity closer of about 10-15mm on average, where it should have been 30mm. Doors were also pushed forward so that they had no overlap with the cavity closer. This would lead to increased heat loss. There were also issues with sealing around the openings.
- The tolerances at the head, cill and jambs of the windows and doors were found to be out by a considerable margin. Window and door tolerances were observed to exceed 5mm on most of the sites, and to exceed 10mm in several cases. On one site windows with a tolerance of over 20mm were observed.
- Glazing cassettes were never installed as specified in the design, having either a different U-value or g-value.
- Installed trickle vents deviated from the design on several sites, where they were the wrong size (both too big and too small) and / or in the incorrect location.

Build Stage 6: First Fix

Service penetrations were sealed to varying degrees and with a number of different methods including grouting, foam and mastic. On some sites some of the services had not been sealed; internal penetrations were often not sealed and ultimately the gaps connect via the floor void to gaps around floor joists in the external wall. As noted above, some ducts and pipes were left in or below the floor screed and then broken out leaving large holes.

On many sites it was noted that staircase strings were not sealed or packed at the first fix stage creating a potential for air leakage paths later when the building moves.

Another issue observed at the first fix stage was the misuse or poor installation of flexible ducting on a couple of sites; for example excessive ductwork lengths and crushed ducting were observed on one site with intermittent extract fans.

Build Stage 7: Drylining / Plaster

One of the most common issues noted in this phase of construction was poor installation of the plane ceiling insulation. The issues noted with this across the various sites included:

- Insulation not being cross-lapped;
- Not pushing insulation between the final truss and wall;
- Rarely pushing insulation through the eaves and over the cavity wall insulation; and
- Not having the correct depth of insulation.

Other points of note included missing insulated boards on the soffits of openings on many of the sites, and that not all external penetrations had been fully sealed prior to drylining. There were also issues with the installation quality of room-in-roof insulation. Many dryliners had not used the correct thickness of laminated insulated boards in walls and ceilings.

Build Stage 8: Second Fix

Examples of variations from the mechanical and electrical system designs were noted, including on one site where weather compensators were omitted as they were not compatible with the boilers specified. The boiler to hot water cylinder primary pipework was fully insulated on only one of the sites where this was relevant. Renewables appeared to be installed correctly on all of the sites on which they were specified.

Issues were observed with the skirting: it was not consistently sealed to the base or rear in mastic; the sealant had generally been applied to the face of the skirting board after the skirting had been fitted. Skirting was found to be missing behind baths and kitchens on a number of sites, leading to potential air leakage paths. Where the skirting was missing, large, unsealed gaps were found in most cases.

Build Stages 9 and 10: Finals and Build Complete, Testing and Commissioning

On all the sites reviewed, roof insulation was found to be poorly installed, at this stage although nearly all sites had the correct type and thickness installed. In addition to the problems observed at Build Stage 7 (Drylining / Plaster), the insulation was often found to have been disturbed post-installation.

Some issues were noted relating to ventilation strategies or systems on most sites, including doors not being correctly trimmed in some naturally ventilated homes and ductwork not being connected to fans. On the majority of sites boiler commissioning forms and stickers were found, but Domestic Ventilation Compliance Guide checklists were often absent.

The use of mastic was commented upon by the site review teams on several sites in situations where it was felt that it should have been used more appropriately. Cracks were observed around skirting seals, and mastic was being used excessively to create the air barrier on several of the sites.

Customer extras were observed in some instances which were not reflected in the SAP assessments, including additional secondary heating and the use of halogen downlights.

Summary of SAP Audit Findings

The SAP Audit draft results include four sites (eight plots). Stage 1 of the Audit found errors in the original SAP assessments in all cases. The errors found are summarised in the table below. On average across all plots audited, an absolute DER deviation of 11% was found.

SAP ENTRY AREA	FREQUENCY OF DEVIATION (% OF PLOTS)	AVERAGE ABSOLUTE DER DEVIATION (%)
Orientation	13%	1.6
Sheltered Sides	50%	1.1
Measurements	75%	5.6
U-values	100%	1.8
g-values	38%	2.0
Thermal Mass	63%	2.1
Linear Thermal Bridging	63%	1.7
Ventilation	25%	1.4
Heating System	63%	1.2
Low and Zero Carbon Technologies	13%	1.2

In all instances changes were found to be occurring in constructed dwellings that are not being reflected in SAP assessments (stage 2 of the Audit). The discrepancies found are summarised in the table below. On average across all plots audited, an absolute DER deviation of 17% was found.

SAP ENTRY AREA	FREQUENCY OF DEVIATION (% OF PLOTS)	AVERAGE ABSOLUTE DER DEVIATION (%)
Measurements	25%	0.6
U-values	100%	5.6
g-values	100%	1.9
Thermal Mass	50%	0.5
Linear Thermal Bridging	100%	7.1
Ventilation	13%	2.3
Heating System	63%	2.3

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