Building Performance Evaluation

Where to start

Future Homes Hub

Building Performance Evaluation
A guide for homebuilders and their advisors

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Foreword

Technical standards for new homes in England are rapidly advancing. Changes to the building regulations in 2021 raised standards for overheating, ventilation and energy efficiency. The 2025 Future Homes Standard will again define standards of energy efficiency and require the use of low carbon technologies (including for heat) whilst providing comfort and ease of use for householders. As standards advance, homebuilders, customers and the Government will increasingly focus on how homes actually perform.

This 'where to start' guide aims to help homebuilders understand the range of techniques available to assess how homes perform in practice. Building Performance Evaluation is important to verify performance to the end user, substantiate performance claims and inform a continuous cycle of design improvement.

We are very grateful to the steering group of building performance evaluation practitioners, technology providers and housing developers who have come together to share their experience and expertise to develop this guide. We hope it is a useful step towards incorporating building performance evaluation into normal business practice. We look forward to continuing the journey to improve the performance of homes for both customers and the planet.

Ed Lockhart

CEO Future Homes Hub

Produced in conjunction with Building Performance Network

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OVERVIEW

Building performance evaluation (BPE) is a way to assess how buildings perform in practice. It can help demonstrate whether the expected building performance (e.g. the designed energy efficiency, comfort and usability) has been delivered. BPE also plays an important role in informing continual improvement; for helping homebuilders improve performance, quality and householder satisfaction across their portfolio.

BPE is particularly important in the context of the current energy and sustainability crises. Regulatory, policy and customer expectations are changing. Whilst some BPE is already required under legislation (such as the Part L air permeability test), it is expected that requirements will expand in future. Also, householders will increasingly have smart home monitors and controls which will provide them with feedback on the performance of their home.

PURPOSE OF THIS GUIDE

This 'where to start' guide is intended to introduce homebuilders, designers, and others involved in the development of new homes, to building performance evaluation (BPE).

The guide introduces the main BPE techniques and why, and when, you may choose to undertake them. It is intended for those with limited pre-existing knowledge of the subject and will provide an "easy way in" to engaging with the subject. The guide covers the basics and signposts to more detailed sources of information.

INTRODUCTION

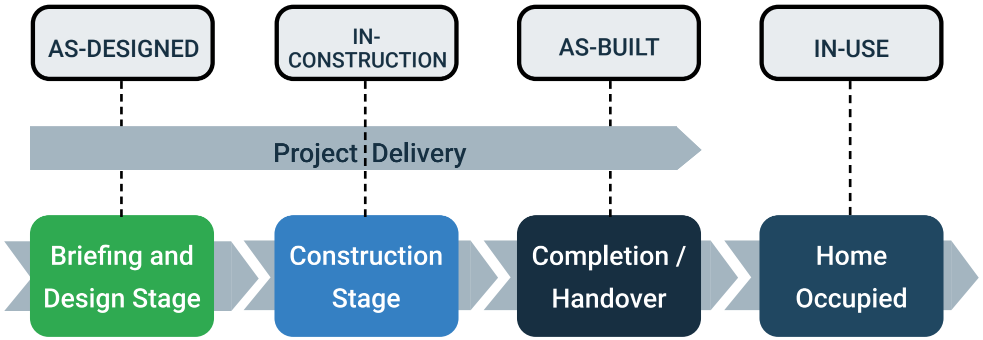
What is BPE?

Building performance evaluation (BPE) is the process of assessing how a building performs. BPE can be used to check that the actual performance of a building meets the design performance.

BPE can cover many aspects, including:

- Fabric thermal performance and airtightness
- Heating and ventilation services
- Energy use
- Indoor air quality
- Overheating
- Householder experience

BPE can be undertaken at different stages, ranging from when the design is still on the drawing board, to when the home is occupied and in use.



BPE at different project stages

Why do BPE?

Under Building Regulations, a house **design** is required to comply with core design requirements. A small number of performance checks are required at completion (e.g. air permeability and ventilation flow rates). However, these checks are for a limited range of aspects and do not confirm that the home overall performs 'as-designed', either at completion or when 'in-use'. This guide is focused on how to assess a home's actual performance and why this is of benefit.

Many studies show there is often a gap between the design intent and actual performance of homes when people are living in them. This can be due to a range of factors. The actual cause is often not readily apparent and this can create further complications for the householder, landlords and homebuilders.

The information gained from BPE identifies how a house or house type is performing in practice and allows comparison with the design intent.

Design reviews, undertaken before construction starts, are used to help anticipate issues and proactively helps to inform enhancements to design specifications. BPE checks during construction, or when the home is built (e.g. at completion stage), can identify concerns before the householder moves in. When the home is 'in-use' (i.e. occupied), BPE techniques shed light on householders' lived experience and provide valuable feedback to improve home designs, identify weaknesses in build processes and understand product performance.

BPE will help homebuilders understand the actual performance of their homes in readiness for the introduction of low temperature heating systems (which will be more vulnerable to fabric underperformance), and of performance monitoring becoming more commonly available to householders.

Increasingly some clients and planners are including aspects of BPE as part of their requirements.

What are the drivers for building performance evaluation?

Ensuring customer satisfaction

Understanding customers' expectations and experience living in their new home is important to deliver a good product and inform continuous improvement.

Verifying design performance

Demonstrating that standard house type designs perform as anticipated 'as-built' and 'in-use'.

Providing build quality assurance

Verifying that the build process is consistently delivering homes that achieve the expected level of design performance 'as-built' or 'in-use'.

De-risking transition to low-temperature heating

As the way we heat buildings changes towards new technologies like heat pumps, it becomes more important to know whether the building fabric and heating systems perform as designed. For example, heat pumps could be unable to produce sufficient heat to overcome under-performing fabric, whereas high output boilers would be able to do this (albeit accompanied by high energy use).

Substantiating performance claims

In order to make claims about the energy performance, comfort or quality of new homes, it is necessary to build an evidence base to demonstrate this performance.

Differentiating from competitors

By demonstrating higher building performance in practice, a homebuilder can differentiate themselves from their competitors who may not have confidence in, or evidence of, their design and build quality to make such claims.

Investigating following customer complaints

Where there is a complaint, BPE techniques can determine the performance level to refute or confirm the problem. Diagnostic techniques can help to identify the root cause if an issue is found.

Developing an understanding of actual performance

The information gained from understanding how homes really perform can be used to improve quality. Knowing how specific house types perform against their design specification provides a feedback loop showing what has worked well and what needs improvement.

Government policy is moving towards demonstrating actual performance, with the BEIS EPC Action Plan stating,

“Energy Performance Certificates will need to move from a reflection of the features of a building (fabric, services..) to a true measure of ‘in-use’ building performance."

BPE Triage

Whilst every aspect of BPE could be undertaken at each project delivery stage on each new home, this would be excessively expensive and time consuming. The purpose of BPE is primarily to identify common lessons and use this feedback to improve the design, build processes and product selection rather than acting as a quality control mechanism. Typically, monitoring or tests are undertaken on a sample of homes to understand the broad performance. If concerns are identified, further, more detailed, diagnostic tests can be undertaken.

"The Future Homes Standard is due to be introduced by the Department of Levelling Up Housing and Communities (DLUHC) by 2025. It will require new build homes to be future-proofed with low carbon heating and world-leading levels of energy efficiency.”

Future Homes Hub

Ready for Zero - Evidence to inform the 2025 Future Homes Standard - Task Group Report

(Image credit: Persimmon PLC)

WHAT INFLUENCES BUILDING PERFORMANCE?

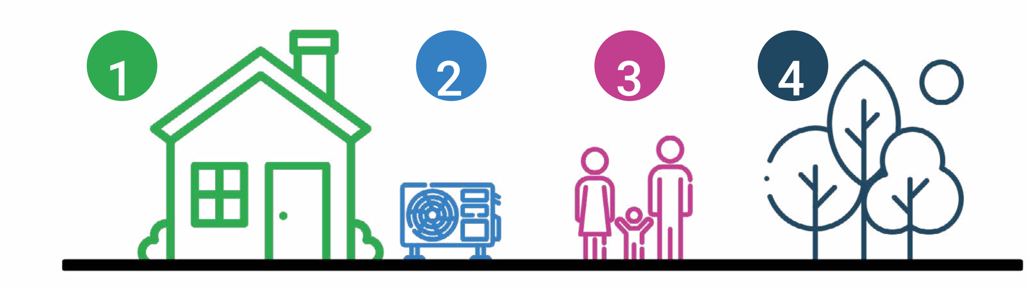
Many things can influence how a building performs in practice. In addition to the design-build quality and the performance of the building products and services, the way householders use the property, and external changes to weather or local environment can all influence how the building performs. Homebuilders have control over some of these and should be aware of the other elements that may come into play and what impact they can have.

When designing a dwelling, assumptions are made about how the home will be lived in. Energy models, for example, calculate 'standardised' performance based on assumptions. In reality, how householders live in a home varies, so the energy performance predicted at design will likely differ to that in-use. This makes understanding performance complicated, but techniques are rapidly evolving to help untangle these intertwined aspects.

The purpose of BPE is to help the homebuilder and their teams understand if the home performs as it was designed; the householders' experience of the home; and what might be improved to enhance this experience. Assessing the following elements (see diagram opposite) can help to develop an understanding of the home's performance and what may be causing any variation from the design intent.

Insights from performance data

This guide introduces BPE techniques that are now available which can take householder behaviour and external conditions into account and allow the performance of the home to be referenced back to standardised conditions. This enables the homebuilder to understand the underlying performance of the home (the part they are responsible for), as well as providing information on how householders are actually living in their homes.



1 Fabric

The building fabric can influence many aspects of a home's performance. Typical fabric BPE includes investigating heat loss and thermal transmittance (at junctions, through penetrations, of elements, etc.) along with measuring air permeability and diagnosing air leakage paths.

2 Services

Typically, BPE can be used to assess whether the performance of building services such as ventilation, heating, hot water, controls and renewables meet the design intent in practice.

3 Householders

The number of occupants in the home and how the home is used can significantly impact how the home performs. Homebuilders have limited influence over this, but may want to know how householders feel about the home's performance so they can address feedback or complaints and improve future designs. This is usually done via householder surveys or home visits.

4 External conditions

External conditions including geographical location, microclimate, weather, nearby pollution, etc will affect how homes perform and are used. Compliance with Part L of the Building Regulations is calculated on a nominal "average UK" location. Weather variations between different locations, or even within a site, can influence how the same house type performs in practice. Data on this is usually gathered from third-party sites (such as the Met Office).

BUILDING PERFORMANCE EVALUATION TECHNIQUES

There are a range of tests and measurements that can be undertaken to evaluate building performance. Tests can be undertaken at different stages, from early in the construction process through to once the building is occupied - depending on the purpose of the testing.

This guide introduces BPE techniques according to where they normally come in the build process:

- Design stage
- In-construction
- As-built
- In-use

A section describing diagnostic tests which can be used to investigate and pinpoint particular issues is also included.

The BPE information obtained at each stage of the build process is different. In-construction quality assurance provides an indication of in-use performance. As-built tests provide more comprehensive information about the likely in-use performance. In-use techniques provide information on both the performance of the home while it is being lived in and the experience and behaviours of householders, but is less convenient to obtain.

BPE at each stage has a role to play in establishing an overall picture of typical performance, with the information combined across a sample of homes to provide feedback for continuous improvement of the design and build process.

Examples of proprietary techniques are included in the 'Example providers' section to give a sense of what is readily available today. However, techniques are developing rapidly and additional companies are entering this field. Many of the providers of BPE services can be found on the BPN website: https://building-performance.network.

Relative cost levels have been indicated against many of the techniques described, on a scale of **£ - ££££**. Actual costs would be dependent on site specific circumstances and scale. It is expected the costs of some newer techniques will reduce rapidly as adoption increases.

Design stage BPE

Typically, this is a desk-based activity where the design concept, construction drawings and product selections are reviewed specifically to understand where weaknesses may exist and identify potential sources of underperformance – anticipating and mitigating potential problems before construction starts.

Design stage BPE often consists of reviewing: key drawings, thermal bridging details, energy and overheating calculations, location and continuity of the air tightness barrier, any high-risk performance items with their mitigation plans, and lessons from previous BPE studies.

Design review meeting

In-construction BPE

Some of the in-construction tests already undertaken for regulatory compliance are BPE techniques. For example:

- Air permeability (Part L, blower door or pulse test)
- Noise (Part E, if not using Robust Details)
- Ventilation commissioning test (Part F, flow/ pressure)
- Boiler / Heat pump commissioning tests
- PV commissioning test
- Photo evidence review (Part L)

Additional tests may also be performed such as:

First fix air permeability checks £

A quick check before boarding, which can be undertaken by the site team, is often carried out when very low levels of air permeability are being targeted.

Site walk-throughs £

Regular site walk-throughs are an important part of in-construction quality assurance. Testing can identify that performance is not achieved but often cannot readily indicate the specific causes without time consuming, and potentially costly/disruptive, diagnostic tests. As all site managers know, regular visual checking of details at key stages of construction provides insights into how well the design specification is being delivered. For example, poor installation of particular elements or unexpected product substitution can often be identified and addressed during the construction phase. Being confident the home has been built as intended is half way to ensuring performance. However, too often, site walk-throughs can be relegated down the priority list when the pressure is on.

As-built BPE

In-construction tests and checks can only verify so much. To understand the performance of the finished home, additional testing is required. A lot can be learnt at completion stage, without anyone living in the home, to understand the dwellings 'as-built' performance. The advantage of testing at this point is that any potential issues can be identified and subsequently rectified before the home is handed over.

Tests featured in this section are generally short duration tests which require an unoccupied home and don't utilise the home's own heating system. Some of the tests described in the 'In-use BPE' section can also be undertaken prior to occupation but rely on the heating system running.

Examples of companies carrying out these types of tests are included in the 'Example providers' section on page 20.

Energy House 2.0 at University of Salford. Environmental chamber for testing fully built homes for R&D purposes. (Image credit: Charles Leek)

Whole house heat loss tests

Whole house heat loss tests determine the Heat Transfer Coefficient (HTC) which is a measure of the rate of heat flow through the building's envelope when a temperature difference exists between the internal and external air. The HTC is for the building as a whole rather than individual elements such as a wall or floor. The HTC of a dwelling is directly correlated with its space heating requirement, and the measured HTC can be compared with design predictions from energy models such as SAP or PHPP.

These types of tests can highlight if there is a discrepancy between expected and measured overall fabric performance, but additional diagnostic techniques would normally need to be carried out to find the root cause(s) – see 'Diagnostic BPE' section.

Short duration whole house heat loss tests £££

Several companies offer variations of this test using slightly different equipment and calculation methods. The test can be carried out on a vacant building any time from first fix to handover and takes approximately 10-12 hours, following pre-heating, provided a difference in temperature between internal and external of typically >10°C can be achieved. Optimum months are therefore between October and April. The test monitors the temperature of the dwelling whilst it is heated and then allowed to cool passively. Data on the heat loss is collected by multiple sensors and monitors located inside and outside the dwelling. This data is then analysed by proprietary software algorithms to produce the measured HTC.

Whole house heat loss test (Co-heating) ££££

Traditional co-heating tests measure the amount of heat lost through the thermal envelope of the completed dwelling and are performed with all ventilation openings and systems off or blocked. Co-heating tests are often the reference standard which other tests are compared with. These tests usually require the dwelling to be unoccupied for 1-3 weeks and should be undertaken in accordance with the LBU Protocol (see Resources section).

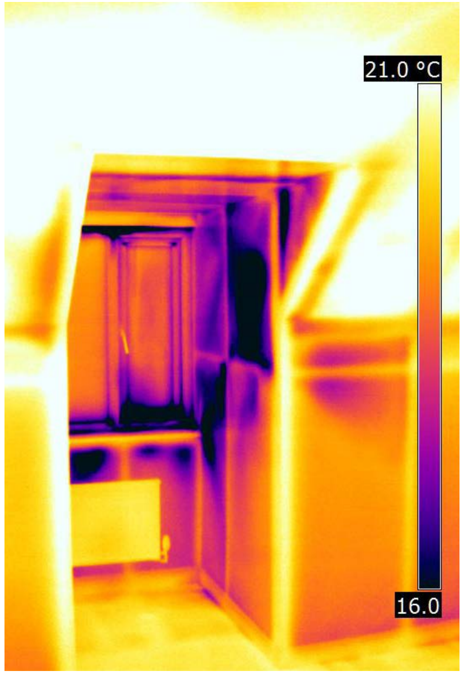
The building is heated to a constant internal temperature (usually 20-25°C) using heaters and fans. The temperature outside needs to be at least 10°C cooler, so the test is usually conducted in the colder months. Testing is carried out by a trained specialist and the Heat Transfer Coefficient (HTC) is derived from the data collected. During the test period additional diagnostic tests, such as thermography and heat flux, can be undertaken as required.

Co-heating test (Image credit: Leeds Beckett University)

Thermal imaging ££-£££

Thermographic (or Infrared) surveys map the thermal efficiency of buildings using an infrared (IR) camera. The results can show where thermal bridging or thermal bypass is taking place, any areas of missing insulation, and poor window, door and junction sealing for example.

Training is required to use the camera and interpret results correctly. Surveys usually take 1-2 hours, ideally pre-occupation, to minimise disruption should any issues be highlighted, but can also be undertaken when the home is in use. Timing of surveys is important and must be carried out after the building envelope is sealed and when a temperature difference exists between internal and external air, i.e. during colder months when internal heating means there is a difference between inside and outside temperatures.



(Image credit: BSRIA)

Services

Mechanical ventilation systems checks £

The installed performance of ventilation systems can be measured. Two key aspects to test are airflows and the electrical energy consumed to generate those airflows. With MVHR the efficiency of heat recovery is also important and can be checked. This testing can be done within one day and should be conducted pre-handover. It can also be undertaken when the home is in use as a diagnostic test if required.

(Image credit: BSRIA)

Heating system efficiency checks £-£££

The installed efficiency of the gas boiler or heat pump system can be measured prior to handover. Test cycles could be developed in which the heating system is run and monitored over a series of days - although to date these techniques, to the limited extent they have been applied, tend to be used to monitor in-use, rather than as-built performance. For more details see page 14.

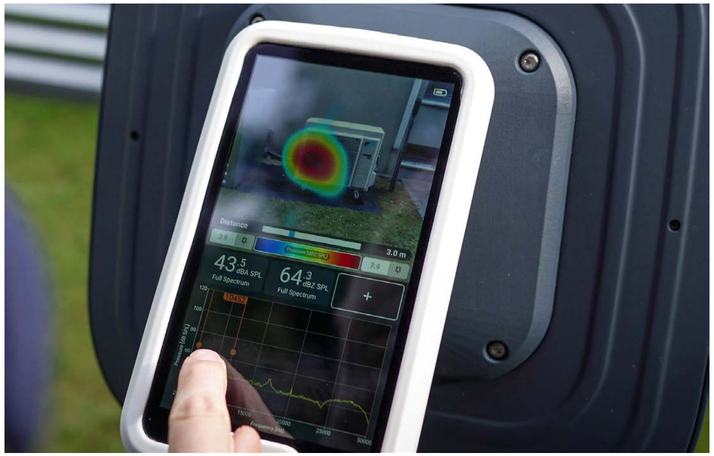
PV system checks £

Whilst the PV system will have been commissioned, it is also useful to check it is generating as expected. Noting the date and the kWh generated and then rechecking a few days later will give an indication. To be more sophisticated, the actual monthly solar generation could be checked against an online calculator. See page 17 for more information.

Equipment noise testing £

Most equipment is designed to be quiet when installed correctly. Noise from compressors, pumps, fans, heating circulation, and heat pumps, can cause a nuisance and can also be an early indication of a problem or fault. Incorrect installation, faulty components or over-cycling can sometimes result in noise in practice being above intended levels. Routine monitoring of noise levels develops a baseline of ‘normal’ data. Checking for excessive noise levels can help identify a problem that needs investigation.

Measurements are conducted using a range of acoustic monitoring equipment, depending on the noise source and location. Monitoring should be conducted by a qualified acoustician in accordance with the relevant standards.



(Image credit: BSRIA)

In-use BPE

Whilst as-built BPE can be undertaken to confirm build quality or gain feedback to improve house types, some aspects of building performance are only really understood when the home is actually being lived in - by a diversity of householders and under a variety of weather conditions. There are a range of different techniques available, including those outlined below.

Examples of companies carrying out these types of tests are included in the 'Example providers' section on page 20.

Whole house heat loss test £££-£££

The total heat loss of the building can be tested when the dwelling is in use, via either overnight testing, as described in the 'As-built BPE' section above (with residents temporarily leaving the building); or using longer-term tests (with residents in occupation). These tests all produce a measure of the Heat Transfer Coefficient (HTC) of the dwelling.

Longer-term techniques use energy consumption data in combination with external weather data to calculate how well the building fabric is performing, rather than requiring specialist heating or sealing of the building. There are a variety of methods, some of which incorporate additional data such as type of ventilation system, occupancy patterns, etc. The more information the evaluation algorithm incorporates, the more accurate the method is expected to be at determining the actual HTC. Testing is non-invasive, using energy consumption data, so tests can be carried out with minimal disruption to householders.

Similar to as-built whole house heat loss tests, these types of tests can highlight if there is a discrepancy between expected and measured overall fabric performance, but additional diagnostic techniques would normally need to be carried out to find the root cause(s) – see 'Diagnostic BPE' section.

(Image credit: Build Test Solutions)

Whole house heat loss - use case

The whole house heat loss test is often used at completion or in-use to verify as-built fabric performance against the original design intent. For example, to check as-built quality or to meet local planning policy conditions. Being non-invasive, such methods are also well suited to measuring a home when lived in, serving to help check performance or resolve householder complaints.

Householder feedback

Engaging with householders whilst the home is in use can help confirm customer satisfaction, enhance the understanding of any issues, and provide information to feed back into future building design and construction. Engagement is usually through questionnaires, interviews and/or home visits. It is usually best to conduct householder engagement a sufficient time after handover and "settling in": 9 months after handover is commonly accepted as the appropriate starting time. Inspection at the end of the defects period may be a convenient point. It is important to engage householders appropriately in advance and ensure the principles of good engagement, including right of refusal and GDPR requirements, are fulfilled.

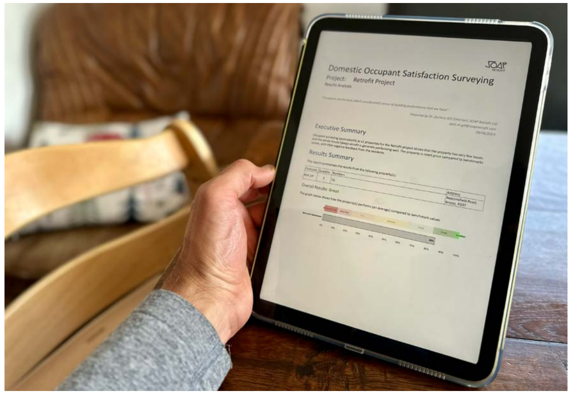
Householder questionnaires £

Obtaining insight into householder comfort and satisfaction can provide useful information to inform all aspects of BPE. Questionnaires are usually conducted to understand any issues and ensure the home performs as intended. They are usually distributed to all residents to maximise insights and provide the best chance of achieving a representative sample of returns.

This may be across regions, house types, demographics etc. Questionnaires should be standardised if possible so that results are comparable. A link to a questionnaire template can be found in the Resources section.

Householder interviews £-££

Interviews can be useful to obtain more detailed information on topics covered in a questionnaire. They usually involve a series of structured questions and recording the long-form answers of participants in detail.



(Image credit: SOAP Retrofit)

Home visits £-££

Visiting the property can provide valuable insights into the current state, as well as any extenuating issues. Site visits usually involve non-invasive observation of the quality of the fabric and services; the way in which the heating and ventilation and other systems are being used; visual checks of any metering; observation of general demographics; and observation of any specific issues highlighted by other tests or forms of engagement.

Indoor air quality and comfort £-££

Environmental monitoring devices are a relatively simple and accessible method of providing temperature, relative humidity, CO_2 and pollutant data on a continuous basis. Even monitoring for a duration of a week or two can be insightful.

Sensors called data loggers collect data at regular intervals depending on the level of detail required and length of assessment period (30-minute to one-hour intervals typically recommended). Some data loggers require regular checks and replacement due to storage capacity but some use remote connectivity via wifi, reducing maintenance. Data is analysed by an air quality specialist to determine any issues.

Services

PV generation can be easily checked to see if it is performing as expected - see page 12.

Increasingly internet connected appliances permit live condition monitoring. For example, some boilers, heat pumps, mechanical ventilation with heat recovery units and PV inverters/ batteries, allow the installer/ householder to connect them to the wifi. This enables the householder and manufacturer to track performance, undertake remote diagnostics, change settings and issue firmware updates etc.

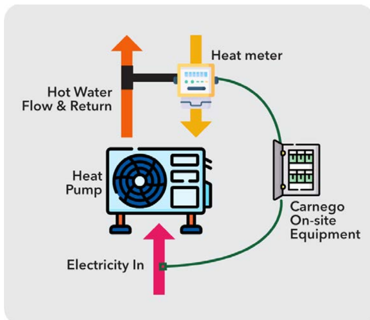
Emerging are 'smart home management' platforms that can permit submetering and control of various devices, circuits, and lighting. Specialist home performance measurement companies, some of which are featured in the 'Example providers' section of this guide, also offer in-use performance monitoring.

Heating system efficiency £-£££

The installed efficiency of the gas boiler or heat pump can be measured. Some companies offer a measurement of coefficient of performance (COP) as part of their overall dwelling performance measurement service. Some heat pumps have integrated COP reporting, although currently with variable reliability and accuracy.

For heat pumps, a packaged solution for measuring COP is now available. The approach is to measure the heat output and the electricity consumption of the heat pump, over a period of use. The heat output is measured using a heat meter which measures flow and the inlet and outlet temperature across the heat pump. The electricity consumption is measured using an electricity meter. The efficiency is simply the kW heat output divided by the kW electricity consumption.

There are many factors that affect the COP, including: the outside air/ ground temperature and the temperature of hot water generated, etc. These and others need to be considered when comparing back to the 'design' performance.



Heat pump efficiency monitoring

(Image credit: Carnego Systems)

Diagnostic BPE

BPE tests can be performed to diagnose or investigate issues (for example, in the case of complaints) or to gather additional data to improve future design or specification of house types.

The types of test are briefly explained below. The icons identify the stages at which the test can be used.

In construction | As-Built | In-use

The approximate relative cost of techniques on a scale of **£ - ££££** is also given (noting that actual costs would be dependent on site specific circumstances and scale. It is also expected that the costs of some newer techniques will reduce rapidly as adoption increases).

Fabric diagnostics

Thermal bridging/ thermal bypass (location): Thermal imaging (or infrared (IR) survey) ££-£££

Infrared cameras can be used to identify thermal bridging or thermal bypass in homes. These cameras record an infrared image that indicates temperature with colour. Surveys should be undertaken by a qualified thermographer, and there needs to be a temperature difference between the internal and external air. IR camera analysis can be conducted quickly, across one or many homes, and can give a good indication of areas where thermal bridging or thermal bypass exist – the cause of which can then be investigated further. Understanding thermal (or cold) bridging can help identify and avoid locations of heat loss and resulting colder surfaces which are often linked to mould formation.

Thermal bridging (root cause): Borescope £-£££

A borescope enables a visual inspection of construction details in areas where there may be thermal bridging or issues with continuity of insulation (identified by thermal imaging for instance). In this non-destructive testing technique, a small hole is drilled through the building fabric in the relevant area and a fibreoptic cable is inserted, connected to a small camera. The images can be viewed in real time or captured for analysis. It is usually performed by a trained specialist.

U-value: Heat flux plate / Infrared tests ££-£££

In an investigation, it can be useful to obtain U-values for whole building elements (e.g. walls, roofs, floors) which may comprise a number of different materials. This differs from the lambda values (thermal conductivity) of specific individual materials, which will usually be provided by suppliers. There are two main techniques for measuring in-situ U-values of building elements - the heat flux plate method and the infrared method.

(Image credits: Build Test Solutions)

Heat flux sensors can be installed in-situ to give a direct measure of heat flux through a construction element (e.g. the U-value of a wall or floor). Although very accurate, heat flux sensors must remain in-situ for a minimum of 72 hours and should be undertaken to the ISO 9869 standard.

Techniques are being developed which use an IR camera to determine the U-values of specific buildings elements. Use of these requires skilled building evaluators but may provide a result within two hours.

Air permeability (measurement): Blower door / Pulse test

£

The blower door (or fan pressurisation) test is carried out with the building pressurised to 50 Pascals, with all air inlets and outlets (e.g. doors, trickle vents, ventilation grilles) blocked. The airflow required to maintain the pressure inside over time is measured, as the dwelling is pressurised or depressurised. Leaks can be located by simultaneously using smoke (see below), simply feeling for leaks with hands or, better, in conjunction with thermography. The home must be unoccupied for the duration of the test.

Blower door test (Image credit: BSRIA)

The low-pressurisation pulse method uses compressed air released from an air receiver positioned within the dwelling. Measuring directly at low pressure with little disruption to householders, the system provides an air change rate measurement that is representative of normal inhabited conditions.

Both the blower door test and the low-pressurisation pulse method are approved airtightness testing methods for building regulations purposes, but their results are not directly comparable.

Pulse test (Image credit: Build Test Solutions)

Air permeability (root cause): Smoke tests

£-££

Smoke tests can be used to identify air leakage paths. There are several ways to carry out smoke tests. They are usually carried out during an airtightness test using a “smoke pencil” to identify local air leakage paths. Tests usually require a specialist and are sensitive to external weather conditions.

Ventilation diagnostics

Ventilation rate: tracer gas testing £££

Tracer gas testing is a non-invasive method that monitors the progress of a tracer gas through a building or room to determine the ventilation rate. CO_2 is often used as a “natural” tracer gas, as it is present in buildings in use, is usually well dispersed, and can be easily measured. Testing is usually conducted by an air quality specialist and undertaken with the home unoccupied during the period of the test.

Indoor air quality: IAQ sensors £-£££

Issues with internal air quality can be investigated using internal air quality sensors. Tests can be for chemical or biological pollutants. Chemical pollutants include carbon monoxide and carbon dioxide, volatile organic compounds (VOCs) like formaldehyde, and the other chemicals like lead and radon. Biological pollutants include mould, dander, pollen, dust mites, and bacteria. Monitoring is often conducted over an extended period to allow for variation over time. Data is analysed by an air quality specialist to determine any issues.

Services diagnostics

Should an issue be raised regarding the performance of any of the systems in the home, then specific diagnostic techniques can be used to investigate further. Specialist advice should be sought to determine the most appropriate techniques, but some examples are given below.

Mechanical ventilation performance £-££

As described on page 12, tests of intermittent extract fans, MEV and MVHR ventilation rates and efficiency can be carried out, and checks on MVHR heat recovery efficiency can be performed.

Heating system efficiency £-£££

The installed efficiency of the gas boiler or heat pump system can be measured, as described on page 14. However, simple measurement of the in-use COP, or efficiency, only gives an indicator of performance as it is affected by other factors. A diagnostic approach would supplement the heating system efficiency with data on the accompanying conditions such as: the outside air/ ground temperature, the temperature of hot water generated (domestic hot water and space heating), the on-off cycling etc. This additional data and analysis helps to provide a more nuanced comparison back to the ‘design’ performance.

PV system output £-££

Checks can be carried out on the PV system to determine if it is generating as expected. For example, the actual monthly solar generation could be checked against an online calculator. These generally work by providing expected typical monthly generation figures for the location, derived from entering the annual expected generation (kWh) from the MCS installation certificate. Specialist providers would be able to carry out a more accurate assessment by measuring the actual solar irradiation during the period of the test.

Householder experience diagnostics £-££

The householder feedback methods (surveys, interviews, home visits) described on page 14 could all play a part in better understanding householder experience and investigating any issue.

This interaction with people will be most successful if the most convenient and appropriate technique is chosen for the individuals involved.
In addition, the monitoring techniques described below could be used to investigate a particular issue.

Householder comfort monitoring £-££

The most commonly monitored comfort, or indoor environmental quality (IEQ) parameters are temperature and humidity. Monitoring is done using widely available sensors placed appropriately in the building and can be undertaken relatively easily. Relating the physical data to resident feedback on comfort and air quality can help address householder concerns and identify the risk of issues such as condensation, mould growth and health impacts due to under-heating or under-ventilation of homes.

Temperature sensors

(Image credit: Build Test Solutions)

Daylight lux level checks ££-£££

As well as affecting lighting energy consumption, the amount of daylight a room receives can have an impact on the health and wellbeing of the householder. The Daylight Factor is a measure of the amount of daylight available inside a room compared to the amount of unobstructed daylight available outside under overcast sky conditions. It is calculated by a specialist, using a lux meter.

Generally, a Daylight Factor of 2% or more can be considered daylit, but electric lighting may still be needed, whereas a factor of 5% would indicate strong daylight.

Testing of daylight levels is currently relatively rare and typically only done in legal disputes or within the context of academic research.

Noise monitoring £-££

Noise monitoring can confirm if noise is within appropriate levels. Different standards and test methods are required for different noise measurement. Monitoring should be conducted by a qualified acoustician in accordance with the relevant standards. Testing is undertaken using a range of acoustic monitoring equipment, depending on the noise source and location.

Internal noise monitoring

(Image credit: UCL Energy Institute)

Accuracy, precision, and BPE performance claims

When evaluating a home's performance, there are a few key questions to consider. These include: "How confident can we be in the answers we receive?" and "How does the level of uncertainty compare to the size of the defect we're trying to detect?" Unfortunately, there are no straightforward answers to these questions, and some background explanation is necessary.

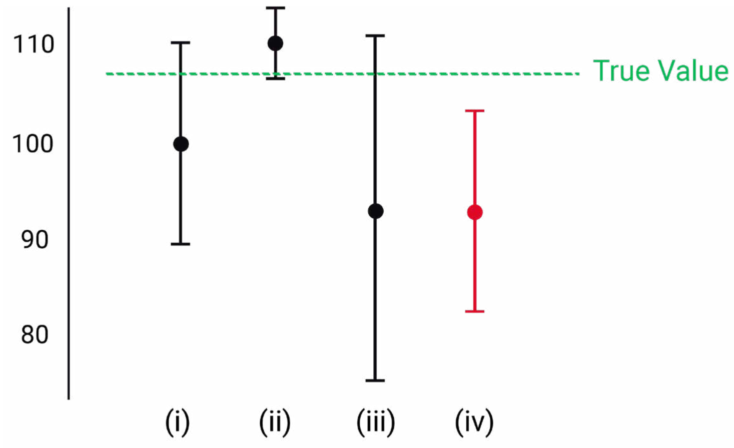
The field of Building Performance Evaluation (BPE) is rapidly evolving and still in its early stages. New techniques are continually being developed and refined. Providers are making performance claims in different ways, based on different sample sizes and which may have been validated on homes with lower performance than the new build homes under test.

Providers should ensure their techniques are validated in similar conditions to those in which they are applied. When receiving results from a measurement provider, each result should come with an individually calculated uncertainty value for that particular measurement. This calculated uncertainty may be either worse or better than the 'general uncertainty' stated by the provider in their literature.

This guide aims to provide a better understanding of the different performance claims, their associated uncertainties, and the significance of the results.

Confidence Interval

A metric that may be quoted by measurement technique providers is the Confidence Interval. A confidence interval is preceded with a '±' symbol and provides the range of values within which we can reasonably expect the true value to fall. For example, a value of 100±10 suggest that the best estimate is 100, but the true value likely lies somewhere in the range 90 to 110. Confidence intervals can also be presented visually, via the use of error bars, as shows below.

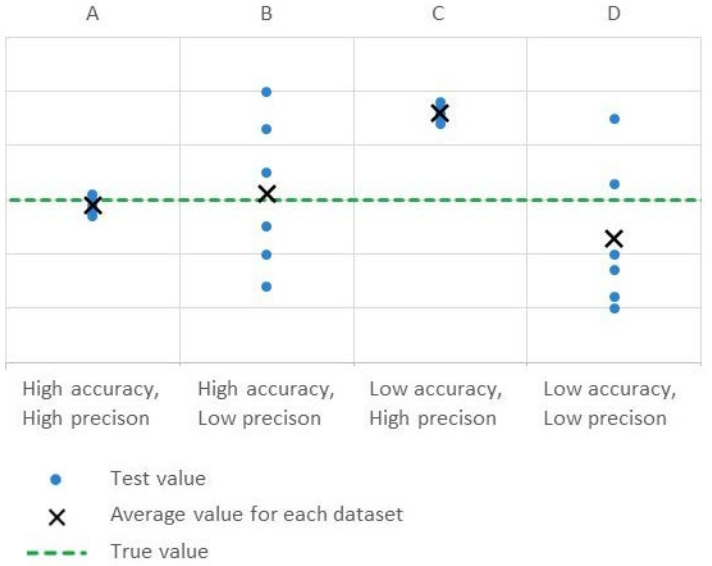


This illustration shows four different techniques each undertaking a single test on the same home, with the 'best estimate' shown by the dots and the confidence interval for each test represented by the error bars. Technique (i) displays the 100±10 value mentioned previously. Technique (ii) shows a measurement with less uncertainty and technique (iii) a value with greater uncertainty.

Technique (ii) is perhaps the most useful of these results, but (i), (ii) and (iii) can all be said to be 'accurate', as the confidence intervals all overlap the true value. Technique (iv) on the other hand, is incorrect. For technique (iv), the true value lies outside the confidence interval, suggesting something is incorrect with this measurement or the technique.

Accuracy and precision

Related to the concept of error bars, are that of accuracy and precision. The illustration below shows four different datasets (A – D) and the associated average value for each. Assume that these are four methods for measuring performance with each method carried out multiple times on a single dwelling.



Where datapoints are clustered around the true value, the dataset can be said to have high accuracy and high precision (e.g. method A).

Where the average of the datapoints is close to the true value but the datapoints themselves are highly distributed, the dataset can be said to have high accuracy but low precision (e.g. method B).

Where the datapoints are clustered around a value that is not the true value, the dataset can be said to have low accuracy but high precision (e.g. method C).

Low accuracy and low precision describe a dataset where the data points are highly distributed, and the average value is not close to the true value (e.g. method D).

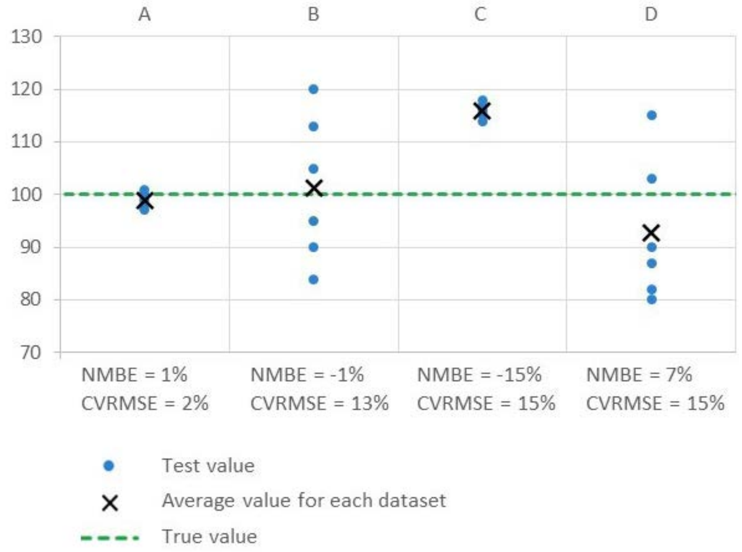
Precision is akin to how wide the error bars are from the previous section

Validating measurement techniques

With the above two examples, it is easy to see which measurements are best, and which fail, as the true values is shown. However, when a technique is deployed commercially, the true value of a buildings thermal performance is usually not known. Thus, if only presented with numbers and confidence intervals, it can be difficult to know if any results have fallen into the trap of technique (iv) or C. To check for this, BPE techniques should undergo validation studies. In validation studies, results are calculated under conditions similar to that experienced in the field, and then compared to known 'true' values to check for correctness.

As validation studies have not yet been widely undertaken on new homes, the validation studies referenced are undertaken primarily in existing, typically poorer performing homes. These studies often quote terms, such as NMBE and CVRMSE to describe how 'correct' the results are (see Glossary for definition).

The illustration below shows what the NMBE and CVRMSE would be for datasets A – D shown to the left.



NMBE quantifies any systematic errors or biases in the predictions. NMBEs closer to 0 are better, and technique C shows a large NMBE, suggesting a problem. Both techniques A and B have small NMBEs but very different spread of results so for a user of the measurement technique may not be a very helpful guide to its usefulness.

CVRMSE describes how close measurements tend to be to the true value. Lower CVRMSEs are better, and Technique A has the lowest CVRMSE of all those presented. Techniques B, C and D have similar values for CVRMSE and warns the user of the measurement technique that the result could be some way from the true value.

For the purposes of this guide, the existing home validation CVRMSE has been quoted in the Provider section, to provide a single metric covering accuracy and precision of different measurement techniques, as it reflects both aspects. However, just because a technique is confirmed to reflect the true value in a validation study on existing homes, it does not confirm the technique's accuracy if used on new, more energy efficient homes - but is the best we currently have. Additional validation will be required.

Validating measurement techniques for high performance (new) homes

If a technique undergoes validation and it can be shown that the confidence interval very often includes the true value, then NMBE and CVRMSE become less important. The confidence interval alone can then provide sufficient information to quickly assess a technique. However, the context of the validation still remains important (i.e. how many homes was it tested on, are they similar to my homes, etc.).

In order to support the mass scale adoption of BPE, there is a need to build confidence in building performance measurement of high performance homes and the creation a framework that encourages, and allows validation of, innovations and assures quality delivery of measurement services. As a first step, the Future Homes Hub and the Building Performance Network are working together with industry and government to facilitate the development of a certification approach for performance measurement techniques for use in new homes.

Single home vs multiple homes

Where a measurement technique is validated but has a worse confidence interval than the performance discrepancy being investigated this renders a single test problematic. For example, a technique which has a confidence interval of ±10 would not be able to detect the impact of a build defect which is expected to only cause a reduction in Heat Transfer Coefficient (HTC) of 5. In this HTC example, the expected reduction in HTC is much smaller than the confidence interval. However, this can be mitigated by undertaking multiple measurements on a single home or single measurements across a number of similar homes, and using the average. This improves the overall Confidence Interval and provides feedback on the consistency of the build process more generally, rather than focusing on the performance of a single home on a site.

British Standard for BPE (BS 40101)

A British Standard (BS 40101) has been developed for the BPE of individual and groups of buildings that are in-use. The standard describes a triage approach with initial tests, including householder feedback, providing indicators of if and where further testing is required. It also provides guidance on additional, more focussed, testing and describes different levels of intensity of testing and monitoring at both a building and development scale. The Standard indicates what should be monitored but is not prescriptive regarding method to allow for innovation in BPE.

A benefit from following the Standard is that it results in robust, comparable datasets and reports for all building performance evaluations.

BS 40101 includes detailed descriptions of BPE techniques and covers how to plan a BPE programme and choose comparators. It also indicates data appropriate to the level of evaluation sought and specifies data naming and storage conventions.

Further information can be found here: https://building-performance.network/advocacy/british-standard-bs40101-launch.

BS 40101 (Image credit: BSI)

Brief lessons from the home retrofit market

Over many years, the savings claimed from retrofitting low energy measures in existing homes have been the subject of debate and revision. Studies looking at the reduction of energy use from retrofitted homes show that realised savings were less than those predicted by energy models. With parallels to the concerns expressed about new homes underperforming, it was difficult to disaggregate all the influencing elements impacting performance - such as the weather, householder, contractor (installation & commissioning) and modelling tool assumptions.

To help address this issue, BEIS (Department for Business, Energy, Innovation and Science) funded an innovation programme (SMETER - Smart Meter Enabled Thermal Efficiency Ratings) for the development of in-use home monitoring techniques for fabric performance. Building on the successful early development of the testing techniques, two major government funded grant programmes [1] now include performance measurement options, alongside the retrofit works, to encourage the development of 'pay for performance' business models.

[1] Social Housing Decarbonisation Fund Wave 2 (£778M) and Energy Company Obligation ECO4 (£4Bn)

EXAMPLE PROVIDERS

This section gives an overview of example providers of BPE services. BPE is a growing field, with new companies coming forward to offer services and new techniques being developed by new and existing companies. This is, therefore, not an exhaustive list of providers.

BPE provider details

Further information on the services offered by the example providers included in this Guide can be found by following the links below. An overview of some of their services can be found on the following pages.

As-built

QUB, https://www.british-gypsum.com/qub

Veritherm, https://veritherm.co.uk

As-built and In-use

Atamate, https://www.atamate.com

BSRIA, https://www.bsria.com/uk

Build Test Solutions (BTS), https://www.buildtestsolutions.com

Carnego Systems, https://www.carnego.net

Knauf Energy Solutions (KES), https://www.knaufenergy.be

Passiv UK, https://www.passivuk.com

Purrmetrix, https://www.purrmetrix.com

Sero, https://sero.life

In-use

SOAP Retrofit, https://www.soapretrofit.com

R&D

Building Energy Research Group at Loughborough University, https://www.lboro.ac.uk/departments/abce/research/building-energy

Energy House 2.0 at the University of Salford, https://www.energyhouse2.com

Leeds Sustainability Institute at Leeds Beckett University, https://www.leedsbeckett.ac.uk/research/leeds-sustainability-institute

UCL Energy Institute, https://www.ucl.ac.uk/bartlett/energy/research/physical-characterisation-buildings

For additional BPE providers please contact the Building Performance Network - https://building-performance.network.

QUB Rapid Heat Transfer Coefficient (HTC) Measurement

Tests for: Whole house heat loss (HTC).

How long? Overnight, 10 -12 hours.

About: The QUB test measures the thermal performance of the whole house, providing certificated evidence of as-built thermal performance of the fabric of the building. The rapid test measures the heat transfer coefficient (HTC) in a single night. During the test the house is heated and then allowed to cool. External and internal temperatures being measured throughout heating and cooling phases, and the data is used to calculate the as-built HTC. QUB is designed to support homebuilders, by enabling them to receive certified evidence that their homes are performing as they are designed.

Stage of build: Recommended prior to handover.

Time of year: Typically, between September and May (min. 10°C temperature differential between internal and external)

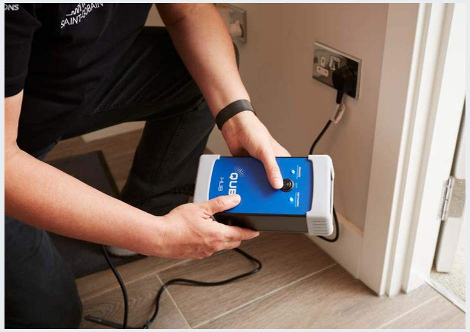
Occupied? Property must be vacant during the test period.

Services required: Power supply.

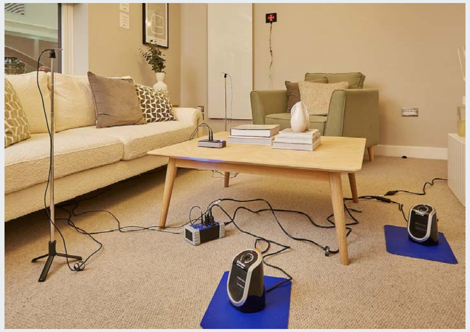
Conducted by: A trained operative.

Providers stated accuracy and / or precision: CVRMSE = 11% [2].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also `Accuracy, precision, and BPE performance claims' on page 19).



QUB deployment (Image credit: Saint Gobain)



QUB test (Image credit: Saint Gobain)

Mini case study

QUB testing was conducted on behalf of a UK homebuilder to demonstrate the alignment of the as-built thermal performance to the designed HTC value. Following the sale of a new home the homebuilder was contacted to question the performance of house purchased. A short series of QUB tests were carried out to evaluate the as-built performance levels. The results from the QUB tests demonstrated that the building performance level was within 5% of the as designed values, providing the evidence for the homebuilder to address the homeowner concerns.

[2] Validation based on 18 tests on a single low-energy detached dwelling, referenced to co-heating tests.

Veritherm HTC

Tests for: Whole house heat loss (HTC).

How long? Takes approximately 10-12 hours.

About: Rapid performance test using small electric heaters to heat the home and then allowed to cool passively during the same test cycle. Typical maximum internal temperature reached = 30°C for a short period. Multiple sensors and monitors are located inside and outside the dwelling. Proprietary algorithms are used to analyse and interpret the data collected.

Stage of build: Any time from first fix to post-handover

Time of year: Typically, between September and May (min. 10°C temperature differential between internal and external)

Occupied? Home must be vacant

Services required: Power supply

Conducted by: A trained operative

Providers stated accuracy and / or precision: CVRMSE = 8%[3].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also `Accuracy, precision, and BPE performance claims' on page 19).

Veritherm HTC test (Image credit: Veritherm)

Mini case study

Veritherm used their rapid HTC test to measure the fabric performance of several homes at the "first-fix" stage of construction - before internal linings were installed. Being insulated and airtight but not complete, provided the homebuilder a chance to identify any major performance issues before the development was completed. The exercise involved comparing the actual performance to the SAP prediction, and any significant discrepancies were investigated and fixed. The homes were then retested. In some cases, the thermal performance was improved by up to 50% between the first and second test.

[3] Validation based on a total of 11 tests across two properties referenced to co-heating tests.. See: https://veritherm.co.uk/wp-

Atamate Ltd - atBOS

Tests for: Whole house performance, indoor environmental conditions, total space heating energy demand and real-time maintenance alerting.

How long? Long term installation advised to provide ongoing performance feedback.

About: atBOS is the Building Operating System developed and maintained by Atamate, with the mission of providing a simple and affordable control and monitoring technology on a single platform. atBOS integrates all building services involved in thermal comfort, e.g. heating, cooling and ventilation, as well as others like lighting and hot water. Sensors collect indoor environmental data, e.g. occupancy, temperature, CO_2 levels etc, in order to optimise the building service provision in real-time, then stores these data sets along with service response and metered energy data which enables building performance evaluation.

Stage of build: As-built (heating system in operation) or in-use

Time of year: Monitoring is carried out continuously. For a classic BPE that focuses on heat loss, then September-March. However, the data collected would also enable an evaluation with respect to overheating in the summer.

Occupied? Can be occupied or vacant

Services required: For heat loss BPE, the heating system must be operational. No other requirements, but other services could be monitored.

Conducted by: Control & monitoring equipment can be fitted by an electrician. Intuitive dashboards are provided via the user interface (for residents, landlords, facility managers etc). A BPE study should be conducted by a suitable practitioner.

Example dashboard on the user interface

(Image credit: Atamate)

Mini case study

In-use performance analysis was carried out on the data collected from six new-build flats in Cardiff. Via the atBOS platform, they were fitted with occupancy-responsive direct electrical space heating and either demand-controlled ventilation or uncontrolled trickle vents. MEV was fitted in kitchens and bathrooms which coupled with an exhaust air heat pump to provide DHW. 12 months of thermal comfort, indoor air quality and energy demand data was assessed. It was shown that the integrated heating and ventilation control resulted in an energy efficiency performance substantially better than that predicted by SAP. Importantly, the data collected was also able to demonstrate that this was not at the expense of occupant comfort, and that a healthy indoor environment was maintained throughout the year.

BSRIA

Tests for: Indoor Environmental Quality.

About: BSRIA offer a range of as-built and in-use performance validation tests including for Indoor Environmental Quality (IEQ). IEQ encompasses air quality and other metrics including acoustics, and thermal and visual comfort [4].

Stage of build: In-use.

Time of year: Anytime.

Occupied? Home can be occupied or vacant.

Conducted by: A trained specialist.

(Image credits: BSRIA)

Mini case study

Post occupancy, a homeowner reported concerns over a "stuffy" and damp environment. BSRIA surveyed the property to establish conditions and found that the ventilation system had been isolated. The homeowner stated the system was "really noisy" and had to turn it off. Measurement of internal temperature, relative humidity and CO2 showed levels exceeding best practice, consistent with poor air quality and potentially hazardous to health. The ventilation system was reinstated, with noise levels and airflow rates measured. BSRIA found that minimum airflow rates were not being achieved and sound levels exceeded recommendations. Inspection of the ventilation installation showed ducting incorrectly installed. Once this was corrected, the ventilation system was recommissioned, taking into consideration the property's air permeability. The system speed could be reduced whilst still achieving the minimum ventilation airflow rates, required by building regulations. The removal of system resistance resulted in reduced noise levels compliant with recommended limits. Subsequent remeasurement of IEQ parameters demonstrated that levels had returned to acceptable levels and resulted in a comfortable environment for occupants.

[4] NZG 2/2023 – Indoor Environmental Quality and Net Zero (BSRIA LSBU Net Zero Building Centre) - https://www.bsria.com/uk/product/BG2J4D/indoor_environmental_quality_and_net_zero_nzg_22023_a15d25e1/

Build Test Solutions SmartHTC

Tests for: Whole house heat loss (HTC).

How long? Over a 3 week + period.

About: Uses real in-use measurements of internal temperature and energy consumption. Readings can come from existing smart home systems or from discreet sensors placed around the house. A proprietary algorithm is used to analyse the data collected and the output is directly comparable with the design expectation in SAP.

Stage of build: As-built (heating system in operation) or in-use.

Time of year: Typically, between September and May (min 7°C temperature differential between internal and external).

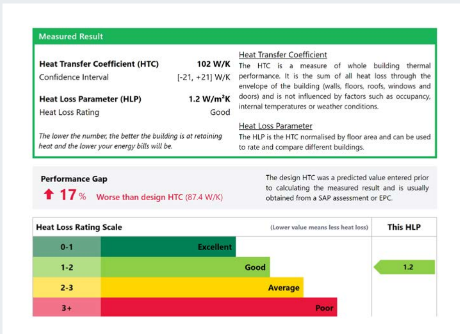
Occupied? Home can be occupied or vacant – but must be heated.

Services required: No additional services.

Conducted by: A trained specialist.

Providers stated accuracy and / or precision: CVRMSE = 11%[5].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also `Accuracy, precision, and BPE performance claims' on page 19).



Measured Result

Heat Transfer Coefficient (HTC)	**102 W/K**	Heat Transfer Coefficient The HTC is a measure of whole building thermal performance. It is the sum of all heat loss through the envelope of the building (walls, floors, roofs, windows and doors) and is not influenced by factors such as occupancy, internal temperatures or weather conditions.
Confidence Interval	[-21, +21] W/K	
Heat Loss Parameter (HLP)	**1.2 W/m²K**	Heat Loss Parameter The HLP is the HTC normalised by floor area and can be used to rate and compare different buildings.
Heat Loss Rating	Good	

The lower the number, the better the building is at retaining heat and the lower your energy bills will be.

Performance Gap
17 % Worse than design HTC (87.4 W/K)

The design HTC was a predicted value entered prior to calculating the measured result and is usually obtained from a SAP assessment or EPC.

Heat Loss Rating Scale	(Lower value means less heat loss)	This HLP
0-1	Excellent	
1-2	Good	1.2
2-3	Average	
3+	Poor	

(Image credits: Build Test Solutions)

Mini case study

Increasingly, local planning policy is placing greater emphasis on delivered as-built performance. Milton Keynes Council requires reports on as-built performance for 10% of dwellings in a scheme, covering 5 years. Testing must cause minimal disruption to the householders, and be practical and affordable to deploy and maintain.

BTS supported a developer to comply with these requirements on a 150-home scheme. 15 homes have low-cost temperature sensors paired with smart meters. These are measuring thermal performance (HTC) and reporting annually whilst the homes are occupied and used normally. The same data is being used to provide an assessment of condensation and mould risk (ventilation effectiveness) and summer overheating risk. The developer benefitted from the performance feedback.

[5] Validation based on 41 tests across a variety of dwelling types (including 30 houses as part of the SMETER project), referenced to co-heating tests. See: https://www.buildtestsolutions.com/files/de368d4cb6a9f0ab62b0d95c82542d01540ece16.pdf

Carnego Systems

Tests for: Continuous monitoring of properties measuring performance outcomes. Includes integration with in-house systems (heating, PV etc) and resident feedback.

How long? From 8 weeks to 10 years+.

About: Uses 'off the shelf' sensors and meters together with integrations to heating, PV/ battery and hot water systems to provide a continuous monitoring solution tailored to each project. Secure data comms is normally provided to remove any dependency on resident wifi / broadband. Detailed data collection to enable key performance metrics and alerts to be calculated for each property and the systems within them. A smartphone app can provide live resident feedback on performance together with 'how to' videos on getting the best from their home. Smart maintenance alerts and remote verification and configuration of in-house systems. Integration with 3rd party algorithms (e.g. HTC).

Stage of build: As-built and In-use.

Time of year: All year round

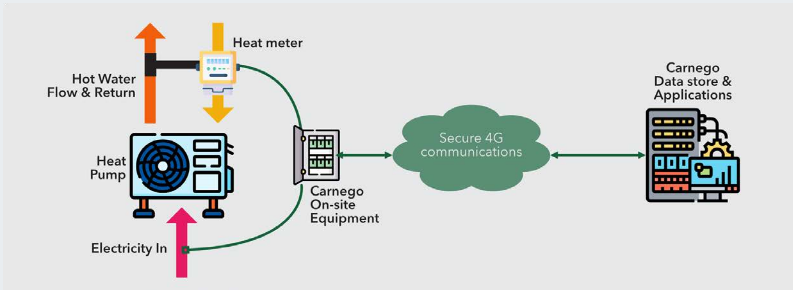
Occupied? Occupied or vacant (heated in winter).

Services required: Most benefit with all services commissioned.

Conducted by: Solution normally integrated with M&E design / installation.

Providers stated accuracy and / or precision: Depends upon the designed solution.

(see also 'Accuracy, precision, and BPE performance claims on page 19).



Heat pump efficiency monitoring (Image credit: Carnego Systems)

Mini case study

A new build development of 14 zero-carbon homes were monitored to assess in-use performance. A solution was designed and installed as part of the M&E package. Data was collected over an initial 18-month period that proved the zero-carbon target was being delivered. The monitoring; a) detected 19 configuration / installation issues with the heating systems between commissioning and full occupation that were then corrected, b) failures of solar PV systems were detected and addressed before seen by residents and impacting performance, c) sub-optimum use of heating systems and home ventilation detected and corrected through a combination of technical changes and resident education. After the initial monitoring period, the engagement was extended to continue to provide smart maintenance and performance monitoring services on an ongoing basis.

Knauf Energy Solutions (KES)

Tests for: Whole house heat loss (HTC) & annual space heating energy demand indicator (EDI).

How long? 8 weeks but methodology is evolving to reduce this.

About: Uses a machine learning system with a sensor kit installed in the home over a period of 8 weeks to provide information on building performance in-use. The approach involves learning the homes' characteristics and then self-checking the algorithm to demonstrate accuracy on a house-by-house basis. KES provide an HTC and an Energy Demand Indicator (EDI) which measures the annual space heating energy demand, which is directly comparable with the design expectation in SAP.

Stage of build: As-built (heating system in operation) or in-use.

Time of year: Typically, between September and May.

Occupied? Home can be occupied or vacant – but must be heated.

Services required: Heating system must be operational.

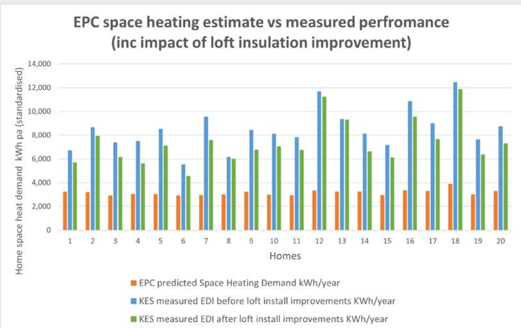
Conducted by: A specialist to install the sensor kit.

Providers stated accuracy and / or precision: CVRMSE = 4% [6]; an average error of less than 7% when estimating a month of energy consumption for heating (kWh)[7].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also `Accuracy, precision, and BPE performance claims' on page 19).

Mini case study

An estate of 20 new homes were monitored. Using a machine learning approach, Knauf Energy Solutions calculated, for each house, an Energy Demand Indicator (EDI) - the annual space heating demand under typical occupancy and weather similar to that in the Energy Performance Certificate (EPC). This showed an average space heating demand across the estate of 2.5x the EPC's space heating estimate with a range of underlying causes. One cause, poorly installed loft insulation, was re-installed correctly giving a performance improvement of 14% across the homes.



(Image credit: Knauf Energy Solutions)

[6] UK government SMETER Phase 2 trial (Appendix 1), based on two homes monitored over a period of 71 and 52 days respectively, referenced to co-heating tests. See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1050881/smeter-innovation-competition-report.pdf.
[7] Energy Systems Catapult blind trial involving 9 homes. No public reference available.

Passiv UK

Tests for: Whole house heat loss and heat pump efficiency monitoring.

How long? Minimum 7 days and ongoing.

About: Passiv's approach to building performance evaluation is built into its smart heat pump control system. These controls use proprietary algorithms that learn a building's thermal performance so that a heat pump can be optimised on an ongoing basis. An initial building characterisation is undertaken across 7 days to develop a baseline that can be used to evaluate performance over time. With appropriate consumer consent, real-time monitoring and evaluation of building and heat pump performance can be provided via an online portal. The building performance evaluation can be integrated within a smart heat pump control system. Once installed, it provides ongoing monitoring and evaluation without further site visits or equipment.

Stage of build: As-built (heating system in operation) or in-use.

Time of year: Typically, between September and May, then ongoing.

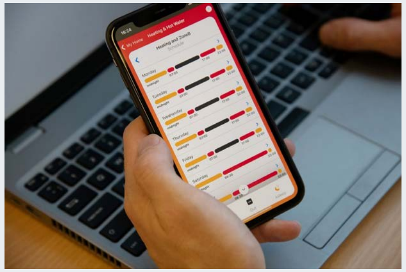
Occupied? Home can be occupied or vacant – but must be heated.

Services required: No additional services.

Conducted by: Initial set up by a trained specialist.

Providers stated accuracy and / or precision: CVRMSE = 24% [8].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also 'Accuracy, precision, and BPE performance claims' on page 19).



(Image credit: Passiv UK)

Mini case study

Passiv's Smart Energy Platform was installed in 20 homes in two specially built developments. The smart control systems in these properties not only improve heat pump efficiency, support energy tariff optimisation, and integrate with other energy assets but they also enable ongoing remote building performance evaluation. An Independent assessment by Energy Saving Trust recently concluded that the Passiv controls increase a heat pump's Coefficient of Performance (COP) by 17%. These properties successfully demonstrated Passiv's Smart Energy Platform providing dynamic building monitoring and indoor environmental data collection on an ongoing basis, whether they are occupied or unoccupied.

[8] UK government SMETER Phase 2 trial, based on 7-day test carried out on 27 homes, referenced to co-heating tests. See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1050881/smeter-innovation-competition-report.pdf.

Purrmetrix

Tests for: Whole house heat loss (HTC), householder comfort, ventilation rates, air quality, condensation risk, energy consumption.

How long? Over a 3 week + period.

About: For as-built and in-use testing and data gathering, Purrmetrix provides a building performance toolset that provides a range of insights into building performance. Based on a number of dedicated temperature/humidity/CO_2 sensors installed in homes plus energy data, the Purrmetrix data platform delivers benchmarks for ventilation, condensation risk, comfort and heat loss (using Build Test Solutions SmartHTC algorithm).

Stage of build: As-built (heating system in operation) or in-use.

Time of year: Information on comfort and ventilation can be provided year-round. Heat loss tests need min 7°C temperature differential between internal and external, so generally September to May.

Occupied? Home can be occupied or vacant – but must be heated.

Services required: No additional services.

Conducted by: System is simple to fit and can be used by any surveyor or assessor with a short period of training.

Providers stated accuracy and / or precision: For heat loss, CVRMSE = 11%[9].

(This uncertainty is not necessarily comparable across the different providers measurement techniques, particularly where sample sizes are small. See also `Accuracy and BPE performance claims' on page 19).

(Image credits: Purrmetrix)

Mini case study

London Borough of Havering have been testing with Purrmetrix during the first wave of Social Housing Decarbonisation Fund, to augment their EPC data and survey work with additional data on the archetypes. Funding was confirmed late in the heating season, so being able to quickly deploy test systems was useful. Working with LBH's contractors, Purrmetrix provided heat loss for 10% of the homes to be upgraded, with measurements of ventilation rate and condensation risk for 20% of stock. The data identified homes with high heat loss and ventilation rates and gave confidence for models being used to design upgrades. Post works it will be used to verify improvements and confirm that tenants have more affordable comfort.

[9] Validation based on 41 tests across a variety of dwelling types (including 30 houses as part of the SMETER project), referenced to co-heating tests. See: https://www.buildtestsolutions.com/files/de368d4cb6a9f0ab62b0d95c82542d01540ece16.pdf

Sero – Building Energy Engine (BEE)

Tests for: Whole house performance and building services efficiency.

How long? Varies depending on aspect of building studied.

About: Sero's BEE is the brain of a smart home, monitoring and controlling via hardware and a cloud-based analytics platform. Occupants can set their own preferences while the system automates how these are achieved whilst minimising energy use and/or carbon emissions. The BEE unit, sensors, and controls can integrate with third party heating, ventilation, PV, and battery systems to optimise data flow and building operation. This integrated system is then able to dynamically adjust connected energy consumption using local battery storage, and interact with grid signals for Demand Side Response events, all with the aim of reducing carbon emissions whilst making sure the occupant remains comfortable.

Stage of build: As-built (building services in operation) and in-use.

Time of year: Anytime for building services fault finding; heating season data for seasonal efficiency and whole house performance.

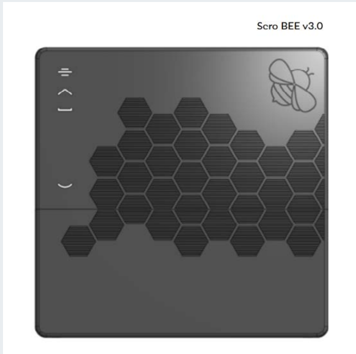
Occupied? Home can be occupied.

Services required: Building heating and ventilation systems in operational state (plus PV and battery as per design).

Conducted by: Installation by a trained electrician / plumber, data analysis via cloud platform and Sero team

Providers stated accuracy and / or precision: Dependent on aspect of building studied.

(See also `Accuracy and BPE performance claims' on page 19).



(Image credit: Sero)

Mini case study

A Wales-based social housing developer used the BEE to investigate the causes of unexpected cycling in the domestic hot water cylinder and elevated room temperatures on a new site. In conjunction with the building services contractor, Sero's data analysts were able to remotely diagnose issues with the installation of control valves and heating circuits in certain homes. These lessons were then included in toolbox talks and work package handover procedures in future phases.

SOAP Retrofit Ltd – Occupant Satisfaction Surveying

Tests for: Building performance from occupant perspective (including, comfort, satisfaction, health and wellbeing, energy, controls, design etc.)

How long? Anytime after 9 months of occupancy.

About: SOAP Retrofit's surveying methodology (developed over the past 15 years) complies with BS 40101:2022 and provides deep insights into the performance of individual homes and portfolios alike, direct from the most important sensor; the occupant. Results are compared to a continually growing database of benchmarks, enhancing the analysis. The overall performance of the home is categorised via high level score (for rapid assessment) and detailed assessment is provided, highlighting any successes or notable issues that could be resolved or improved upon.

"Occupants are the best sensor of building performance that we have…they're just uncalibrated"

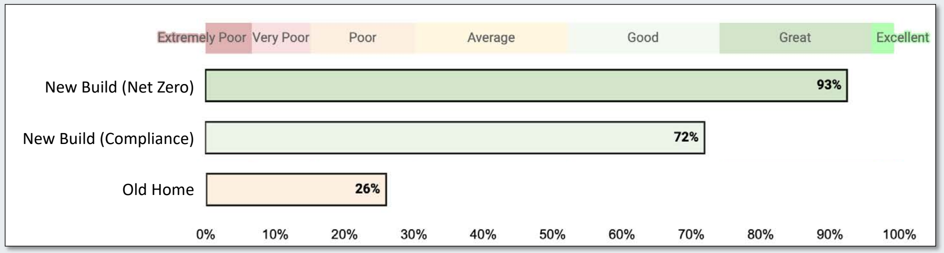
Stage of build: In-use.

Time of year: Anytime. Recommended to avoid implementing during significant weather events (i.e. heat waves, cold snaps, storms etc.).

Occupied? Occupants surveyed must have lived in the home for at least 9 months (to experience full summer and winter conditions).

Services required: No additional services required. Can be integrated with other performance measurement tools for further insights (i.e. HTC measurement, air tightness testing, thermal imaging, damp and mould risk assessment, energy consumption monitoring etc.).

Conducted by: Survey typically distributed by client or contractor via digital methods (i.e. emails, smart phone web-links, QR codes etc.). Analysis, benchmarking and reporting conducted by SOAP Retrofit Ltd.



Example overall occupant comfort and satisfaction rating (Image credit: SOAP Retrofit)

Mini case study

SOAP Retrofit's survey was licensed by Woodknowledge Wales to evaluate the performance of a pioneering Passivhaus development for social rental. The results showed that the development was highly successful and with some minor low-cost improvements to specific elements (including hot water controls, MVHR maintenance procedures, resident induction and handover), satisfaction could be enhanced even further.

Energy House 2.0 at University of Salford

Tests for: Whole house performance of completed homes built in environmental chambers.

How long? Determined by type and number of tests carried out.

About: Energy House 2.0 is a set of large-scale environmental chambers where houses (total of 4) can be built at full scale, and tested under varying climatic conditions, including: temperature -20°C to +40°C; wind; rain; solar radiation; snow.

This type of research is suitable for testing prototype new buildings and can also be used to recreate retrofit scenarios. The aim of the lab is to provide cutting edge research on indoor air quality, energy performance, thermal comfort, and robust mechanisms to deal with climate change. The climatic conditions achievable can cover around 95% of the globally populated land mass.

Stage of build: As-built/ Prototype (buildings can also be occupied by the public).

Time of year: All year round.

Occupied? Home can be occupied or vacant.

Service required: No additional services.

Conducted by: Researchers in the area of building physics and social science.

(Image credit: Charles Leek)

Mini case study

Bellway's dedicated testing facility, The Future Home, is currently located within the Energy House 2.0 research facility. A testing regime has been drawn up to help Bellway identify best practice when it comes to: storing solar energy at home; recovering heat from wastewater; placement and maximisation of air source heat pumps; other carbon-reducing technologies. Halfway through the project, the house will be retrofitted to offer a unique opportunity to measure the difference in energy efficiency between double and triple glazing on windows, and ceiling- and wall-mounted infrared radiators versus underfloor heating. Throughout testing, The Future Home will be exposed to temperatures as high as 40°C and low as -20°C with the recreation of wind, snow, solar radiation, and other weather conditions.

Leeds Sustainability Institute, LBU - Co-heating test

Tests for: Whole house heat loss (HTC). Also facilitates detailed measurements of U-values and thermography.

How long? 2-3 weeks.

About: The co-heating test is considered the gold-standard in measuring HTCs. The method has existed for many years, but was formalised in the Leeds Beckett co-heating protocol in 2013. The co-heating test raises the internal temperature of a property to a fixed value (usually around 20°C) using electric heaters and fans. The power required to maintain this temperature is recorded. Internal and external temperature readings are monitored, and used alongside the power data to calculate a HTC. Data on solar irradiances is also collected, so that heat gains due to solar can be accounted for. Likewise, if party walls are present, Heat Flux Plates are placed on party elements to quantify heat loss to the neighbour and include this in analysis. The consistent internal temperature often allows for U-value measurements to be calculated in line with ISO9869, and causes thermal defects to become visible, meaning the co-heating test pairs well with other building forensic investigation techniques.

Stage of build: As-built

Time of year: October to March

Occupied? Requires vacant property for duration of test

Services required: Electricity supply required.

Conducted by: Specialist teams, including Leeds Beckett University.

Providers stated accuracy and / or precision: Typical Confidence Interval ±6%. Like all BPE techniques, weather and party-wall heat exchanges can impact on accuracy so each test has its own uncertainty value. (See also `Accuracy, precision, and BPE performance claims' on page 19).

Co-heating test (Image credit: Leeds Beckett University)

Context: The co-heating test is the standard used in most scientific BPE projects. These include the TSB (now Innovate UK) Building Performance Evaluation Programme and the BEIS (now DESNZ) DEEP project. An adapted co-heating test, with less stringent requirements, was also employed in the SMETER project, acting as a metric against which other technologies were judged. The co-heating test underpinned the identification of the performance gap and the development of the Zero Carbon Hub reports on this subject. It is an internationally accepted robust protocol and is currently being converted into a CEN

GLOSSARY

Accuracy: How close a measurement is to the true or accepted value.

As-built: The status of the building when it is completed but before it is occupied.

Building performance evaluation (BPE): Gathering and assessing performance data about the performance of a building.

Coefficient of Variation of Root Mean Square Error (CVRMSE): CVRMSE describes how much the estimates vary around the true value. A large CVRMSE suggests that estimates are dispersed around the true value, while a small CVRMSE suggests they are clustered around the true value.

Comparator: a target or standard used for comparison of design aspirations/ design intent.

Confidence Interval (CI): A confidence interval is a range of values around a measured number, which describes the level of confidence in the estimate. The true value of the measured number has a high probability (usually 95% chance) of lying somewhere within the confidence interval.

Daylight Factor: a measure of the amount of daylight available inside a room compared to the amount of unobstructed daylight available outside under overcast sky conditions.

Heat Transfer Coefficient (HTC): The rate of heat loss in Watts from the entire thermal envelope of a building per Kelvin of temperature differential between the internal and external environments (ΔT), expressed in W/K

Householders: Those living in the home

Indoor Air Quality (IAQ): The quality of air within the building, including the levels of pollutants and VOCs.

Indoor Environmental Quality (IEQ): The quality of the indoor environment, including IAQ, as well as lighting and moisture.

In-construction: The status of the building during construction

In-use: The status of the building when it is being lived in.

Lambda value (λ): The thermal conductivity of a material, measured in W/mK.

Normalised Mean Bias Error (NMBE): NMBE is a way to see if estimates are consistently too high or too low compared to the real values. It shows whether estimates have a tendency to be off and by how much.

Passive House Planning Package (PHPP): A modelling tool used in the design of Passivhaus projects and energy efficient homes. Cannot be used for Building Regulations compliance.

Precision: How close measurements of the same item are to each other.

SAP: The Standard Assessment Procedure (SAP) is the methodology required under Building Regulations to assess and compare the energy and environmental performance of dwellings.

U-value: A measure of the thermal transmittance (W/m^2K) of a building element such as a wall, floor or roof.

Volatile Organic Compounds (VOC): Compounds that have a high vapor pressure and low water solubility, for example solvents. Some VOCs are dangerous to human health or cause harm to the environment.

RESOURCES

Further reading on the performance of homes

Closing the gap between design and as-built performance: Evidence Review report, Zero Carbon Hub (2014): https://building-performance.network/library-item/housing/zero-carbon-hub-report-closing-the-gap-between-design-and-as-built-performance-evidence-review-report

Closing the gap between design and as-built performance: End of term report, Zero Carbon Hub (2014): https://building-performance.network/library-item/housing/zero-carbon-hub-report-design-vs-as-built-performance-gap-end-of-term-report

Building for 2050 – a research project to help homebuilders meet the challenge of delivering low cost, low carbon housing (2022): https://www.buildingfor2050.co.uk/

Building Performance Evaluation Programme: Findings from domestic projects, Innovate UK (2016) https://www.ukri.org/wp-content/uploads/2021/12/IUK-071221-DomesticBuildingPerformanceReport2016.pdf

UK housing: Fit for the future?, Committee on Climate Change (2019): https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

Designed to perform by Tom Dollard, RIBA (2022) (includes site inspection check sheets): www.ribabooks.com/Designed-to-Perform-An-Illustrated-Guide-to-Delivering-Energy-Efficient-Homes_9781914124266

Better Buildings: Learning from buildings in use by Richard Partington & Simon Bradbury, RIBA (2017): https://www.ribabooks.com/Better-Buildings-Learning-from-buildings-in-use_9781859465868

Further information on BPE

Building Performance Network (BPN) Resource Hub: https://building-performance.network/resource-hub

Building Performance Evaluation Guide & Toolkit, Wood Knowledge Wales (2021): https://woodknowledge.wales/building-performance-evaluation-guide/

State of the nation review - Performance evaluation of new homes, Building Performance Network (2020): https://building-performance.network/wp-content/uploads/2020/06/State-of-the-nation-report-June-release-FINAL-UPDATED-1.pdf

Building Performance Evaluation: what, why and the benefits that it brings, BPN (2023): https://building-performance.network/training-module/module-1

Planning BPE: where to start and common techniques, BPN (2002): https://building-performance.network/training-module/module-2-mock-up

Undertaking dwelling BPE, BPN (2023): https://building-performance.network/training-module/undertaking-dwelling-bpe

LBU Protocol - Whole House Heat Loss Test Method (co-heating): https://www.leedsbeckett.ac.uk/-/media/files/research/leeds-sustainability-institute/coheating-method-for-whole-house-heat-loss/lsi_cebe_coheating_test_method_june2013.pdf

BS 40101:2022. British Standard on Building performance evaluation of occupied and operational buildings (using data gathered from tests, measurements, observation and user experience), BSI (2022): https://knowledge.bsigroup.com/products/building-performance-evaluation-of-occupied-and-operational-buildings-using-data-gathered-from-tests-measurements-observation-and-user-experience-specification/standard

Towards net zero: Paper II – A proposed methodology for Post Occupancy Evaluation (2022) (contains householder questionnaire template): https://pollardthomasedwards.co.uk/download/Towards_Net_Zero_2050_Part%20II.pdf

Indoor Environmental Quality and Net Zero Topic Guide (NZG 2/2023), BSRIA LSBU Net Zero Building Centre (2023): https://www.bsria.com/uk/product/BG2J4D/indoor_environmental_quality_and_net_zero_nzg_22023_a15d25e1

Domestic Ventilation Systems - a guide to measuring airflow rates (BG 46/2022), BSRIA (2022): https://www.bsria.com/uk/product/np48mn/domestic_ventilation_systems_a_guide_to_measuring_airflow_rates_bg_462022_a15d25e1/

Thermal Imaging Report Guide (NF86), NHBC Foundation (2020): https://www.nhbc.co.uk/foundation/thermal-imaging-report-guide

Housing Fit For Purpose by Fionn Stevenson, RIBA: https://www.ribabooks.com/Housing-Fit-For-Purpose-Performance-Feedback-and-Learning_9781859468241